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Good Agricultural Practices for greenhouse vegetable production in the South East European countries

Principles for sustainable intensification of smallholder farms

FAO PLANT PRODUCTION AND PROTECTION PAPER 230

Good Agricultural Practices for greenhouse vegetable production in the South East European countries

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PART III: CROP TECHNOLOGIES

ANNEX

Acknowledgements

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Preface

A very significant event in the history of the world was mankind's domestication of plants – the moment when humans ceased to depend on harvesting from the wild. This enabled sedentarization, and people began to explore the planting of seeds or cuttings to propagate a wide range of plants close to their dwellings.

The need to protect these domesticated plants from abiotic and biotic stress factors subsequently led to another important agricultural breakthrough: protected cultivation. Protected cultivation made it possible to protect crops from adverse weather conditions and predators, allowing year-round production and the application of an integrated crop production and protection management approach for better control over pests and diseases.

Greenhouse crop production is now a growing reality throughout the world with an estimated 405 000 ha of greenhouses spread throughout Europe, of which some 105 000 ha are located in the South Eastern European (SEE) countries. The degree of sophistication and the technologies applied depend on local climatic conditions and the socio-economic environment.

Greenhouse production originated in northern Europe, and experience there stimulated development in other areas, including the Mediterranean, North America, Oceania, Asia and Africa, with various degrees of success. Experience has shown that a mere transposition of north European technologies to other parts of the world and different agro-ecological environments is not a valid process. Technologies must be adapted to match the local requirements and further research is needed in each environment.

The last 20 years have seen a revolution in greenhouse production in terms of structure design and type and quality of covering materials; plant nutrition management; mulching; use of high-yielding hybrids and cultivars; plant training and pruning techniques; integrated pest management; use of pollinator insects; climate control; soil solarization and other technologies. Just a few years ago, a tomato yield of 100 tonnes/ha in a greenhouse was considered a good performance. Today, a harvest of 600 tonnes/ha is not unusual in high-tech greenhouses.

In SEE countries, protected cultivation is still in a period of transition following a decline in importance in the wake of the social changes of the 1990s. The shift from centrally controlled greenhouse industrial units to small-scale family enterprises has been slow as a result of dependency on the technological capacity and investment potential of small-scale growers.

At present, the total protected cultivation area in South East Europe amounts to about 104 560 ha, accounting for approximately 5.31 percent of total vegetable cultivated area. A large proportion of greenhouses are low tech and covered with plastic. Heating and advanced climate control are not yet widespread, although in several countries there are many examples of successful implementation of high-tech greenhouse cultivation.

As a result of improving living standards, the demand for high-quality and safe horticulture produce is increasing in SEE countries, where the consumption of a diverse range of fruits and vegetables is still below the daily intake of 400 g per capita recommended by WHO. This situation creates a favourable opportunity for further development of the greenhouse production sector as a means of sustainable crop production intensification to make best use of available land and water resources.

Since 2001, the FAO Plant Production and Protection Division, together with the Regional Office for Europe, has facilitated intercountry cooperation among SEE countries by supporting training and research and development initiatives to strengthen national capacities and upgrade greenhouse technology.

The present document – *Good Agricultural Practices for greenhouse vegetable production in the SEE countries: Principles for sustainable intensification of smallholder farms* – builds on experience gained through partnerships forged by the FAO Regional Working Group on Greenhouse Crop Production in SEE, and represents a partnership effort spanning through almost two decades. It summarizes the knowledge and practical experiences of "good agricultural practice" (GAP) gained by a group of scientists from Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Greece, Hungary, Kosovo, The former Yugoslav Republic of Macedonia, Republic of Moldova, Montenegro, Romania, Serbia, Slovenia and Turkey, in collaboration with the Commission of Protected Cultivation of the International Society for Horticultural Science and a worldwide panel of specialists on the subject.

The activities of the Regional Working Group support FAO's Strategic Objective 2: "increase and improve provision of goods and services from agriculture, forestry and fisheries in a sustainable manner". In addition, by increasing the availability of high-quality fruits and vegetables, greenhouse crop production will help to achieve Strategic Objective 1: "contribute to the eradication of hunger, food insecurity and malnutrition". As a labour-intensive activity, greenhouse cultivation creates employment and income opportunities and thus reduces rural poverty (Strategic Objective 3), and enhances business opportunities along the horticulture value chain involving a series of stakeholders from production to consumption – thus furthering Strategic Objectives 3 and 4. Finally, in a world increasingly characterized by hazardous climate phenomena, protected cultivation strengthens resilience against unforeseen climate disasters, including drought, heavy rains, and excessively warm or cold temperatures – Strategic Objective 5.

Greenhouse cultivation is particularly suited to offset the effects of climate change since, by definition, greenhouse cultivation is based on controlled climate parameters including temperature, humidity, light and day length, wind and CO_2 concentration.

Protected vegetable cultivation in SEE countries is predominantly carried out by small-scale producers in both greenhouses (mostly plastic-covered) and low tunnels. The vast majority of greenhouses are still unheated or only occasionally heated. The activities of the Regional Working Group, therefore, support FAO's Regional Initiative on Empowering Smallholders and Family Farms in Europe and Central Asia.

This publication illustrates and discusses good agricultural practices that adopt sustainable intensification of greenhouse crop production as their guiding principle. It is in line with the FAO "Save and Grow" paradigm: produce more and better with reduced and optimal use of inputs, thereby limiting negative impacts on climate. Different aspects of greenhouse crop production and protection are illustrated, with special emphasis on greenhouse technologies, design, climate control and cropping systems. There is comment and analysis of both environmental and economic sustainability.

It is believed that the further "technification" of greenhouse crop production in SEE countries will sustain employment and income for the young generation. Greenhouse crop production – with biological control and integrated pest management (IPM) – is seen as a means to sustainable crop intensification, leading to water-use efficiency and better control of product quality and safety.

By sharing their knowledge and experience, the authors of this publication wish to improve the competitiveness of the vegetable greenhouse sector in SEE countries and contribute to its further development for the benefit of growers, consumers and the environment.

The publication is intended as a training guide for trainers and as a technical reference for growers and stakeholders in the greenhouse vegetable value chain. It is also expected to be a valuable source of information for programme managers, international and multilateral development organizations, NGOs and the private sector, as well as for researchers, advisors and professionals in greenhouse agriculture.

Vladimir Rakhmanin
FAO Assistant Director-General and
Regional Representative for Europe and
Central Asia

Hans Dreyer
Director, FAO Plant Production and
Protection Division

List of acronyms and abbreviations

AM	Arbuscular mycorrhizal
AMAP	Association for the Maintenance of Family Farming (France)
ANBP	Association of Natural Bio-control Producers
ASAE	American Society of Agricultural Engineers
AW	Available water
BCMV	Bean common mosaic virus
BCTV	Beet curly top virus
BER	Blossom-end rot
BPYV	Beet pseudo-yellows virus
BR	Blotchy ripening
BYMV	Bean yellow mosaic virus
CEC	Cation exchange capacity
CFC	Chlorofluorcarbon
CIHEAM	International Centre for Advanced Mediterranean Agronomic Studies
CMV	Cucumber mosaic virus
CNFA	Cultivating New Frontier in Agriculture
CON	Conventional agriculture
CSA	Community supported agriculture
DIF	Day–night temperature difference
DSS	Decision support system
DT	Day temperature
DTPA	Diethylene triamine penta acetic acid
EC	European Community
EC	Electrical conductivity
EEA	European Environment Agency
EEI	Ecological efficiency index
EIL	Economic injury level
ELO	Extra light oil
ET	Evapotranspiration

EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FORL	*Fusarium oxysporum* f. sp. *radicis-lycopersici*
GAP	Good agricultural practice
GAS	Solidarity purchase group (Italy)
GHG	Greenhouse gas
GM	Gross margin
GMV	Garlic mosaic virus
GRIS	Greenhouse Information System
GWP	Global warming potential
HFC	Hydrofluorcarbon
IFOAM	International Federation of Organic Agriculture Movements
INT	Integrated crop production
IPM	Integrated pest management
IPP	Integrated production and protection
IS	Irrigation scheduling
ISHS	International Society for Horticultural Science
IYSV	Iris yellow spot virus
LBVV	Lettuce big-vein virus
LCA	Life cycle analysis
LDPE	Low density polyethylene
LER	Land equivalency ratio
LYSV	Leek yellow stripe virus
MAD	Management allowable depletion
MilBBV	Mirafiori lettuce big-vein virus
NFT	Nutrient film technique
NIR	Near-infrared radiation
NT	Night temperature
OECD	Organization for Economic Co-operation and Development
ORG	Organic production
OYDV	Onion yellow dwarf virus
PAMV	Potato aucuba mosaic virus
PAR	Photosynthetically active radiation
PCR	Polymerase chain reaction

PE	Polyethyelene
PepYMV	Pepper yellow mosaic virus
PG	Public Goods
PGPR	Plant growth promoting rhizobacteria
PISWD	Pre-irrigation soil/substrate water deficit
PPP	Plant protection products
PVC	Polyvinyl chloride
REU	Regional Office for Europe and Central Asia (FAO)
RH	Relative air humidity
RWG	Regional Working Group
SAS	Safety access system
SC	Scheduling coefficient
SC	Soilless culture
SCIS	Soilless Culture Information System
SCrV	Strawberry crinkle cytorhabdovirus
SEE	South East Europe
SIA	Social Impact Assessment
S-LCA	Social Life Cycle Assessment
SMART	Sustainability Monitoring and Assessment RouTine
SO	Strategic Objective (FAO)
SPI	Sustainable process index
SROI	Social return on investment
TICV	Tomato infectious chlorosis virus
ToMV	Tomato mosaic virus
TRV	Tobacco rattle virus
TSS	Total suspended solids
TSWV	Tomato spotted wilt virus
UNDP	United Nations Development Programme
UNECE	United Nations Economic Commission for Europe
UV	Ultraviolet
VPD	Vapour pressure deficit
WUE	Water-use efficiency
YSD	Yellow shoulder disorder

PART I

Introduction

1. Regional Working Group on Greenhouse Crop Production in SEE: history and development

A. Hodder, [a] W. Baudoin,[a] A. Nersisyan,[b] Y. Tüzel[c] and A. Balliu[d]

[a] *Plant Production and Protection Division, Food and Agriculture Organization of the United Nations, Rome, Italy*
[b] *Regional Office for Europe and Central Asia, Food and Agriculture Organization of the United Nations, Budapest, Hungary*
[c] *Ege University, Faculty of Agriculture, Department. of Horticulture, Izmir, Turkey*
[d] *Agricultural University of Tirana, Albania*

PLANT PRODUCTION AND PROTECTION DIVISION OF FAO (AGP): APPROACH AND ROLE IN PROMOTING REGIONAL COOPERATION IN SUPPORT OF GREENHOUSE CROP PROTECTION

In line with the "Save and Grow" concept, AGP works to strengthen global food and nutrition security by promoting sustainable crop production intensification, which aims at producing more from the same area of land while conserving resources, reducing negative impacts on the environment and enhancing natural capital and the flow of ecosystem services.

AGP's mandate is to enhance and strengthen:

- effective and strategic decisions that increase crop production using an ecosystem approach and nutrition-sensitive crop diversification;
- national capacities to monitor and respond effectively to transboundary and other important outbreaks of pests;
- policies and technologies to enable member countries to reduce the negative impact of pesticides; and
- conservation and sustainable use of plant genetic resources with strong linkages between conservation, plant breeding and seed sector development.

As part of its programme areas, AGP and the Regional Office for Europe and Central Asia (REU) jointly support the development of greenhouse technology for horticulture and high-value crops as a means for sustainable crop intensification in South East European countries (SEE). In this context, AGP and REU are facilitating the activities of a Regional Working Group in SEE, which was established in 2000 with a view to capitalize and exchange know-how and undertake joint research and development projects.

South East European countries are keen to develop greenhouse crop production as a means to better supply emerging local markets and take advantage of export opportunities. In the context of the "transition" from a centrally-planned economy in certain SEE countries to free market exchange, greenhouse vegetable production has attracted particular interest as a source of employment and income. However, as a result of past heritage and lack of knowledge and confidence, growers are not yet properly prepared as modern greenhouse crop production entrepreneurs. There is a significant lack of access to information on modern production practices that could lead to increased productivity and reasoned use of agrochemicals.

Member Institutes of the FAO Regional Working Group

• Albania	Agricultural University of Tirana
• Bosnia and Herzegovina	University of Sarajevo
	Agricultural Extension Regional Office, Bijelijina
• Bulgaria	Maritsa Vegetable Crops Research Institute, Plovdiv
• Croatia	University of Zagreb
• Greece	Agricultural University of Athens
	School of Agricultural Sciences, University of Thessaly
• Hungary	Corvinus University of Budapest
	Szent István University, Gödöllő
• Kosovo	University of Pristina
• The former Yugoslav Republic of Macedonia	Institute of Agriculture, Skopje
• Republic of Moldova	Technical University of Moldova, Chișinău
	Vegetable Department, State Agrarian University of Moldova, Chișinău
• Montenegro	University of Montenegro, Podgorica
• Romania	Horticulture Faculty, University of Agriculture Sciences and Veterinary Medicine, Iasi
• Serbia	Ministry of Agriculture Forestry and Water Management, Belgrade
	University of Novi Sad
• Slovenia	Faculty of Agronomy, University of Maribor
	University of Ljubljana
• Turkey	Department of Horticulture, Faculty of Agriculture, Ege University, Izmir

The activities of the FAO Working Group have raised awareness of the potential of greenhouse crop production as a means of sustainable intensification and diversification.

Greenhouse crop production offers great **potential**:

- Increase productivity by unit of land area and extend the duration of the cropping season.
- Offset the effects of climate change by protecting crops against variable climatic phenomena.
- Improve pest and disease control with reduced use of chemical pesticides and more widespread adoption of biological control.
- Provide control over production planning to meet consumer demand with higher-quality and safer products.

SCOPE OF THIS PUBLICATION AND MAIN OBJECTIVES

The publication of *GAP for greenhouse vegetable production in the SEE countries: Principles for sustainable intensification of smallholder farms* is a major achievement and also a key milestone of the FAO Regional Working Group on Greenhouse Production in SEE. Its scope is to capitalize the know-how and experiences of the FAO network of scientists. Since the creation of the Regional Working Group, a broad range of crop- and technology-related aspects of greenhouse crop production and protection have been studied and debated.

The main **objectives** of this publication are:

- Provide a compilation of greenhouse production practices and technologies presently in use in SEE countries that have helped increase vegetable productivity and quality.
- Provide recommendations on good agricultural practices based on the current best knowledge of the different crop and technology aspects for greenhouse vegetable cultivation in SEE countries.

The document is in line with the new FAO “Save and Grow” principles that advocate the sustainable intensification of farming systems and strengthen their resilience to socio-economic and climate risks. The publication is meant to be a reference document for scientists, teachers and students, as well as private sector entrepreneurs. It is proposed as a training support document for upgrading the technical know-how of trainers and proactive growers as well as other actors in the greenhouse vegetables value chain in SEE countries.

ORIGIN AND OPERATIONAL MODALITIES OF THE GREENHOUSE REGIONAL WORKING GROUP

An FAO workshop on greenhouse crop production in the South East European region was held in Thessaloniki (Greece), on the occasion of the 2nd International Balkan Symposium on Vegetables and Potatoes, 11–15 October 2000, with the participation of the following countries: Albania, Bulgaria, Croatia, The former Yugoslav Republic of Macedonia, Greece, Hungary, Republic of Moldova, Romania, Turkey, Serbia and Montenegro. As a result of that workshop, the participants solicited FAO to take the initiative to formally establish a Regional Working Group on Greenhouse Crop Production in SEE.

As a follow-up, FAO organized a series of surveys carried out in various countries in the region to assess the opportunities and constraints of the greenhouse crop sector in cooperation with relevant national horticulture institutions and growers' associations. This permitted the preparation of baseline documents, which provided for an interesting background to develop future initiatives.

Consequently, FAO sought and obtained endorsement from the ministries of agriculture for the formal establishment of a Regional Working Group on Greenhouse Crop Production in SEE. The 12 countries responded positively and each nominated a national representative who attended the first coordinating meeting held from 20 to 22 October 2004, in the premises of the FAO Regional Office for Europe in Budapest, Hungary.

On behalf of the FAO Regional Office for Europe, Ms Maria Kadlecikova welcomed the participants and gave information on the main activities of the FAO Regional Office, which coordinates activities in 20 countries and Byelorussia. She highlighted the fact that horticulture-based activities were gaining importance (for example, tomato production with IPM in Poland). This kind of production, with high labour requirements, could be one solution to offset the high unemployment rate in the region (from 15% to as much as 60% in rural areas).

The meeting promoted debate on the scope and objectives of the Working Group. It was agreed that the regional cooperation should concentrate on greenhouse crop production. Its activities should ultimately lead to enhancing the scientific knowledge and technical capacity of the growers in order to improve the competiveness of the greenhouse crop sector in SEE countries.

At the first coordinating meeting, the participants established a framework for cooperation, relating to the following **five subject areas:**

1. **Plant material:** species, cultivars, propagation, diversification.
2. **Technology:** greenhouse design, covering materials, climate control, irrigation, fertigation, soilless culture.

3. **Cultivation practices:** plant density, training and pruning, plant nutrition, weed control.
4. **IPM:** biological control and safe application of pesticides in respect of international and national regulations.
5. **Production** economics, quality norms and standards, organic horticulture.

It was agreed to entrust the management of the Working Group to a regional coordinator by consensus for a 2-year term on a rotating basis. In cooperation with FAO, the regional coordinator's mandate is to facilitate and monitor the implementation of the activities of the Working Group elaborated on occasion of the biannual coordinating meeting and organize and host the next coordinating meeting.

The activities of the group concentrate on the following **three clusters:**

1. **Information, management and dissemination,** including: publication of technical documents and newsletters; data collection and exchange related to the greenhouse crop sector and the performance of horticulture cultivars in HORTIVAR; distribution of information on good agricultural practices.
2. **Capacity-building:** implementation of training and demonstrations with national training sessions; organization of international conferences and symposia; preparation and publication of training material (including IPP cards and an extension manual); organization of seminars and field days.
3. **Project formulation and implementation** at national level (or for intercountry cooperation, at subregional and regional level), including resources mobilization for implementation (UNDP, GCP, TCP, EU etc.).

At the WG establishment meeting, baseline information was gathered on the status of the greenhouse crop sector in the participating countries. The analysis of the country papers provided an insight into the overall environmental context and potential for protected cultivation in view of the diversified agro-ecological conditions in the different countries. It became apparent that the prevailing conditions varied considerably both between and within countries. Major constraints were highlighted in various areas: from the lack of knowledge on greenhouse design, covering materials, and heating and ventilation technologies and practices, to limited understanding of the crop diversification options and IPM, as well as deficiencies in farmers' organization, product quality, packaging and labelling (traceability), and a lack of technical specifications of inputs adapted to different greenhouse types. Furthermore, there was a general absence of guidance and advice with regard to good agricultural practices. The area under greenhouse development at the time the regional cooperation was initiated is summarized in Table 1.

TABLE 1
Distribution of protected cultivation area (ha) in selected SEE countries

	Year	Glasshouse	PE greenhouse, walk-in tunnels, low plastic tunnels, mulching and direct covers	TOTAL
Albania	2004	97.7	562.9	660.6
Bosnia and Herzegovina	2004		1 200.0	2 000.0
Bulgaria	2001	642.2	1 026.7	1 668.9
Croatia	2004	40.0	1 370.0	1 410.0
The former Yugoslav Republic of Macedonia	2003	185.0	10 000.0	10 185.0
Greece	2002		14 733.0	14 733.0
Hungary	2003			5 185.0
Republic of Moldova	2003	40.0	253.0	293.0
Romania		1 300.0	6 000.0	7 300.0
Serbia and Montenegro				10 000.0
Slovenia				140.0
Turkey	2002			53 603.0
TOTAL		**2 304.9**	**35 145.6**	**107 178.5**

The **WG establishment workshop** took place in Thessaloniki, Greece, convened by FAO on the occasion of the 2nd International Balkan Symposium on Vegetables and Potatoes, 11–15 October 2000.

The following **coordinating meetings** have since been held:

- First coordinating meeting: 20–22 October 2004, Budapest, Hungary, convened by FAO. Dr Yüksel Tüzel from Turkey was nominated as WG coordinator.
- Second coordinating meeting: 7–11 April 2008, Izmir, Turkey, convened by Dr Yüksel Tüzel, Ege University, Turkey. Dr Zdravko Matotan from Croatia was nominated as WG coordinator.
- Third coordinating meeting: 9–12 October 2011, Tirana, Albania, on the occasion of the 5th Balkan Symposium on Vegetables and Potatoes, convened by Dr Astrit Balliu, Agricultural University of Tirana, Albania. Dr Bozidar Benko from Croatia was nominated as WG coordinator.
- Fourth coordinating meeting: 29 September – 2 October 2014, Zagreb, Croatia, on the occasion of the 6th Balkan Symposium on Vegetables and Potatoes, convened by Dr Bozidar Benko, University of Zagreb, Croatia. Dr Yüksel Tüzel from Turkey was nominated as WG coordinator.
- Fifth coordinating meeting: 11–14 April 2016, on the occasion of the 3rd International Symposium on Organic Greenhouse Horticulture in Turkey, convened by Dr Yüksel Tüzel, Ege University, Turkey. Dr Martina Bavec from Slovenia was nominated as WG coordinator.

FAO Regional Working Group on Greenhouse Crop Production in SEE Members and Cooperating Scientists

Balliu, Astrit
Professor, Horticulture Department
Agricultural University of Tirana
Albania
Tel. (+355) 6 860 22105
aballiu@ubt.edu.al

Baudoin, Wilfried
Senior Agronomist – Horticulture
Plant Production and Protection Division
FAO
Rome, Italy
Tel. (+39) 06 57054588
wilfried.baudoin@fao.org

Bavec, Martina
Faculty of Agronomy, University of Maribor
Slovenia
Tel. (+386) 2 2505800
martina.bavec@uni-mb.si

Bosoanca, Iulia
Counsellor, Horticultural Department
Agriculture Ministry
Bucharest, Romania
Tel. (+40) 21 3078432
iulia.bosoanca@maa.ro

Gruda, Nazim
Division of Horticultural Sciences, Institute of
Plant Sciences and Resource Conservation
University of Bonn
Germany
Tel. (+49) 176 341055 70
ngruda@uni-bonn.de

Guri, Shpetim
Director, Ministry of Agriculture and Food
Tirana, Albania
Tel. (+355) 4 223952
salimetani@yahoo.com

Jerkic, Irena
Professional Assistant, Ministry of Agriculture
Sarajevo, Bosnia and Herzegovina (Federation)
Tel. (+387) 33 218402
jseko@bih.net.ba

Hodder, Alison
Senior Officer – Horticulture
Team leader AGPML
Plant Production and Protection Division
FAO
Rome, Italy
Tel. (+39) 06 57054846
alison.hodder@fao.org

Lacatus, Victor
Scientific Director, Research Institute for
Vegetable and Flower Crops
Vidra, Romania
Tel. (+40) 21 4680794
inclf@mediasat.ro

Masheva, Stoyka
Assistant Professor, Maritsa Vegetable Crops
Research Institute
Plovdiv, Bulgaria
Tel. (+359) 32 960179
izk@plov.omega.bg

FAO Regional Working Group on Greenhouse Crop Production in SEE Members and Cooperating Scientists (cont.)

Matotan, Zdravko
Manager, Podravka d.d.
Koprivnica, Croatia
Tel. (+385) 48 651711
zdravko.matotan@podravka.hr

Moor, Andrea
Scientist, ex-VRCI
Budapest, Hungary
Tel. (+36) 1 2173053
andrea.moorne@mail.tvnet.hu

Nersisyan, Avetik
Agriculture Officer, AGP/REU
FAO
Budapest, Hungary
Tel. (+31) 1 8141240
avetik.nersisyan

Nicola, Silvana
Co-Chair of International Affairs
Department of Agricultural, Forest and Food Sciences, University of Turin
Vice-President and Vice-Chairperson of the Board of Directors of ISHS
Responsible for the Scientific Activities of the Society
Turin, Italy
Tel. (+39) 011 6708773
silvana.nicola@unito.itl

Olympios, Christos
Professor, Agricultural University of Athens
Greece
Tel. (+30) 210 5294521
olympios@aua.gr

Pasko, Pandeli
Liaison Officer for Balkans International Cooperation Area, Mediterranean Agronomic Institute (CIHEAM)
Bari, Italy
Tel. (+39) 080 4606322
pasko@iamb.it

Popsimonova, Gordana
Deputy Director, Institute of Agriculture
Department of Vegetable Crops
Skopje, The former Yugoslav Republic of Macedonia
Tel. (+389) 2 3230910
gpopsimonova@yahoo.com

Rosca, Victor
State Agrarian, Department of Vegetables
University of Moldova
Chişinău, Republic of Moldova
Tel. (+373) 22 577930
vrosca@moldova.cnfa.org

Shima, Xhevat
Director, Institute of Vegetables and Potatoes
Tirana, Albania
Tel. (+355) 4 228422
salimetani@yahoo.com

Stanciu, Constantin
General Manager, S.C. LEOSER S.A.
Bucharest, Romania
Tel. (+40) 21 3321285
inclf@mediasat.ro

FAO Regional Working Group on Greenhouse Crop Production in SEE Members and Cooperating Scientists (cont.)

Tanny, Josef
Head, Department of Environmental Physics and Irrigation
Institute of Soil, Water and Environmental Sciences
Agricultural Research Organization
Volcani Center
Rishon LeTsiyon, Israel
Tel. (+972) 3 9683410
tanai@volcani.agri.gov.il

Terzi, Anatolie
Director of Agribusiness Enterprise
Support Department, CNFA
Chişinău, Republic of Moldova
Tel. (+373) 22 557933
aterzi@moldova.cnfa.org

Tompos, Daniel
Vegetable Department, Corvinus University
Hungary
Tel. (+36) 1 2276454
daniel.tompos@uni-corvinus.hu

Tüzel, Yüksel
Professor, Faculty of Agriculture,
Ege University
Izmir, Turkey
Tel. (+90) 232 3881865
tuzel@ziraat.ege.edu.tr

Urban, Laurent
Campus Agroparc, University of Avignon
France
Tel. (+33) 490 842214
Laurent.urban@univ-avignon.fr

Zaric, Dragan
Manager, Agricultural Extension Service
Ministry of Agriculture
Banja Luka, Bosnia and Herzegovina
(Republika Srpska)
Tel. (+387) 55 240034
pssbn@rstel.ne

Zarubica, Katarina
Advisor, Ministry of Agriculture Forestry and Water Management
Belgrade, Serbia
Tel. (+381) 11 602829
katazara@yahoo.com

ACTIVITIES, RESULTS AND ACHIEVEMENTS OF THE WORKING GROUP

Capacity-building has been pursued through a series of FAO-sponsored technical workshops. As a group, the network members play a leading role in promoting the exchange of information on greenhouse crop technology and have been able to organize several international symposia, often in conjunction with the Commission Protected Cultivation of the International Society for Horticulture Science:

- 2nd International Balkan Symposium on Vegetables and Potatoes, Thessaloniki (Greece), 11–15 October 2000
- International Horticulture Congress in Lisbon, 22–27 August 2010
- Greenhouse Cooling, Almería, Spain, 23–24 May 2006
- Sustainable Greenhouse Crop Production Technologies in Mild Winter Climates, Antalya, Turkey, 6–11 April 2008
- 3rd International Symposium on Organic Greenhouse Horticulture in Turkey Organic Greenhouse Production, Izmir, 11–14 April 2016

Some 3 640 data sets on the performance of horticulture cultivars in greenhouse cultivation have been inserted in **Hortivar**, as well as 39 “Good Morning Horticulture” messages. Countries have submitted 27 pairs of “IPP cards” (integrated production and protection), illustrating good agricultural practices (GAPs) for greenhouse crops; these too have been uploaded in Hortivar.

Templates have been designed and statistical information compiled on soilless culture systems in SEE countries in the Soilless Culture Information System (SCIS). Templates and statistical information on the greenhouse crop sector in SEE countries has also been compiled in the Greenhouse Information System (GRIS). Both SCIS and GRIS have been integrated into Hortivar. Research for development has been strengthened and transfer of know-how to growers has been facilitated through the formulation and implementation of field projects.

The WG members have been very active in formulating **research–development projects** and mobilizing resources for their implementation from various sources, including the Food and Agriculture Organization of the United Nations (FAO), the European Union (EU) and the United Nations Development Programme (UNDP):

- **Bulgaria:** “Improvement of greenhouse crops production technology and efficiency” (FAO- TCP/BUL/3002 [A]).
- **Croatia and Slovenia:** “Soilless culture of vegetables in Croatia and Slovenia” (2000–02), a subregional research project, formulated and jointly implemented by the Faculty of Agriculture, University of Zagreb, Croatia, and the Biotechnical Faculty, University of Ljubljana, Slovenia.

- **Serbia and Slovenia:** "Studying quality of products – vegetable holistic approach" (2012–13), involving the Biotechnical Faculty, University of Ljubljana, Slovenia, and University of Novi Sad, Serbia.
- **Albania and Italy:** Erasmus+ KA1 – Learning Mobility of Individuals. Extra-EU 2015–16. Mobility of learners and staff. Internationalization programme on protected cultivation, by University of Turin, Italy, and Agricultural University of Tirana, Albania.
- **Bulgari, Albania and Greece:** "Increasing the competitiveness of greenhouse sector in Balkan countries", involving University of Thessaly, Greece, Albanian Horticultural Association, Agricultural University of Tirana, Albania, and Maritsa Vegetable Crops Research Institute, Plovdiv, Bulgaria.
- **Slovenia and Italy:** Project realized during 2009–10 between the Faculty of Agriculture, University of Novi Sad, Serbia, and the Campania–Basilicata Region (Italy, CRA-ORT). Technical–Scientific Cooperation in the Agriculture Sector of the Integrated Operational Program (POI) Campania–Basilicata in Serbia
- **Albania and Italy:** Erasmus+ KA1 – Learning Mobility of Individuals. Extra-EU 2015–16. Mobility of learners and staff. Internationalization programme on protected cultivation, by University of Turin, Italy, and Agricultural University of Tirana, Albania.
- **Germany and Croatia:** Erasmus+ KA1 – Learning Mobility of Individuals. Extra-EU 2016–17. Mobility of learners. "Sustainability and Product Quality", involving University of Bonn, Germany, and University of Zagreb, Croatia. (Project approved and undergoing)
- **Croatia and Slovenia:** "Studying quality of products – vegetable holistic approach", involving the Biotechnical Faculty, University of Ljubljana, Slovenia, and University of Zagreb, Croatia
- **Turkey and Greece:** Erasmus+ KA1 – Learning Mobility of Individuals. Mobility of learners and staff. LLP/Leonardo Da Vinci European Programme "Improving competitiveness and professional experiences of young agriculturists on sustainable agriculture, new agricultural technologies and employment opportunities", involving Ege University, Turkey, and Agricultural University of Athens, Greece.
- **Turkey and Italy:** Erasmus+ KA1 – Learning Mobility of Individuals. Inter-institutional agreement for 2017–2021. Mobility of learners and staff. By University of Catania, Italy, and Ege University, Turkey.

Other **projects are in the pipeline:**

- **Albania, Greece and The former Yugoslav Republic of Macedonia:** “Increasing the competitiveness of the greenhouse sector in Balkan countries”, submitted in the framework of the BalkanMed Programme (financed by the EU). The proposal is led by the University of Volos, Greece, and partners from Albania, The former Yugoslav Republic of Macedonia and Cyprus.
- **All 13 countries:** “Strengthen the capacity for the adoption of Good Agriculture Practices for greenhouse vegetable production in the South Eastern European Countries”, a FAO–TCP regional project proposal.
- **Greece and Italy:** “Promoting sustainable consumption patterns, resource efficient technologies and policies in the EU greenhouse markets”, submitted to the Life+ call for proposals. The coordinating beneficiary is the University of Thessaly.

CAPITALIZATION AND EXCHANGE OF INFORMATION

On occasion of the Fourth Coordinating meeting, which took place in Zagreb in September 2014, the participants considered that the time was appropriate to take stock of the information accumulated and the experiences gained through regional cooperation. They invited FAO to take the lead in compiling a multi-author technical document which would serve the double purpose of compiling the know-how gained and translating this knowledge into pragmatic recommendations on good agriculture practices.

During the meeting in Zagreb, the basis was laid for the Table of Contents and the lead and co-authors were identified for the various different chapters.

A business meeting was convened in Chişinău, Republic of Moldova, on 16 June 2015 to review the first draft; a second business meeting took place in Izmir on 12 April 2016, allowing for cross-review of the final draft. Technical proofreading and editing was begun in June and completed in December 2016. Translation into Russian was gradually initiated as the completed and proofed chapters became available.

The Working Group members agreed to establish a corporate working library for the sharing of documents and scientific articles of common interest. The list of these documents is provided in the Annex on p. 415.

THE WAY FORWARD

The activities of the FAO Regional Working Group on Greenhouse Crop Production in SEE have undoubtedly impacted on the improvement of the greenhouse production sector in the region. The RWG has contributed to the mutation from centrally-managed industrial units during the former Soviet Union to small-scale family-owned enterprises. It has been specifically instrumental in forging scientific relationships among researchers, which has facilitated the access to financial resources for the implementation of intercountry and regional projects. The RWG members are committed to continuing their cooperation to jointly implement research and development projects of common interest in support of the greenhouse crop sector in the SEE region. As a network of scientists, they will pursue their interaction with FAO and serve as a resource for information exchange, training and capitalization of know-how.

RECOMMENDED READING

Proceedings of the Regional Working Group meetings:

- Thessaly, Greece, 11–15 Oct. 2000
- Budapest, Hungary, 20–22 Oct. 2004
- Izmir, Turkey, 7–11 April 2008
- Tirana, Albania, 9–12 Oct. 2011
- Zagreb, Croatia, 29 Sept. – 2 Oct. 2014
- Izmir, Turkey, 11–14 April 2016

2. Current situation and future trends of protected cultivation in South East Europe

N. Gruda[a] and G. Popsimonova[b]

[a] *Federal Office for Agriculture and Food, and University of Bonn, Germany*
[b] *University Ss Cyril and Methodius, Skopje, Republic of Macedonia*

ABSTRACT

Although protected cultivation in some South East European (SEE) countries has declined in importance following the social changes of the 1990s, vegetable production under protected conditions remains a vital part of the horticulture industry. The total protected cultivation area in South East Europe amounts to about 101 888 ha, accounting for approximately 5.15% of the total vegetable cultivated area. Production is about 7 962 240 tonnes, i.e. approximately 19.09% of total vegetable production. However, some countries – notably Turkey and Greece – have not undergone such changes and are renowned for vegetable production in the Mediterranean region and worldwide. Recent developments in other countries – e.g. Albania – have led to an increase in vegetable greenhouse production. This chapter presents the current status quo and future perspectives of protected vegetables for sustainable production in South East Europe. Questionnaires were used to gather data on production area, vegetable cultures, ages and types of construction, equipment, heating, irrigation and cultivation systems. For some SEE countries, it was the first time such data had been collected. Although the data are not always complete, they do provide a relatively detailed picture of the current situation of greenhouses and tunnels and reveal the trends in this area. The data were used to perform an analysis of protected cultivation. Recommendations are then made, and it is hoped that they will impact future government policy and serve as guidelines to initiate new research projects within this field.

INTRODUCTION

Many countries in South East Europe (SEE) shared a certain socio-economic context when walk-in tunnels first appeared in the mid-1970s. Markets were closed and self-sufficient, and existing greenhouse operators had no incentive to increase productivity or introduce new cultivating technologies. In recent years, as SEE features new emerging economies, there is a new attitude in favour of sustainable use of protected cultivation. Various structures are adopted, depending on the crop, the climatic region and the expected benefits. There is ample scope for improvement with the adoption of good agricultural practices (GAPs).

Covering not only protects the crop from external natural hazards, but also allows for artificial manipulation of the micro-environment to optimize plant performance, extend production duration, induce earliness of flowering, and improve production and product quality (Gruda and Tanny, 2014, 2015).

This chapter outlines the current situation of protected cultivation in SEE countries. Given the lack of official statistics, data were gathered based on the results of a regional survey, and the main elements of greenhouse development are presented herein. Finally, future challenges are discussed briefly.

MATERIALS AND METHODS

For a full picture of greenhouse sector development, a questionnaire was distributed among members of the Regional Working Group for protected crops comprising 14 SEE country representatives (Gruda, 2015).[1]

The **questionnaire** was structured in five main parts:

- Basic information for greenhouses
- Basic information for tunnels
- Energy supply
- Proposals for optimization
- Other relevant sector information

The first three parts requested numeric data and semi-open questions were included to enable comparisons. The last two parts contained open-ended questions. The results were further enriched using FAOSTAT data and information from regional reports and articles.

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[1] Representatives from 12 countries – Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Greece, Kosovo, Montenegro, The former Yugoslav Republic of Macedonia, Republic of Moldova, Serbia, Turkey and Slovenia – provided data. No representatives from Hungary and Romania were available.

GENERAL DATA ON PROTECTED CULTIVATION IN SOUTH EAST EUROPE

Area

Protected crop area refers to the combined area under greenhouses and tunnels and varies between countries: from 48 ha in Montenegro to 61 512 ha in Turkey. The percentage of cultivated area under protected crops is low, with only two countries exceeding 10%: Greece (14.58%) and the Republic of Macedonia (10.25%). Total protected cultivation area in SEE amounts to about 101 888 ha, i.e. approximately 5.15% of the total vegetable cultivated area (Table 1).

VEGETABLE PRODUCTION AND CROP STRUCTURE

Vegetables are by far the most cultivated crops in the region (> 98%), followed by cut flowers, potted ornamentals and small fruits (e.g. strawberries). Vegetable production amounts to about 7 962 240 tonnes, accounting for approximately 19.09% of the total cultivated area of vegetable crops (Table 1). In line with global trends and market requirements, the area under tomato is more than double that of any other protected vegetable crop, followed by cucumber, pepper and lettuce

TABLE 1
Vegetable harvested area, production and percentage of protected crops

Country	Area[a] (ha)	Protected crops[b] (ha)	%	Production[a] (tonnes)	Protected crops[b] (tonnes)	%
Albania	41 926	1 733	4.13	957 202	105 807	11.05
Bosnia and Herzegovina	75 000	715	0.95	649 733	n.a.	n.a.
Bulgaria	40 809	1 060	2.59	557 726	99 244	17.79
Croatia	15 027	492	3.27	583 998	52 355	8.96
Greece	93 150	13 581	14.58	3 159 000	619 817	19.62
Hungary	76 802	3 920	5.10	1 363 075	353 000	25.90
Kosovo	12 450	234	1.88	331 000	12 569	3.80
Montenegro	6 832	48	0.70	134 587	n.a.	n.a.
The former Yugoslav Republic of Macedonia	47 873	4 905	10.25	716 052	58 935	8.23
Republic of Moldova	40 031	677	1.69	285 230	20 310	7.12
Romania	258 762	7 490	2.89	3 535 916	328 000	9.28
Serbia	147 764	5 422	3.67	1 072 033	367 202	34.25
Slovenia	1 587	99	6.20	71 954	4 250	5.91
Turkey	1 117 618	61 512	5.50	28 280 809	5 940 751	21.01
Total	**1 975 631**	**101 888**	**5.15**	**41 698 315**	**7 962 240**	**19.09**

[a] Total harvested area and production data according to FAOSTAT, 10 September 2014; for Kosovo, according to Ministry of Agriculture, Forestry and Rural Development, 2011; for Turkey, according to the Turkish Statistical Institute, 2013; for Croatia, according to Croatia Extension Services.

[b] Protected crops data estimated from questionnaires; for Hungary, according to Berczi, 2012; for Romania, according to van der Veen and Bejan, 2013.

n.a. = not available.

(Table 2).[2] Given the lack of sufficient statistical data for area and production under protected crops, it is difficult to estimate the average yield per unit of area, by crop. However, there is a general perception that there is room for increase in both yield and quality.

GREENHOUSE STRUCTURE

A wide range of approaches to protected cultivation are possible; growers can adopt and adjust technologies according to climatic and specific crop requirements. High-tech greenhouses produce high yields but also have high initial costs; naturally ventilated plastic tunnels and greenhouses are a low-cost alternative suitable for growers with limited capital or in regions with fluctuating demand (Gruda and Tanny, 2104, 2015). In SEE countries, most of the 54 585 ha of greenhouse area is plastic-covered without heating (Table 3, Plate 1). Sometimes heating is installed for a very short period when temperatures are particularly low (on cold days or at night). The greatest concentration of this type of structure is in the south of the region, on the island of Crete in Greece and in the region of Antalya in Turkey. The primary energy source is natural solar radiation. Various interventions are increasingly common to control light and radiation efficiency in greenhouses: appropriate covering materials are used to maximize light entering the greenhouse during the winter; either whitewashing or shade screens as well as evaporative cooling are used to reduce the consequences of the greenhouse effect

TABLE 2

Vegetable structure of protected cultivation in SEE countries

Surface (ha)	Glasshouses		Plastic greenhouses		Total		
	With heating	Without heating	With heating	Without heating	With heating	Without heating	TOTAL
Tomato	192	39	532	3 030	724	3 069	3 793
Cucumber	73	29	237	1 463	310	1 492	1 802
Pepper	44	9	126	1 455	170	1 464	1 634
Lettuce, cabbage etc.	11	4	57	2 535	68	2 539	2 607
Others	0	0	1	26	1	26	27

Note. No data are available for Turkey and Montenegro. There are > 1 million tonnes of cucumber produced every year in Turkey, one of the biggest producers in the SEE area. Therefore, it is assumed that the harvesting area for cucumber ranks second directly after tomato.

TABLE 3

Greenhouse surface in SEE countries (ha)

Glasshouses		Plastic greenhouses		Total		
With heating	Without heating	With heating	Without heating	With heating	Without heating	TOTAL
363	8 305[a]	1 151	46 280[a]	1 514	54 585[a]	56 099[a]

[a] Note that the data for Turkey include tunnels.

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[2] See Part III.

Plate 1
Plastic greenhouses. Top: Albania, cucumber. Middle: Turkey, tomato. Bottom: Republic of Moldova, strawberry.

during the hot season; and specific covering materials with filtering or fluorescent properties are adopted to increase photosynthetic efficiency and improve control of plant growth processes.

Recently, high-tech greenhouses with galvanized iron support structures and polyethylene (PE) covering have been built in the region (Plate 2). They vary in size from < 1 to > 4 ha. A significant proportion of vegetable greenhouse area is occupied by high tunnels. High tunnels are covered by impermeable transparent plastic film which may include roof and side vents to allow natural ventilation of the interior by wind or buoyancy forces. Opening and closing of the vents can be manual or automatic. Low tunnels are also widely used, particularly for early melon and watermelon production.[3]

Plate 2
Modern plastic greenhouse, Turkey

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[3] See Part III, Chapter 5.

TABLE 4

Age of greenhouse construction in SEE countries[a]

	Harvested area (ha)						
	Glasshouses		Plastic greenhouses		Total		
Age	With heating	Without heating	With heating	Without heating	With heating	Without heating	TOTAL
< 10 years	36	0	114	619	150	619	769
10–25 years	14	0	88	2 983	102	2 983	3 085
> 25 years	199	149	47	173	246	322	568

[a] Data not available for Bosnia and Herzegovina, Greece, Montenegro and Turkey.

GREENHOUSE TECHNOLOGY

Most greenhouses were erected 10–25 years ago, at the time of the transition from public to private ownership. They are mainly non-heated PE tunnels and greenhouses, although there also glasshouses built prior to this period, which, while still functioning, are poorly maintained (Table 4). The equipment and technology applied in glasshouses is outdated and production costs are therefore high. A small number of sophisticated models – so-called “high-tech” greenhouses – exist. Such structures can be equipped with computerized control systems, enabling climate control and a wide range of growth manipulations, such as shading/cooling by wet pad or fogging, heating, dehumidification and artificial illumination (Gruda and Tanny, 2014).[4]

Typical greenhouse-grown vegetables in the region, such as tomatoes, cucumbers, peppers and lettuces, may contain ≥ 90–96% water. For these crops, the availability of **good quality** water in **sufficient quantity** is indispensable. Protected crop areas in the region are usually situated near to water sources; nevertheless, there may still be water shortage problems, for example, in Albania or the Republic of Moldova. The source of the irrigation water is also crucial. Water from self-bored wells or collected from drainage channels may have a high sodium or chloride content or generally high soluble salts (electrical conductivity [EC] ≥ 3 dS m^{-1}), which can lead to plant growth problems. Rainwater is a very good and easy alternative; however, collection systems are not widespread in the region.

Good **irrigation management** is also fundamental for various reasons:

- There is no natural precipitation in protected cultivation – in soilless culture, even the groundwater is unavailable.
- Compared with open-field production, there is a high intensity and large quantity of year-round biomass production.
- Production is focused on high added-value crops.

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[4] See Part II, Chapters 1 and 7.

Detailed data on irrigation management are not always available; nevertheless, drip irrigation appears to be the most widely adopted system in the region. The questionnaire asked SEE producers: "Where do you see a need for irrigation system optimization?", and the most common responses were: "to reduce humidity", "to improve plant health" and "to switch from open to closed system in soilless culture".[5]

Integrated pest management has an important place in plant protection in all SEE countries. However, in reality, the region's smallholders do not typically implement GAP recommendations.[6]

Soilless cultivation entails high initial costs and is not widespread. The largest soilless cultivation area is in Turkey (700 ha), where both open- and closed-loop systems are adopted (Table 5). Both organic and inert substrates are used. In some cases nutrient film technique (NFT) is adopted in newly erected greenhouses.

Plates 3–6 give an overview and some details of soilless culture production of tomatoes near Zagreb, Croatia. Zarja grupa d.o.o. is a market leader in the production of fresh tomatoes, including cherry tomatoes, in the region. Participants at the Sixth Balkan Symposium on vegetables and potatoes visited the company and were given a technical tour.

TABLE 5
Soilless cultivation area in SEE countries (ha)

Country	Open-loop system	Closed-loop system	Total
Albania	3	0	3
Bosnia and Herzegovina	4	0	4
Bulgaria	n.a.	n.a.	140
Croatia	38.5	21.5	60
Greece	50	130	180
Kosovo	0	0	0
Montenegro	n.a.	n.a.	n.a.
The former Yugoslav Republic of Macedonia	18	0	18
Republic of Moldova	2	0	2
Serbia	12.3	4.8	17.1
Slovenia	1	4	5
Turkey	n.a.	n.a.	700

n.a. = not available.

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[5] See Part II, Chapter 3.

[6] See Part II, Chapter 5.

GRUDA

Plate 3
Greenhouse overview

GRUDA

Plate 4
Visit to Zarja grupa d.o.o., Zagreb, Croatia

GRUDA

Plate 5
Tomato cultivated in rockwool growing media

GRUDA

Plate 6
Cherry tomatoes produced in rockwool media

Nursery production varies widely among SEE countries: from almost 100% in Albania, Greece, Turkey and Croatia, to near 0% in the Republic of Moldova, The former Yugoslav Republic of Macedonia, Montenegro and Serbia. Specialized nursery farms use modern greenhouses (e.g. passively ventilated high-roof greenhouses – Plate 7) and new technologies (e.g. grafting). In some countries, growers produce their own transplants or import them from the nearest specialized nurseries.

ENERGY

Since the first energy crisis at the end of the 1970s, there have been massive efforts to reduce heating costs. Growers benefit from increased profitability as lower heating costs combine with improved yields and higher quality of produce grown in greenhouses; moreover, increased energy-use efficiency fits well with current environmental concerns and the objective to reduce carbon dioxide (CO_2) emissions within protected cultivation (Gruda and Tanny, 2014).

Plate 7
Interior of passively ventilated greenhouse used for vegetable seedling and transplant production, Albania

Plate 8
Ready-to-be-transported pepper seedlings, Albania

At lower latitudes (e.g. in Turkey and Greece), daytime temperatures become too high and ventilation is needed to provide sufficient cooling during the summer. On the contrary, in temperate climates (e.g. in Slovenia and the Republic of Moldova), heating is indispensable and – combined with ventilation – enables year-round temperature control.

Small glasshouse companies – where crude oil is the common energy source – lack state-of-the-art equipment and have higher energy costs than large greenhouses. Furthermore, many greenhouses are not well equipped for energy-use efficiency (Gruda *et al*., 2009). Outdated heating boilers and heating systems, poor isolation and inappropriate cultivation technologies result in excessive energy consumption: 1 kg of crude oil costs more than 1 kg of tomato. Increased automation is required to improve the energy efficiency of heating systems.

RESEARCH, EDUCATION AND EXTENSION

The importance of greenhouse production is fully recognized. A course or module is included in higher education curricula in all countries (with the exception of Slovenia). Research centres for protected crops operate in one-third of SEE countries: Turkey, Greece, Croatia and Montenegro. More extension services and training programmes are required, especially in countries with a large area and high number of protected crop producers.

Although good agricultural practices are adopted in high-tech greenhouses, they still need to become widespread among small growers. This is an important objective of research projects involving the cooperation of SEE countries. One such project is the FAO Working Group in the Mediterranean region, which focuses on three main areas: information management and dissemination, training and demonstration, and project formulation and implementation (Papasolomontos *et al*., 2013).

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PART II

Thematic approach

1. Structures: design, technology and climate control

C. Kittas,[a] N. Katsoulas[a] and T. Bartzanas[b]

[a] *University of Thessaly, Greece*
[b] *Centre for Research and Technology, Hellas, Greece*

ABSTRACT

This chapter provides an overview of good agricultural practices for greenhouse climate control and associated structure and design considerations in South East Europe. It presents the main greenhouse types in the area and discusses the most relevant issues related to greenhouse climate control and covering materials. Guidelines are provided for photoselective covering materials with a view to integrated greenhouse crop production with reduced use of pesticides. Since the majority of greenhouses in the area are small structures with rudimentary equipment, special focus is given to technologies for greenhouse climate control, with an emphasis on heating and ventilation. The importance of natural ventilation is stressed: it can control high air temperature during the summer months and can also remove excess humidity during the winter and maintain CO_2 levels close to the level of the outside air. Suggestions for improving natural ventilation through structural changes and optimal management are proposed. GAP recommendations for evaporative cooling systems are given.

GREENHOUSE DESIGN BASED ON CLIMAGRAPH DATA

The majority of plants grown in greenhouses in SEE countries are warm-season species suited to average temperatures of 17–27 °C, with approximate lower and upper limits of 10 and 35 °C. If the average minimum outside temperature is < 10 °C, heating will probably be necessary, particularly at night. When the average maximum outside temperature is < 27 °C, ventilation will prevent excessive internal temperatures during the day; however, if the average maximum temperature is > 27 °C, artificial cooling may be necessary. The maximum greenhouse temperature should not exceed 30–35 °C for prolonged periods.

To determine the climate suitability of a greenhouse location, it is necessary to examine the relevant climagraph (Kittas, 1995). A climagraph compares the average monthly air temperatures with the corresponding global irradiance. It is then possible to identify the appropriate period for cultivating various crop

Key questions

Site selection

- What are the characteristics of the right greenhouse location?
- Is it possible to move site and when is this appropriate?
- Which is the most appropriate greenhouse type?
- Is greenhouse heating and/or cooling necessary?

Covering materials

- Is a glass-covered greenhouse the best option or are alternative materials more appropriate, depending on the site?
- Which materials should be used? Does the material depend on the crop?

Climate control

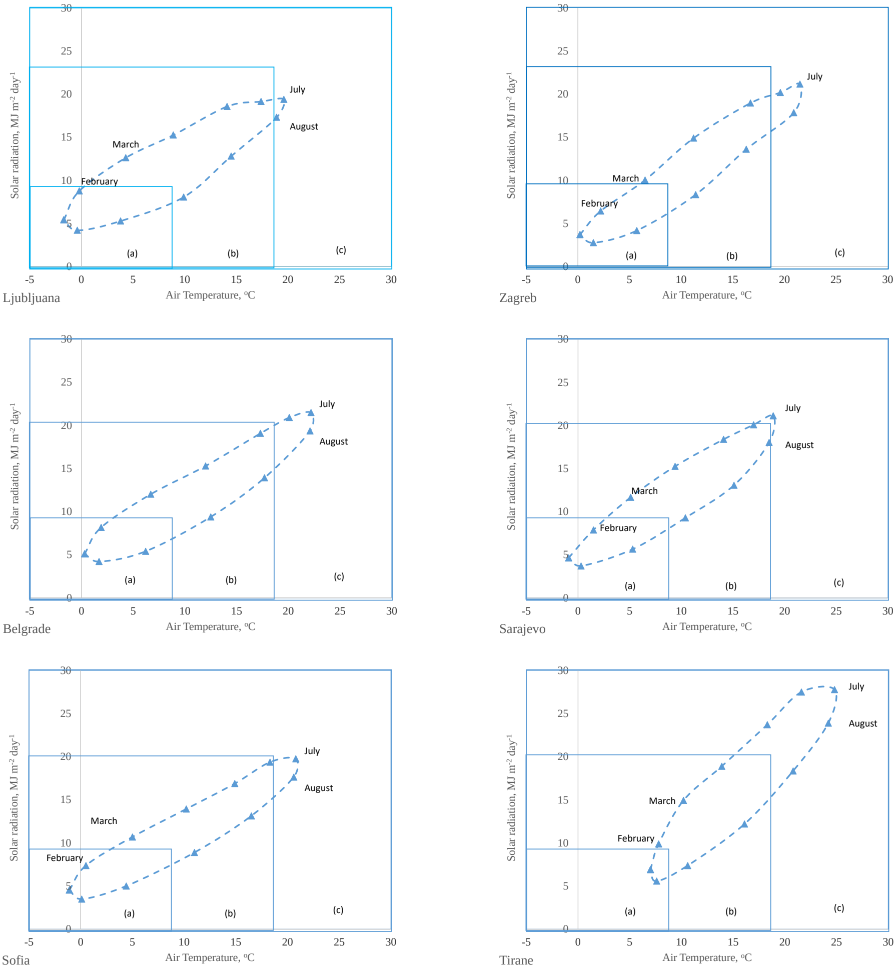
- Can heating and cooling (when possible) improve control of crop productivity?
- What are the benefits of heating and cooling technologies?
- Is heating cost-effective? For which crops?
- What are the appropriate energy sources? How can energy efficiency be improved?
- What are the effects of excessive humidity? How can excessive humidity be reduced?
- What is the effect of high light intensity?
- How can the negative effects of excessive heat in the greenhouse be avoided during the summer months?

species, taking into consideration the heating, ventilation, shading and cooling requirements. A climagraph is, therefore, a potentially useful tool in the primary assessment of suitability for covered crop cultivation in SEE regions. Climatic data (average monthly air temperature and average monthly solar radiation integral) were gathered from Athens, Antalya, Belgrade, Ljubljana, Tirana, Sarajevo, Sofia and Zagreb, and the climagraph for each region is presented in Figure 1. Taking into consideration also the above-mentioned greenhouse climate limits, it is then possible to determine the greenhouse climate control requirements for each location.

Climate control equipment

For year-round cultivation in all the above regions, day- and night-time heating is needed from mid-October to mid-February in Belgrade, Ljubljana, Sarajevo, Sofia and Zagreb, where the average monthly air temperature is < 8 °C in this period. On the other hand, in these locations, there are few cooling or shading requirements in the summer, when the average greenhouse air temperature is < 22 °C. However, in Athens and Antalya, natural ventilation is insufficient between May and

FIGURE 1
Mean daily solar radiation and air temperature during the year for six different locations around SEE



September, and cooling and shading are required in these locations. Finally, winter cultivation in unheated greenhouses is possible only in Athens and Antalya.

Structure design

A single structure (tunnel or single/multispan greenhouse) with vent and shading may be used from spring to autumn in all regions; however, a cooling system is required in Nicosia, Athens and Antalya (and partially in Tirana) during the hot period (June–Aug.). The same structure could be used for winter cultivation in Sarajevo, Zagreb, Belgrade, Sofia and Tirana (for low-temperature-tolerant crops, e.g. leafy vegetables), or in Athens and Antalya (for crops suited to temperatures of > 8 °C).

Covering materials

It is the covering that transforms a greenhouse from a skeleton to an environment compatible with plant cultivation, capable of achieving the desired greenhouse effect. The covering influences the characteristics of the microclimate provided by the greenhouse. There are three main types of greenhouse covering suited to the above SEE regions: glass, polycarbonate sheets and polyethylene film. Each offers advantages, but for economic reasons over 90% of greenhouses worldwide are covered with plastic material.

Polycarbonate is an affordable and energy-efficient alternative to glass, especially when a rigid covering is the preferred solution. Polycarbonate sheets are more durable than polyethylene films, which need changing every 4 years. Furthermore, light transmission is almost as effective as with glass, and when double-walled, the insulation factor is slightly superior to that of a double layer of polyethylene film.

Polyethylene films offer an affordable and efficient solution for greenhouse covering. Thanks to technological breakthroughs in film development in recent years, this type of covering can effectively influence the climate in the greenhouse and create optimal culture conditions. Additives may be included in the resin during the film's manufacturing process, to control the quantity and quality of light entering the greenhouse, as well as prevent common problems such as condensation. Furthermore, when used in a double layer inflated with air, polyethylene films can provide an insulation factor that makes the greenhouse energy-efficient and reduces heating costs, whether year-round or during specific periods.

Various kinds of film are available on the market, including diffusing, thermal, anti-virus, anti-condensation and infrared films. Each has its own characteristics, advantages and specific usefulness. Ultraviolet **(UV)-absorbing** films do not only block insect pests but also reduce the spread of insect-transferred viruses. Furthermore, UV-absorbing films can reduce crop diseases caused by a range of fungi that use UV as an environmental cue for sporulation (Halevy, 1997; Antignus *et al*., 1998; Costa and Robb, 1999; Costa *et al*., 2002; Raviv and Antignus, 2004). It is well documented that UV-absorbing films suppress several foliar diseases (Kittas *et al*., 2006). In a study of the effects of UV-absorbing films on eggplant crop behaviour and production, the absence of UV radiations resulted in increased plant height (21%), larger leaf area (17%) and higher marketable fruit yield. In terms of nutritional quality, it is well established that light affects lycopene content as well as ascorbic acid (Giuntini *et al*., 2005) and other compounds contributing to fruit composition. Some authors report that UV radiation affects plant secondary metabolism by restricting the production of UV-absorbing compounds including flavonoids and other phenolics (Allen *et al*., 1998; Caldwell *et al*., 2003). These compounds significantly affect fruit composition and therefore fruit nutritional quality. Lycopene content and ascorbic acid are crucial quality parameters (Giuntini *et al*., 2005). However, while ascorbic acid is present in all vegetables (Davey *et al*., 2006), lycopene is found only in red tomato and watermelon fruit (Bramley, 2000). Papaioannou *et al*. (2012) tested the effect of UV-absorbing films on tomato yield and quality, and concluded that – in terms of crop yield and quality – use of UV-absorbing greenhouse covering films leads to a reduction in the number of insect-injured fruit and gives a similar or higher marketable yield; on the other hand, fruit quality characteristics (size, shape), nutritional value (ascorbic acid and lycopene) and organoleptic quality (pH, titratable acidity, total soluble solids) are not affected.

Application of **photoselective** covering materials containing near-infrared radiation (NIR) reflecting pigments can improve greenhouse microclimate control during warm periods (Hemming *et al*., 2006a). The special pigments help reduce the incoming solar heat load without affecting photosynthetically active radiation (PAR). An ideal photoselective covering material for cooling purposes would reflect NIR incidence on the greenhouse cover, with a corresponding reduction in solar radiation heat load of almost 50%. Simulation studies revealed that under average summer conditions in the Netherlands, an NIR-reflecting greenhouse cover could reduce the mean temperature of the greenhouse air by 1 °C. On the other hand, greater differences occurred at the highest temperature of the greenhouse air when solar radiation levels were at a maximum (Hemming *et al*., 2006a).

Finally, diffuse light can penetrate deeper than direct light into a plant canopy and can increase photosynthesis. A crop benefits from even light distribution at the various levels of the crop, and this can be achieved by adopting modern covering materials containing pigments, macro- or microstructures able to transform all incoming direct light into diffuse light. The most efficient materials make the light diffuse with no significant reduction in light transmission. However, in several cases, an increase in diffuse light decreases total light transmission (Hemming and Reinders, 2007). Diffuse light penetrates deeper into a plant canopy than does direct light. Hemming *et al*. (2006b, 2008) demonstrated production increases of 8–10% for greenhouse cucumber by applying diffusing materials, indicating the advantages of diffusing natural light in greenhouses. In southern regions, summer crops are often shaded using lime, as high (sun) light intensity combined with high crop temperatures and vapour pressure deficit (VPD) can also negatively affect photosynthesis.

VENTILATION AND COOLING

Greenhouses (both plastic- and glass-covered) act as a solar collector, and on sunny days they trap solar radiation and cause the inside temperature to rise (the "greenhouse effect"). If this heat is not removed from the greenhouse it can result in undesirable conditions for plant growth and development. The inside air temperature can be reduced by:

- reducing incoming solar radiation (shading);
- removing extra heat through air exchange (ventilation); and/or
- increasing the fraction of energy partitioned into latent heat (evaporative cooling).

Shading

A range of techniques are available for shading: paints, external shade cloths, coloured nets, partially reflective shade screens, water film over the roof and liquid foams between the greenhouse walls. Each offers advantages and disadvantages. Shading tends to be the least favoured solution for cooling greenhouses, because it may affect productivity (reducing solar radiation which may result in decreased plant photosynthesis). However, shading – by reducing greenhouse air and crop temperature – may also help to increase photosynthesis (photosynthesis minus photorespiration) and reduce mitochondrial respiration, thus increasing carbon gains and the potential commercial yield. In addition, shading may sometimes contribute to improved product quality and it significantly increases the fraction of diffuse irradiance, which is known to enhance the radiation-use efficiency.

Roof whitening is widely adopted during the summer in the Mediterranean Basin. Whitening is low cost and does not impact ventilation, unlike internal shading nets which reduce the effectiveness of roof ventilation. On the other hand, the major disadvantage of whitening is its lack of flexibility: the position and degree of whitening applied cannot be adjusted in line with natural changes in solar radiation intensity during the cropping period. Moreover, while it is easy to apply additional whitening, it is difficult to remove the material at the end of the

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Plate 1

Shading by whitening of the greenhouse cover

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Plate 2

External shading net above the cover

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Plate 3

Internal shading thermal screen

warm season, when natural solar radiation intensity decreases and shading may restrict crop light perception to critical levels.

Mobile shading can improve the greenhouse climate, especially during the hottest part of the day. It reduces canopy transpiration and water uptake, and significantly increases water-use efficiency. Flexible and efficient, shading screens have become increasingly common in the last 15 years (Cohen *et al*., 2005; Castellano *et al*., 2008). Mobile shading reduces the energy load inside the greenhouse, especially in climates characterized by high evaporative demand and limited water resources (Lorenzo *et al*., 2006).

The optical properties of the screens (fabric type and shade factor) and the nature of the whitening applied (product type and concentration) modify the diffuse-to-direct radiation ratio and cooling performance, while reducing air and crop temperature. There are consequent effects on the radiation absorbed by the crop, stomatal conductance, and net assimilation of CO_2, and hence on crop growth and productivity.

Ventilation

A proper ventilation system is critical for achieving an optimal growing environment during the summer period of the year. Ventilation is the simplest greenhouse climate control system; it is essential for air temperature and humidity management. It is based on the difference in pressure between the greenhouse and the outside environment; this difference is a result of the outside wind and the temperature gradient between the outside and the inside air.

Natural ventilation

Natural or passive ventilation uses very little external energy. Natural ventilation can be achieved through side vents, roof vents or a combination of side and roof vents (usually in multispan greenhouses). The external cool air enters the greenhouse through the lower side openings while the hot internal air exits through the roof openings due to the density difference between air masses of different temperature and resulting in the lowering of temperature in the greenhouse.

In order to prevent insect intrusion and decrease insecticide use, it is comon practice to position insect screens in the ventilation openings. While the fine mesh screens reduce insect migration and subsequent crop damage, they also reduce the ventilation rate, causing higher temperatures and levels of humidity as well as an increase in the thermal gradients within the greenhouse (Katsoulas *et al*., 2006).

GAP recommendations – Natural ventilation

- Adopt a total ventilator area equivalent to 15–30% of the floor area (> 30% produces a negligible effect on the temperature difference).
- Position roof ventilators in consideration of the following:
    - Optimum ventilation rate per unit ventilator area is achieved by positioning flap ventilators (creating an angle with the greenhouse structure as they open) facing the wind (100%), followed by flap ventilators facing away from the wind (67%).
    - Lowest rates of roof ventilation are obtained with rolling ventilators open vertically to greenhouse structure (28%).

- Apply a shading factor of 20–40% to maintain the greenhouse air temperature at a level close to the summer outside air temperature.
- Increase the ventilation opening area by about 50% when using insect-proof screens.

Mechanical ventilation

Since natural ventilation is highly dependent on outside environmental conditions, its efficiency is limited in areas (or in periods) with low or zero wind speeds. Furthermore, while efficiency increases in relation to the height of the greenhouse, this also entails additional costs. Therefore, mechanical ventilation represents an alternative means for alleviating excess heat load. Forced ventilation is based on the creation of an airflow through the greenhouse. Fans suck air out on one side, while openings on the other side let air in. Forced ventilation using electric fans is the most effective way to ventilate a greenhouse, but it is not energy-efficient: ventilation of a greenhouse located in the Mediterranean consumes an estimated 100 000 kWh per greenhouse ha.


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Plate 4

Mechanical ventilation view of fan ventilators used to extract the internal greenhouse air: external (left) and internal (right)

GAP recommendations – Mechanical ventilation

- Develop ventilation fan capacity of about 30 Pa static pressure (3 mm on a water gauge).
- Locate fans on the leeside or the lee end of the greenhouse.
- Establish a distance between two fans not in excess of 8–10 m.
- Leave an inlet opening on the opposite side of the fan of at least 1.25 times the fan area.
- Regulate the velocity of the incoming air so that it is not too high in the plant area – air speed should not exceed 0.5 m s^{-1}.
- Establish automatic closing of the air inlet and outlet openings when fans are not in operation.

Kittas *et al.* (2001) studied the influence of greenhouse ventilation (natural or forced) on the energy partitioning of a well-watered rose canopy over several days in warm Mediterranean conditions (eastern Greece in the summer period). It was found that, when not limited by too low external wind speed, natural ventilation may be more appropriate than forced ventilation, as it creates a more humid and cooler environment (albeit less homogeneous) around the canopy.

Evaporative cooling

Neither shading nor ventilation (natural or mechanical) can lower greenhouse air temperature to levels below the outside air temperature. If a lower temperature is required, an evaporative cooling system should be adopted. Evaporative cooling systems are based on the conversion of sensible heat into latent heat by means of evaporation of water supplied directly into the greenhouse atmosphere (mist/fog system or sprinklers) or through evaporative pads (wet pads).

Fog system

Water is sprayed as small droplets (in the fog range, i.e. 2–60–µm in diameter) with high pressure into the air above the plants in order to increase the water surface in contact with the air. Free-fall velocity of these droplets is slow and the airstreams inside the greenhouse easily carry the drops. This can result in high efficiency of water evaporation while keeping the foliage dry. Fogging also creates high relative humidity, resulting in cooling inside the greenhouse.

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Plate 5
Evaporative cooling by means of a fog system

GAP recommendations – Fog system

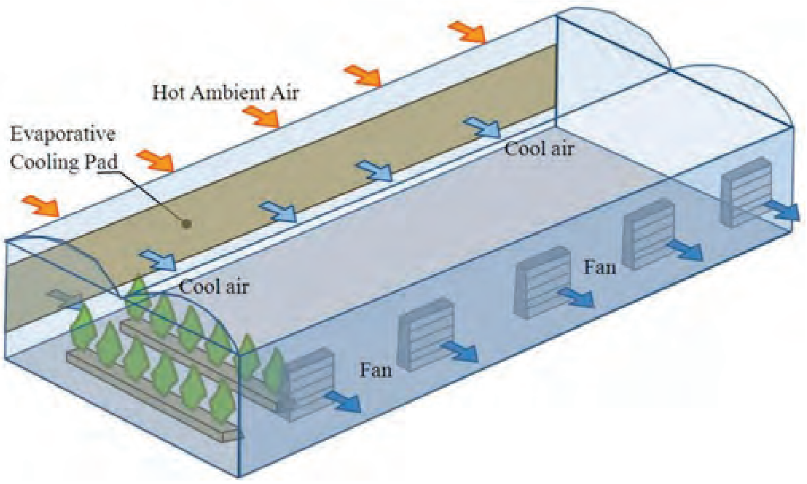
- Note that high pressure (40 bars) systems are more effective than low pressure (5 bars) systems.
- Locate the nozzles of the fog system as high as possible inside the greenhouse to allow water evaporation before the droplets reach the crop or the ground.
- Maintain a vent opening of 20% of the maximum aperture throughout operation of the fog system.
- Bear in mind that while investment costs are around €6.5 m^{-2}, running costs are not considered significant.
- Use high-quality water or demineralization facilities with high pressure mist systems.

Fan-and-pad cooling

The fan-and-pad cooling system is most commonly used in horticulture in warm climates. Air from outside is blown through pads covering as large a surface as possible. The pads are kept permanently wet by sprinkling. The water from the pads evaporates and cools the air. For this reason, the outside air humidity must be low (Figure 2).

FIGURE 2

Greenhouse fan-and-pad evaporative cooling



Franco *et al.*, 2014.

GAP recommendations – Fan-and-pad cooling

- Regulate the cooling efficiency to provide inside air humidity of about 85% at the outlet.
- Pay attention to the characteristics of the pad material:
    - large surface area for evaporation;
    - good wetting properties;
    - high efficiency in increasing the air relative humidity;
    - source of little pressure loss;
    - durability.

- Establish a pad area of about 1 m^2 per 20–30 m^2 greenhouse area. The pad area depends on the airflow rate necessary for the cooling system and the permissible surface velocity over the pad. Average face velocities are 0.75–1.5 m s^{-1}.
- Consider that a basic airflow rate of 120–150 m^3 per m^2 greenhouse area per hour will permit satisfactory operation of an evaporative cooling system.

The water flow rate, water distribution system, pump capacity, recirculation rate and output rate of the fan-and-pad cooling system must all be carefully calculated and designed to ensure that the pad is sufficiently wet and to avoid deposition of material in it. It is essential to observe the manufacturers' guidelines for pad selection and installation. The system consumes an estimated 8–12 kWh m^{-2} per year to operate the fans and the water circulation pumps.

HEATING

Greenhouses provide a controlled environment for plant production with direct sunlight that increases inside air temperature. However, to ensure year-round production of acceptable quality, heating systems must be adopted. Optimum air temperature is essential – not only for high-quality production, but also for disease control and plant survival.

The problem of low temperatures during the winter period is easily overcome by supplying heat to the greenhouse during the critical periods. The problem is not technical (it is easy to heat an enclosed space). On the other hand, given the relatively high capital and running costs, there is an economic problem. The use of conventional or alternative heating systems is not, therefore, widespread in SEE countries. The economic benefits of greenhouse heating in SEE countries is not immediately apparent, given the competition from countries with milder climates (e.g. Mediterranean countries).

Heating needs

Several formulae are available for calculating greenhouse heating needs (Hg) (W). The simplest is proposed by ASAE (2000):[1]

$$Hg = U\ A\ (T_i - T_o)\ (1)$$

where,

U = total heat loss coefficient ($W\ m^{-2}\ K^{-1}$) (see Table 1)
A = greenhouse cover surface area (m^2)
T_i = inside air temperature[2] (K)
T_o = outside air temperature[3] (K)

TABLE 1

Total heat loss coefficient at wind speed of m s^{-1}

Covering materials	U value ($W\ m^{-2}\ K^{-1}$)
Single glass	6.0–8.8
Double glass (9 mm air space)	4.2–5.2
Double acrylic (16 mm)	4.2–5.0
Single plastic	6.0–8.0
Double plastic	4.2–6.0
Single glass plus energy screen of:	
- single film (non-woven)	4.1–4.8
- aluminized single film	3.4–3.9

ASAE, 2000.

Note that the estimation of greenhouse heating needs using equation (1) does not take into account heat loss due to infiltration. Heat loss by air infiltration depends on the age, condition and type of greenhouse. Older greenhouses or those in poor condition generally have cracks around the doors or holes in the covering material, through which large amounts of cold air can infiltrate. Greenhouses covered with large sheets of glazing materials, large sheets of fibreglass or a single or double layer of rigid or flexible plastic are less subject to infiltration.

Rational use of heating is vital, as heating can account for ≤ 35% of total production costs. The annual energy use for heating is very high (e.g. 850 MJ m^{-2} for tomato in Mediterranean areas). Depending on the crop, the greenhouse energy efficiency, the fuel used and the efficiency of the heating system, heating costs are usually €3.5–15 m^{-2}.

Heating systems

The heating system must provide heat to the greenhouse at the same rate at which it is lost. Many heating systems present a major drawback – marked gradients of climate distribution in the greenhouse space. Any energy-efficient heating system

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[1] While this equation is simple and widely used, it can lead to an underestimation of heating needs, in particular in locations with strong wind. Moreover, it is important to not underestimate radiative exchanges with the sky canopy; to do so may result in a marked decrease in greenhouse temperatures in conditions of clear sky (a common occurrence when there is a lot of wind).

[2] This is the target temperature.

[3] The average minimum of the year for the region of interest.

that provides **uniform temperature control** without releasing material harmful to the plants is acceptable. Several types of heating systems are available, but the two most common are air heaters and heating pipes. They may also be used in combination.

Air (unit) heaters

In this system, warm air is blown from unit heaters equipped with self-contained fire boxes. They may be floor-mounted or supported, are normally fuelled with natural or fuel oil and use fans for heat distribution. Unit air heaters are popular because they require a relatively moderate capital investment, are easy to install, and can be easily expanded if necessary. Unit air heaters should be spaced and directed so as to blanket the entire greenhouse area with heated air. Heaters are located throughout the greenhouse, with each one heating a floor area of 180–500 m². The main drawback of the system is the heterogeneous distribution of heat. However, this can be overcome by connecting the unit heater with a blower linked to a duct or poly tube positioned under or over the growing benches or over the crop for soil cultivations. In this way heat distribution will be more homogeneous in the area covered by the crop.

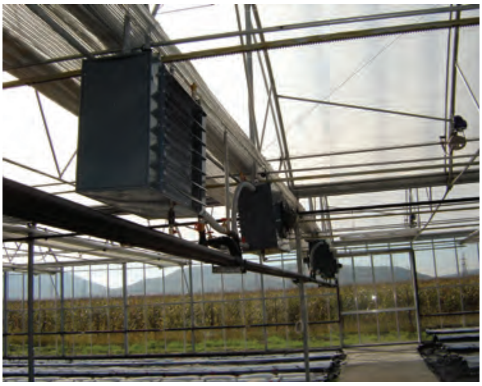
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Plate 6
Unit heaters above the crop


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Plate 7
Poly tubes below the crop

Central pipe heating

Steam or hot water is produced and the heat dissipated throughout the greenhouse by means of a radiating mechanism – a pipe system (steel or plastic) installed around the perimeter, under the benches or overhead. The system comprises a boiler, valves and other controls. In contrast with unit heater systems, some of the heat from central boiler systems is delivered to the root and crown zone of the crop. The warm environment and the low air current developed near the crop surface can lead to improved crop growth and a higher level of disease control.

The correct **positioning of the heating pipes** is essential to prevent excessive heat loss. Overhead placement should generally be avoided, as it leads to considerable heat loss through the roof. However, central pipe systems can also provide supplementary heat to the roof, especially in areas with snow;

Plate 8
Central boiler

Plate 9
Heating pipes

furthermore, overhead heating is sometimes adopted to control botrytis and stimulate growth of apical meristems. The placement of pipes in the walls, on the other hand, results in significant losses through the sides of the greenhouse; this can be partially compensated for by perimeter-wall heating, which contributes to a uniform thermal environment in the greenhouse. The optimal arrangement, when the layout permits, is the in-bed coil (floor heating). Heating pipes positioned near the base of the plants warm the roots and crown of the plants better than the overhead system. Air movement caused by the warmer under-bench pipes reduces the humidity around the plant. Floor heating is more effective than in-bed pipe coil heating. In addition to the advantages of in-bed coils, floor heating can dry the floor quickly – a major advantage when flooded floors are used for irrigation/ fertilization or when plants are grown directly on the soil. In such systems, air movement caused by the warmer floor reduces the humidity around the plant.

Thermostats and controls

Several types of thermostats and environmental controllers are available for commercial greenhouse production. For maximum accuracy and efficiency, follow the guidelines below:

- Place sensing devices at plant level in the greenhouse (thermostats hung at eye level are easy to read but do not provide the input required for optimum environmental control).
- Install an appropriate number of sensors throughout the production area (≥ 2 per compartment), as climate parameters (air temperature, air humidity) can vary significantly within a small space due to climate heterogeneity.
- Do not place thermostats under direct solar radiation, as this will obviously result in poor readings.
- Mount thermostats so that they face north or in a protected location.
- Ventilate and insulate temperature sensors to avoid absorption of radiative energy and guarantee accurate measurement of air temperature and humidity.

Energy heaters and generators

Heaters and boilers depend on electricity. If a power failure occurs during a cold period, such as a heavy snowfall or ice storm, crop loss due to freezing is likely. A backup electrical generator is, therefore, essential for any greenhouse operation. Even if it is only used on one critical cold night, it is a highly profitable investment. The minimum generator capacity required is 1 kW per 200 m^2 of greenhouse floor area.

Heating for frost protection

In regions susceptible to frost, greenhouse heating is used both to protect crops from freezing and to keep the air temperature inside the greenhouse at levels above the critical thresholds for condensation control. Heating systems do not need to be heavy and complicated; a unit heater is usually enough. In addition to installation of a heating system, other useful steps can be taken to avoid freezing of fruits:

- Place the north wall adjacent to an existing external structure (e.g. a house or building) for extra wind protection and insulation.
- Use water to store heat (simple passive solar heating system). Barrels or tubes filled with water and placed inside the greenhouse capture solar energy during the day and release the heat at night when temperatures drop.
- Insulate the greenhouse. For plastic greenhouse constructions, place foam sheets over the structure at night and remove them during the day; add a layer of plastic to the interior of the greenhouse for extra insulation.

Geothermal energy for greenhouse heating

Heating may account for up to 40% of greenhouse operating costs, depending on the climate. Since the greenhouse energy requirements can be met with low-level heat sources of between 45 and 85 °C, greenhouses are especially well suited for geothermal resources.

For the past 25 years, greenhouse heating has been the most common application of geothermal energy in agriculture. In many European countries, geothermal heat is used to produce vegetables, fruits and flowers on a commercial scale all year round. Indeed, greenhouses account for a large share of agriculture's total consumption of low-enthalpy energy. The use of geothermal energy to heat greenhouses has several benefits (Popovski and Vasilevska, 2003):

- Reduced cost compared with other available energy sources.
- Relatively simple installation and maintenance.
- Proximity of low-enthalpy geothermal reservoirs to greenhouse areas.
- Improved efficiency by making use of locally available energy sources.

Greenhouses are the single largest global agricultural productive use of geothermal energy today. High-value fruits and vegetables, as well as nurseries, are well suited for greenhouse production. Geothermal-powered greenhouses provide significant local benefits and economic development. An average greenhouse can save over three-quarters of its operational fuel costs by using geothermal heating. In warmer regions, greenhouse heating is often done primarily for humidity control since decreased humidity also decreases incidence of crop fungus.

Geothermal energy represents enormous potential to further expand the horticulture industry. The vigorous development of direct-use geothermal resources could make an important contribution to making SEE countries major exporters of vegetables.

GAP recommendations – Heating

- Keep a backup heating device in case the heater fails.
- Use simple passive solar systems to reduce energy needs and protect the crop from extreme conditions.
- Do not seal the greenhouse too much in winter, because low ventilation causes humidity and the CO_2 concentration of the air drops below the compensation point in over-insulated greenhouses.
- Establish a weather station that serves as a greenhouse internal temperature monitor.
- Place the plants on shelves in the greenhouse.
- Buy and use a thermostat to maintain the constant minimum temperature inside the greenhouse.
- Install an alarm system for fire, smoke and CO buildup.
- Use greenhouse fans to circulate the heat from the greenhouse ceiling to the floor.

Heating checklist – Structure

- Covering
  - Replace damaged or excessively darkened panels
  - Repair or seal cracks or holes
  - Remove unnecessary shading compound to allow light penetration
- Vent system
  - Repair or adjust vents to reduce cracks at mating surfaces
- Thermal blankets
  - Operate through a complete cycle
  - Check that all seals close properly
  - Repair all holes and tears

Heating checklist (cont'd) – Heating system

- Unit heater (forced air)
  - Check and clean burner nozzles
  - Ensure that adequate outside air is available to burners
  - Check flues for proper size and obstructions
  - Check fuel lines for leaks
  - Check heat exchangers for cracks and carbon and dirt buildup
- Boilers (steam or hot water)
  - Check and ensure that safety or relief valves are operative and not leaking
  - Clean tubes – both fireside and waterside
  - Clean blower fan blades
  - Maintain accurate water treatment records
  - Check boiler operating pressure and adjust to proper pressure
  - Insulate hot water heater or boiler
  - Make sure wiring is in good condition
  - Make sure good quality water is available for the system
- Steam or hot water delivery and return system
  - Fix pipe leaks
  - Be sure that there is enough pipe to transfer the available heat to maintain desired greenhouse temperatures
  - Clean heating pipes as needed, clean both inside and out, and clean heating fins
  - Adjust valve seats and replace if needed
  - Check for the proper layout of piping for maximum efficiency
- Control
  - Ensure that heating and cooling cycles or stages do not overlap
  - Check for accuracy of thermostats with a thermometer
  - Calibrate, adjust or replace thermostats
  - Make sure that thermostats are located near to or at plant level and not exposed to nearby heat sources
- Stand-by generator
  - Clean and check battery
  - Drain and refill generator fuel tanks
  - Check fuel tank and lines for leaks
  - Start and run weekly

Bucklin *et al.*, 2009.

Practical recommendations for energy saving

The grower can reduce the greenhouse energy requirement by making strategic choices in relation to construction, covering and environmental equipment (e.g. heating system, ventilation, cooling, screens). For any decision regarding equipment, it is essential to consider the return on investments, and each specific situation is different. However, some general recommendations can be made with regard to energy consumption.

- Carry out regular maintenance of the greenhouse hardware (doors, cover, sidewalls, foundation, ventilators, pad/fan, screen material etc.).
- Keep doors closed, seal air leakages, replace broken cover material and ripped screens.
- Select greenhouse cover materials with low transmission to the infrared region.
- Use (mobile) thermal screens for areas with low average or night temperatures.

HUMIDITY MANAGEMENT

Humidity is potentially the most difficult environmental factor to control in greenhouses. Maintaining set points and correcting humidity (excess or deficit) can be a challenge for even the most sophisticated monitoring and control equipment. Problems with humidity management in greenhouses are usually associated with high humidity levels occurring mainly during the cold period of the year and resulting in condensation on greenhouse or plant surfaces. Condensation occurs when warm, moist air in a greenhouse comes into contact with a cold surface (e.g. glass, fibreglass, plastic or structural components). Air coming into contact with the cold surface cools to the temperature of the surface. If the surface temperature is below the dew point temperature of the air, the water vapour in the air will then condensate onto the surface. Heavy condensation forms between sunset and several hours after sunrise, with a possible peak just before or at sunrise. During daylight hours, there is sufficient heating in the greenhouse from solar radiation to minimize or prevent condensation, except on very cold, cloudy days. Condensation can lead to significant problems, including germination of fungal pathogen spores (e.g. botrytis and powdery mildew), and at certain times of the year is almost impossible to avoid. However, some growers choose to ventilate and heat the greenhouse at the same time to tackle condensation; while this can be effective, it is not energy-efficient.

Avoiding condensation in the greenhouse

Combined used of heating and ventilation systems

Common practice is to open the ventilation points, allowing the relatively dry outside air to replace the moist greenhouse air. This method does not consume additional energy when excess heat is available in the greenhouse and ventilation is already required to reduce the greenhouse temperature. However, when the ventilation required to lower the temperature is less than the ventilation required to remove moisture from the air, the dehumidification process consumes additional energy. The warm humid greenhouse air is replaced by cold dry outside air, and the temperature inside the greenhouse falls below the desired level. It is then necessary to reheat the greenhouse resulting in higher energy consumption.

Absorption using hygroscopic material

There has been little research on the application of hygroscopic dehumidification in greenhouses, because installation is complex and the use of chemicals should be avoided in greenhouses. During the process, moist greenhouse air comes into contact with the hygroscopic material, the water vapour is absorbed and the latent heat of vaporization is released. The hygroscopic material must be regenerated at a higher temperature level. Up to 90% of the energy supplied to the material for regeneration can be returned to the greenhouse air with a sophisticated system involving several heat exchange processes, including condensation of the vapour produced during the regeneration process.

Anti-drip covering materials

The use of anti-drip covering materials is an alternative technology for greenhouse dehumidification. The anti-drip films contain special additives which eliminate droplets and form instead a continuous thin layer of water running down the roof gables and sidewalls. Condensation on the wall removes water vapour from the air and humidity is reduced.

GAP recommendations – Humidity management

- At dusk: Reduce humidity to 70–80% as night falls, to prevent condensation.
- At dawn: Reduce humidity to prevent condensation, and initiate transpiration as the sun rises.
- Avoid sudden temperature elevation at sunrise by programming a gradual pre-dawn temperature rise and dehumidification period.
- Remove any excess sources of water from your greenhouse.
- Turn on your greenhouse fan to improve the air circulation.
- Open the windows or the door of your greenhouse and allow excess moisture to escape by ventilation.
- Place radiant heat sources (e.g. water barrels or plastic tubes) near the crop to keep plant surfaces slightly warmer than air.
- Use thermal screens at night to prevent radiative heat loss from plant surfaces.

CONCLUSION

For successful greenhouse cultivation in SEE regions, the main considerations are summarized below.

- Consider the most appropriate greenhouse type – tunnels or multispan polyethylene-covered greenhouses are recommended.
- A heating system is necessary – air heaters or a central heating system are the most appropriate.
- A ventilation and cooling system is required.
- Insect screens may be installed in ventilation openings, but their effect on air renewal should be taken into consideration.
- Soilless cultivation is suited to greenhouses and may reduce the need to control irrigation. Giving plants water in a non-limiting way may reduce the need to control temperature and humidity in hot weather conditions.

In conclusion, while the technologies for greenhouse climate control do exist, it is essential that greenhouse microclimate control combine:

- choice of the most appropriate system;
- suitable dimensioning of the cooling system; and
- automation.

Proper climate control results in increased energy efficiency and improved crop performance and represents an important step towards the sustainability of greenhouse horticulture. Nevertheless, further research and continuous education is required.

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2. Soil conservation, soil fertility and plant nutrition management

D. Savvas,[a] G. Ntatsi[a] and P.E. Barouchas[b]

[a] Agricultural University of Athens, Laboratory of Vegetable Production, Athens, Greece
[b] Technological Educational Institute of Western Greece, Department of Agricultural Technology, Laboratory of Soil Science, Patra, Greece

ABSTRACT

Soil fertility depends on various soil characteristics, including texture, porosity and concomitant hydraulic properties, ion exchange capacity, organic matter content, salinity and acidity, and levels of plant available nutrients. Cultivation of plants in greenhouses alters soil properties and may damage fertility, which can only be maintained though conservation. Soil conservation involves a combination of land-use and management strategies aimed not only at the prevention of land degradation but at the preservation and improvement of soil health and quality. The most important conservation interventions are those designed to prevent soil erosion and salinization. A rapid and reliable method for assessing the nutritional status of greenhouse soil is to determine its water extractable nutrient levels. An alternative method is to measure saturation extracts; this gives a more reliable estimation of the soil nutrient status, but the procedure is time-consuming because it is necessary to dry and grind the sample soils. Moreover, balanced fertilization is crucial for the production of uniform, good quality vegetables in greenhouses. In soil-grown crops, the application of liquid fertilization via the irrigation system on the basis of chemical soil analysis can enhance yield and produce quality.

INTRODUCTION

Soil fertility is complex and depends on the physical properties of the soil and on the soil conservation and management practices. Appropriate soil conservation and fertilization practices are essential to maintain soil fertility. Balanced fertilization and maintenance of soil fertility are crucial for the production of uniform, quality vegetables in greenhouses. Imbalanced fertilization with an excessive or inadequate supply of nutrients can cause serious yield losses and quality impairment. Nutritional disorders (deficiencies and toxicities) may arise in soil or soilless media due to poor fertilization practices. In modern greenhouses, the supply of nutrients during the cropping period is combined with irrigation via fertigation.

Key questions

- What are the best practices for "soil conservation" management in greenhouse cultivation?
- How can you maintain and improve soil fertility in greenhouse cultivation?
- How do you assess the soil fertility status?
- How can mineral fertilizers be applied to supply the main nutrients?
- What is the role of organic matter application during soil preparation?
- What is the purpose of a liquid fertigation system?
- How do you observe plant nutrition deficiency symptoms on crops?
- How can you avoid excessive nitrate concentrations in green leafy vegetables such as lettuce?

SOIL CONSERVATION IN GREENHOUSES

The term "soil conservation" refers to a combination of **land-use and management strategies** to prevent soil degradation, man-induced or natural deterioration, depletion of soil nutrients and destruction. The principal soil threats to prevent through soil conservation actions are land degradation processes – such as acidification, salinization (including sodification), erosion, chemical soil contamination and alteration by overuse – in addition to loss of organic matter, reduced biodiversity and nutrient depletion. Frequent use of heavy machinery, improper crop rotation and poor irrigation practices can further accelerate soil degradation. Other factors contributing to land degradation are drought, flooding and severe waterlogging or unsuitable soil thermal regimes. Practices aimed at combating land degradation include soil conservation practices and farming techniques, such as crop rotation, no- or minimum-tillage farming, contour farming, sediment control, organic farming and terracing (Table 1).

TABLE 1
Soil conservation practices and farming techniques in greenhouse and open-field crops

Soil conservation practice	Open-field	Greenhouse
Use of good-quality water	yes	yes
Balanced fertilization	yes	yes
Crop rotation	yes	no
Incorporation of crop residues in the soil	yes	yes / no
Minimized input of chemicals for crop protection	yes	yes
No-tillage farming	yes	yes / no
Contour farming	yes	no
Fallow	yes	no
Organic farming	yes	yes
Terracing	yes	no

Savvas *et al*., 2009.

Plate 1
Use of machinery in greenhouse crops has to be carefully applied to avoid soil compaction

Soil conservation involves treating the soil as a **living ecosystem**. An important farming practice is, therefore, to return organic matter to the soil on a continual basis, while considering the potential disadvantages of nutrient eutrophication and greenhouse gas (GHG) emissions. Organic matter improves soil structure and water availability by increasing water-holding capacity, promotes soil infiltration rates, and protects the soil from compaction and erosion.

Land degradation in its various forms is a fundamental problem. Soil conservation is a combination of land-use and management strategies aimed not only at the prevention of land degradation but also at the preservation and improvement of soil health and quality. The implementation of soil conservation measures combating land degradation is essential in SEE regions, which are characterized by broad biodiversity and soil resources of high environmental value. The intensification of production in some SEE regions and the concurrent abandonment in others represent a major threat to the soil. Soil conservation and other measures aimed at combating land degradation due to erosion and salinization have to be deployed to maintain soil fertility.

Soil conservation practices are not widely adopted by farmers in most SEE countries, despite extensive technological options for improved soil management. Furthermore, the prevention of soil degradation is limited by scarcity of data. In 2006, the European Commission (EC) adopted the Soil Thematic Strategy (EC, COM, 2006) to protect soils across the European Union (EU) from key threats, including soil erosion and salinization. The European Commission Directorate-General for the Environment and the European Environment Agency (EEA) have identified soil organic matter conservation and mitigation of soil loss by erosion as priorities for the collection of policy-relevant soil data on a European scale.

Soil erosion in protected crops occurs when farmers fail to prevent the removal of soil by natural and physical forces. Inappropriate farming practices include techniques such as deep soil tillage and cultivation up and down the slopes (as opposed to following contour lines), in addition to a lack of crop rotation and cover crops. In agriculture, soil erosion refers to the removal of a field’s topsoil – whether by the natural forces of water and wind or as a result of farming activities such as tillage. Topsoil is the most fertile soil layer, rich in organic matter and mineral micronutrients and, therefore, it deserves special attention from growers.

Soil salinization is a major problem in southern European countries and global warming is expected to increase the threat of secondary salinization. Salinization is the result of the accumulation of salts and other substances from irrigation water and fertilizers. Accumulated salts include sodium, potassium, magnesium and calcium, chloride, sulphate, carbonate and bicarbonate. High levels of dissolved salts will eventually make soils unsuitable for plant growth. The salinization process refers to a buildup of salts in the soil and affects approximately 7% of the global land area and 3.8 million ha in Europe. It induces water stress and can reach toxic levels for plants. The main cause of salinization is the inappropriate management of irrigated agricultural land. In extreme cases, damage from salinization is so great that it is technically unfeasible or uneconomic to reverse the process. In some cases of vegetable crop production, especially in greenhouses, land is abandoned because it is too salty to farm profitably.

Salinization is a potential problem particularly in poorly drained soils when the groundwater level is no deeper than 3 m and in soils of greenhouses located near the sea: saline water rises to the surface in a capillary movement and then evaporates through the soil surface. Soil salinization in protected cultivations is mostly fuelled by low quality irrigation water, over-irrigation and poor drainage. The most effective measures to combat soil salinity involve leaching out the excess salts through improved drainage and/or use of better irrigation water quality. In most cases, salt leaching from salt-degraded soils can take years; furthermore unless long-term amelioration and sustainable land management practices are implemented, the original conditions may return.

SOIL FERTILITY

The soil has a major impact on the success of a crop, since – with the exception of soilless cultivations – soil is the medium that stores and provides water and nutrients to the plants. The soil's nutritional status at a given time is a function of its content of readily available nutrients and loosely bound nutrients that can easily become accessible to the plants. The term "readily available" refers to nutrients dissolved in the soil water (soluble nutrients). The uptake of soluble nutrients reduces their concentration in the space surrounding the roots. Therefore, a sufficient supply of inorganic nutrients to plants presupposes first, that new quantities of nutrients will continually reach the root area and second, that new roots will develop to exploit new soil zones. The maximum distance from which root hair can take up nutrients depends mainly on the concentration of the nutrient in the soil


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Plate 2
A greenhouse tomato crop grown in a fertile soil

and the factors affecting this. Water soluble nutrients move towards the root through: 1) mass flow of water; and 2) diffusion.

Ions adsorbed by colloidal electrical charges can be exchanged with those freely moving in the soil solution. The ability of the soils to adsorb cations is quantitatively expressed as "cation exchange capacity" (CEC). The type of exchange (i.e. what is adsorbed and what is released) depends on the changes in concentration of the ions in the soil solution caused by the activity of roots and water movement, as well as by pH alterations. Soil's ability to store nutrients and release them in controlled amounts is due to the CEC. Likewise, the CEC protects nutrients from leaching (caused by rain) and plants from toxicities and saline stress phenomena (which would otherwise occur if all the ions were simultaneously dissolved in the soil water).

Soil fertility

A fertile soil is characterized by:

- sufficient concentrations of plant available nutrients;
- high ion exchange capacity;
- suitable pH;
- high potential water content and water accessibility;
- high air capacity; and
- high microbial activity (provided the microbial flora does not include pathogens for the particular crop).

Cation exchange capacity (CEC)

CEC is an indicator of:

- soil fertility;
- nutrient retention capacity; and
- the capacity to protect groundwater from cation contamination.

Soil CEC depends on the type of clay, organic matter and pH. It is expressed as milliequivalents (meq) of adsorbed cations per 100 g of dry soil (meq$^+$/100 g) or, in SI, as centimol (cmol) of adsorbed cations per kg (cmol$^+$/kg).

To estimate plant nutrient availability, determine the CEC by using ammonium acetate and diethylene triamine penta acetic acid (DTPA) solutions to extract plant available macro- and microcations, respectively.

Rating	CEC (meq$^+$/100 g)
Low	< 10
Medium	10–20
High	> 20

TABLE 2

Desired levels of exchangeable cations, plant available P (Olsen) and B (hot water extraction) in greenhouse soils based on experience and standard laboratory practices

Nutrient	Desired range (mg g^{-1} of dried soil)	Nutrient	Desired range (mg g^{-1} of dried soil)
Ca	1 200–5 000	Fe	5–150
Mg	60–350	Mn	2–80
K	120–500	Zn	0.7–2
Na	> 500	Cu	0.5–2
P	10–40	B	0.3–1.5

Savvas *et al*., 2009.

Table 2 gives the target levels of exchangeable cations and other nutrients. Determining exchangeable cations is a laborious and time-consuming process requiring the drying of soil samples. Moreover, the method adopted is suited only to cations; to determine essential nutrients occurring as anions (phosphorus, nitrogen) or uncharged compounds (boron), it is necessary to adopt other procedures (e.g. the Olsen method, which is routinely used to estimate the phosphorus available for plants in Mediterranean soils).

PLANT NUTRITION AND FERTILIZATION OF SOIL-GROWN GREENHOUSE CROPS

Inorganic fertilization

In soil-grown greenhouse crops, part of the nutrients required by the plants are applied as a base dressing, in particular phosphorus, because it has low mobility in the soil. Nitrogen, on the other hand, is highly soluble in water as both nitrate and ammonium salts, and is supplied through the irrigation system after planting. This operation – widely known as fertigation – saves time, labour and resources, and maintains (or even improves) crop yields. The use of suitable dosing pumps or injectors to maintain optimal nutrient concentrations in the irrigation water is a prerequisite for balanced plant nutrition. However, what is “optimal” depends on the particular greenhouse crop, and nutrient concentrations must be adjusted and specialized accordingly.


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Plate 3

Supply of nutrients through the irrigation system using a system of dosing pumps to inject stock solutions to the irrigation pipe

In most SEE countries, many greenhouse growers determine fertilizer application rates by “rule of thumb”, resulting in excess fertilizer application rates. There may be excessive application of one or more nutrients and inadequate supply of others, exacerbating the incidence of single nutrient toxicities or deficiencies, or even resulting in multinutritional disorders. It is important to adopt balanced fertilization schemes based on plant nutrient requirements and soil nutrient reserves, determined by chemical soil analysis. It is then possible to estimate optimum rates for each nutrient by deducting the soil reserves from the total plant requirements. However, it is not simple to apply this theory. Growers are faced with a vast range of methods to estimate the levels of available nutrients in the soil, and the soil analysis data (even the most credible and accurate) then need interpretation and conversion into quantitative recommendations (in the form of target nutrient concentrations, whether in the fertigation solution or in the fertilizer formula to be applied).

Impact of plant nutrition on quality of greenhouse vegetables

The impact of the various **macronutrients** may be summarized as follows:

- **Potassium (K).** An adequate supply of potassium enhances the sugar content and titratable acidity of vegetable fruits (Savvas *et al*., 2009), considerably improving fruit flavour. Low levels of K in soilless cultivated tomato plants are associated with ripening disorders, while adequate K improves fruit colour and restricts the incidence of yellow shoulder and other fruit colour disorders.
- **Nitrogen (N).** An increased nitrogen supply to tomato above a standard threshold level may reduce fruit quality by decreasing the sugar content.
- **Phosphorus (P).** It appears that variations in the phosphorus supply to soil-grown tomato crops do not significantly influence the total soluble solids, pH or acidity of tomato juice, or the fruit colour characteristics.
- **Calcium (Ca).** Calcium plays a key role in the quality of tomato, pepper and eggplant fruits, mainly because of its impact on the physiological disorders, blossom-end rot (BER) and internal fruit rot (Adams, 2002). Furthermore, an enhanced supply of calcium may reduce the incidence of shoulder check crack, which leads to a deterioration in fruit quality.
- **Magnesium (Mg).** Magnesium does not directly affect vegetable fruit quality. However, under conditions of severe Mg deficiency, the size and overall appearance of the fruit may be reduced. On the other hand, an Mg supply above the standard recommended levels may considerably increase the incidence of BER in tomato crops (Savvas *et al*., 2008).

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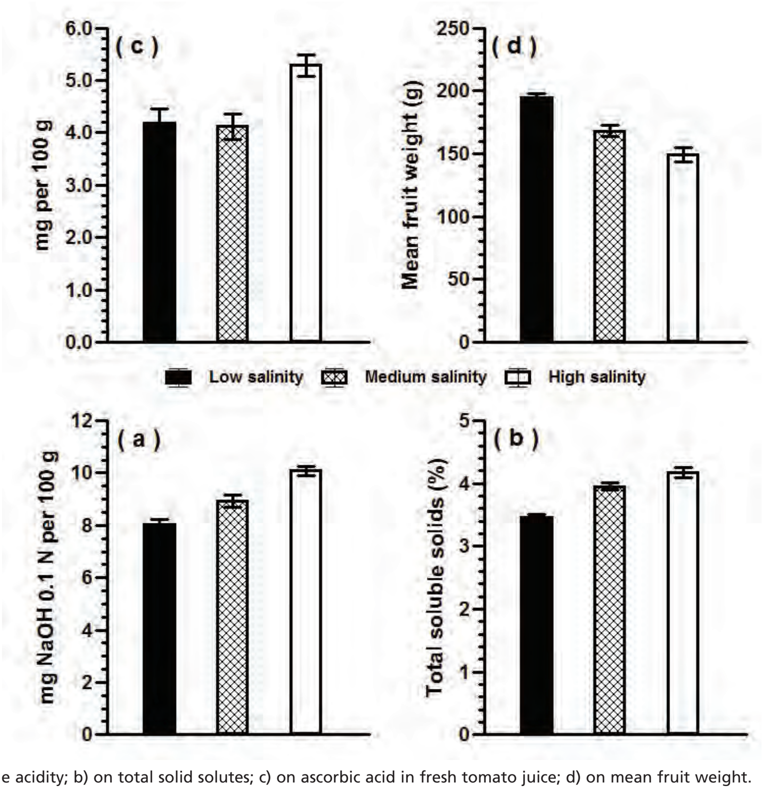
Plate 4
BER symptoms in tomato fruit caused by excessive Ca concentration in the roots of tomato plants

Micronutrients may impair the quality of fruit vegetables, but only when the plants exhibit severe deficiency symptoms as a result of an overall imbalance of plant metabolism. The trace element that has the greatest effect on fruit quality is boron (B): an inadequate supply of B to tomato increases the incidence of shoulder check crack, and incidence of this disorder can be markedly reduced by spraying the foliage of tomato with B.

The total salt concentration in the root zone also affects fruit quality. In general, a moderate increase of salinity in the root environment improves the quality of vegetable fruits, but it depends on the crop. More specifically:

- **Tomato.** Overall, moderate salinity levels enhance the total soluble solids, fruit acidity, dry matter content, fruit firmness, ascorbic acid, total carotenoid and lycopene concentrations, as well as various other specific quality attributes. Figure 1 indicates the impact of salinity on the levels of titratable acidity, total solid solutes and ascorbic acid in tomato fruit juice.

FIGURE 1
Impact of NaCl salinity



a) On titratable acidity; b) on total solid solutes; c) on ascorbic acid in fresh tomato juice; d) on mean fruit weight.
Low, medium and high salinity levels correspond to 2.5, 5.0 and 7.5 dS m^{-1}, induced by including 0.3, 21.5 and 43 mM of NaCl in a standard nutrient solution for tomato, respectively.

Savvas *et al.*, 2009.

- **Pepper, melon, cucumber and other vegetable fruits.** A controlled increase in salinity improves the flavour and some additional quality characteristics.
- **Root and leafy vegetables.** High salinity may have an indirect effect on quality, due to its impact on the incidence of physiological disorders, such as tip burn in lettuce.

PHYSIOLOGICAL DISORDERS

Errors in fertilization may cause **physiological disorders**, resulting in non-marketable produce. A typical physiological disorder related to plant nutrition is blossom-end rot (BER) affecting Solanaceae crops (tomato, pepper and eggplant). Blossom-end rot usually begins as a small water-soaked area at the blossom end of the fruit and develops into a dry rot. This disorder is due to a localized shortage of **calcium (Ca)** in the distal part of the fruit, resulting in tissue disorganization due to the impairment of plasma membranes and/or cell walls. In most cases, environmental conditions (e.g. low relative humidity in the air, high air temperature and solar radiation intensity) and fertilization and irrigation management may restrict the translocation of Ca to the affected part of the fruit. In most cases, the fruit Ca level correlates poorly with the appearance of BER, presumably because the damage in fruit cells due to Ca shortage occurs during a period of rapid cell elongation, while the visible symptoms appear later (once the Ca supply has recovered). BER generally appears during the hot season (early spring to summer) and is rare in the cold season (early autumn to winter).

The occurrence of colour spots or flecks in tomato and pepper fruit is also related to plant nutrition, as is blotchy ripening (BR) in tomato fruit. While most of the surface of tomato fruit turns red at ripening, some patches remain strikingly green, grey or yellow. When grey patches are prevalent, the disorder is known as “grey wall”. The tomato plant is more susceptible to BR at relatively low nutrient levels in the root zone; indeed, an increase in nitrogen fertilization has been reported to reduce the incidence of internal BR. Yellow shoulder disorder (YSD) is a ripening disorder of tomato characterized by discoloration of the proximal-end tissues of the fruit, which remain yellow or green, while the rest of the fruit surface turns red. There is evidence that YSD is influenced by the potassium, nitrogen and phosporus supply.

Fruit cracking is a nutrition-related physiological disorder found in tomato and pepper fruit. It occurs when the internal fruit expands more rapidly than the epidermis, which then splits. Factors contributing to the reinforcement of the cell walls and membranes may reduce the incidence of fruit cracking. Calcium is one such factor and the adequate transport of calcium to the tomato fruit reduces both the number of cracked fruits and the severity of cracking.

Base-dressing fertilizers for soil cultivation

The nutrients provided to the soil through base-dressing are:

- **Phosphorus (P)** (corresponding to the full needs of a crop – due to low mobility)
- **Nitrogen (N)** (only a fraction of the total needs – through irrigation after planting)
- **Potassium (K)** (only a fraction of the total needs)

In addition to NPK (see Box), depending on the soil analysis results, the base dressing may also include **magnesium (Mg)** and, in special cases, **calcium (Ca)** or **micronutrients**.

Nitrogen (N) is crucial for the yield and the quality of greenhouse vegetables. Excessive N fertilization may result in delayed maturity and the formation of disease-sensitive plant tissues. High NO_3^- concentrations in edible plant parts constitute a potential threat for human health and, therefore, many countries have set maximum legal limits. However, nitrate does not accumulate in fruit and the nitrate content is, therefore, not a problem for fruit vegetables. Nevertheless, nitrate accumulates in leaves, stems and, to a lesser extent, in hypogeal plant parts. Hence, excessive nitrate concentrations in leafy vegetables cultivated in greenhouses (e.g. lettuce and rocket) can pose a serious health problem for consumers. It is recommended to maintain low nitrate contents in the edible plant parts (leaves, stems etc.) of greenhouse crops grown for consumption. It is, therefore, important to avoid excessive supply of nitrogen fertilizers. Both NH_4^-N and organically bound N contained in urea, manure or other organic fertilizers, are gradually converted into NO_3^- through nitrification in the soil; an excessive supply of NH_4^-N or organic-N fertilizers can also result in excessive NO_3^- accumulation in vegetative edible parts.

An adequate supply of **potassium (K)** is important for high yield and quality in greenhouse tomato crops. Potassium is highly mobile through the phloem; deficiency symptoms therefore appear in older leaves and severe K deficiency causes necrosis of old leaves. However, it is important to avoid excess K, which can increase the incidence of blossom-end rot (BER) and other physiological disorders related to low calcium translocation to the fruit.

An adequate supply of **phosphorus (P)** is crucial for optimal fruit-setting and hence high yield in greenhouse vegetable crops. A high P supply to soil-grown tomato increases both the quantity and the quality of pollen, enhancing fitness through the male function. The uptake of P depends on the temperature of the soil: P uptake falls markedly at soil temperatures of < 14 °C. Consequently, P deficiency – characterized by the development of a purple to violet colour on the undersides of the leaves of tomato plants – may occur in soils with adequate P levels if the soil temperature drops below 14 °C for some time.

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Plate 5
Tomato plants with Fe-deficiency symptoms caused by an excessively high supply of Mn that acts antagonistically to Fe uptake

In well-managed, fertile greenhouse soils with pH levels of 6–7, the Ca, Mg, S and micronutrient requirements of tomato may be covered by the soil reserves. Nevertheless, a complete soil analysis must be carried out at least once a year to check the soil fertility and adjust it on the basis of the analysis results. A low Ca level in the root zone is rarely a limiting factor for the vegetative growth of tomato.

With respect to the **micronutrients**, the crucial factor for an adequate supply of tomato with Fe, Mn, Zn and Cu is the soil pH. In most cases, deficiencies of these nutrients are observed at very high pH levels in the soil; hence, the most appropriate way to cope with this problem in the long term is to properly adjust the soil pH. However, ion antagonism between metallic micronutrients may also result in micronutrient deficiencies. Iron deficiency is associated with a drastic reduction of the leaf chlorophyll content which results in chlorosis symptoms. The application of chelated micronutrients – especially iron chelate – either via irrigation or by foliar spraying, can effectively prevent or even cure micronutrient deficiencies in soils with unfavourable pH levels.

Boron (B) deficiency in greenhouse tomato may occur when the soil B concentration is < 1.5 mg g^{-1} of dried soil. Low B levels in the root zone result in brittle and pale green leaves, abscission of a large proportion of the flowers, lack of firmness in the fruit and a considerable reduction in fruit-set (especially if no other means for pollination, such as vibration, is applied).

Management of salinity in soil- and soilless-grown greenhouse crops

To cope with the presence of salts in the irrigation water used to prepare nutrient solutions, water supply should exceed water consumption, in order to ensure salt leaching out of the root environment through the excess water that runs off. It is important to prevent buildup of high ionic concentrations near the roots resulting from imbalances between the amounts of elements supplied and the amounts taken up by plants. In theory, diffusion can mitigate this phenomenon, but it is too slow. Therefore, convective movements must be favoured – achieved by supplying nutrient solutions in excess. The delivery of nutrient solution in excess of uptake is also needed to counterbalance irrigation shortages in sections of the greenhouse crop; such shortages can arise as a result of emitter and tube variability, or because of pressure loss within irrigation circuits. On the other hand, over-irrigation in substrate-grown crops allowing free drainage of the runoff solution results in wastage of water and fertilizers, as well as pollution of the groundwater with nitrates and phosphates. Therefore, irrigation should be limited to the absolute minimum required by the crop. Typically, leaching fractions of 25–35% are recommended in open soilless cultivation systems. Nevertheless, if the salt concentration in the irrigation water is excessively high, even higher leaching fractions may be inevitable.

If the nutrient supply is balanced, the growth and yield of hydroponically grown plants decrease as salinity increases in the root zone (Sonneveld, 2002). However, the impact of nutrient solution salinity on plant growth in hydroponics also depends on the prevailing climatic conditions. As a rule, the detrimental effects of nutrient solution salinity are more pronounced under high light intensity and/ or low air humidity. On the other hand, excessively high air humidity levels may increase the adverse effects of salinity on plant growth due to the impairment of calcium transport to the growing leaves.

In summary, for salinity control in the root zone, apply the following practices:

- Use high-quality water.
- Use appropriate K : Ca : Mg ratios in the nutrient solution.
- Schedule irrigation on the basis of frequency and target leaching fraction.
- Adjust the target EC in the nutrient solution supplied to the crop by taking the EC and composition of the drainage solution into consideration.

To optimize irrigation scheduling, irrigation frequency should be related to energy input (solar radiation, heating), preferably by employing suitable models. The use of pure irrigation water to wash out salts from substrates is an erroneous practice, resulting in nutrient imbalances in the root zone – unless rainwater is available.

In closed-cycle cultivation systems, the drainage percentage is not restricted by environmental concerns and the irrigation frequency may be considerably higher than in open cultivation systems. High irrigation frequency improves crop performance due to the higher availability of nutrients, specifically P and Mn. Furthermore, high irrigation frequency is associated with constantly elevated moisture levels in the root zone of substrate-grown plants (increasing the hydraulic conductivity of the substrate and thus water availability). With regard to salinity, frequent irrigation resulting in high drainage fractions may delay the rate of salt accumulation in closed hydroponic systems, thereby enhancing yield and improving fruit quality, without increasing the discharge of polluting fertigation effluents into the environment.

Long-term recycling of the leachate solution may result in an accumulation of sparingly absorbed ions, such as Na^+ and Cl^-. To ensure an adequate nutrient supply under such conditions, it is essential to monitor salt concentrations in the drainage solution in order to estimate the contribution of the accumulating salts to the total electrical conductivity (EC) of the nutrient solution supplied to the crop. Hence, the EC of the outgoing nutrient solution may be adjusted in real time to a value that ensures a constant nutrient supply to the crop. Currently, reliable tools providing real-time monitoring of specific ion levels in the drainage solution are not available at prices affordable to growers. An alternative is the development of mass-balance models able to simulate salt accumulation in the recycled solution. Such models aimed at a more efficient management of salinity in closed hydroponic systems have been tested for cucumber, bean, pepper and tomato (Savvas *et al*., 2013). These models are another step towards the development of intelligent systems designed for the complete automation of nutrient supply in greenhouse crops grown in closed-cycle cultivation systems.

Organic fertilization

Organic fertilizers are produced from plant or animal residues (e.g. manure), composted by-products from industrial biomass (coconut, sugar beet, cottonseed meal, olive mill pomace etc.), crop residues (leaves, prunings etc.), seaweed, blood and slaughterhouse waste and fish industry residues. The nutrient content is usually lower than in inorganic fertilizers. For example, the N content of animal manure is 0.4–1.3% on a weight basis (Table 3). Table 4 lists commonly used organic fertilizers, indicating their origin and N, P_2O_5 and K_2O content. Nutrient contents may vary considerably for a given organic fertilizer. For example, in raw bone meal, the nitrogen content is 2–6% and the phosphorus content 15–27%.

Organic fertilizers are used both for base-dressing fertilization in soil-grown crops and as amendments in organic substrates. Some organic fertilizers are formulated to correspond to specific nutrient ratios using various sources and they are then sold as organic fertilizer compounds. However, most of the N and part of the P in such fertilizers are bound in organic substances, and (since plants take up nutrients in their inorganic form) the organically bound fraction of the nutrients is not immediately available. This is especially the case with N, which is released gradually during the decomposition of organic matter through microbial activity in the soil.

TABLE 3
Mean composition (% w/w) of animal manure originating from different animal species

Animal species	Dry matter	Organic matter	N	P_2O_5	K_2O	CaO	MgO
Cattle	23	20	0.40	0.16	0.50	0.45	0.10
Sheep	36	32	0.80	0.23	0.67	0.33	0.18
Pig	20	18	0.55	0.76	0.50	0.40	0.20
Chicken	26	17	1.30	1.10	0.60	3.40	–

TABLE 4

Nutrient composition (% w/w)[a] of some standard organic fertilizers originating from waste materials

Fertilizer	Source	N	P_2O_5	K_2O
Alfalfa meal or pellets	Alfalfa	2	1	2.4
Beef vinasse	Residues from sugar beet industry	2	0.6	5.5
Blood meal	Slaughterhose blood	13	1.5	0.6
Bone meak	Slaughterhouse bones	4	20	0
Chicken pellets	Chicken manure	4	3	2.5
Cottonseed meal	Cottonseed after oil extraction	6	0.4	1.5
Cow pellets	Cow manure	2	1.0	2.7
Feather meal	Feathers and claws of chicken	12	0	0.5
Fish emulsion	Fluid remains of fish industry	5	2	2
Fish meal	Heat-dried fish waste	10	6	2
Guano (high N)	Dried bird manure	10	3	1
Guano (high P)	Dried bird manure	3	10	1
Malt pellets	Brewery waste	5	1.4	4.8
Ricinus pellets	Residues from castor oil industry	5	1.5	8

[a] The figures are average values calculated from various literature sources and should be considered only as indicative.

Organic fertilizers are increasingly used in organic agriculture. Organic farming systems rely on ecologically sound practices (e.g. biological pest control, composting, enhancement of soil fertility through biological processes, and crop rotation) and exclude the use of synthetic chemicals in crop production. In organic agriculture, only organic fertilizers are used to supply N to the crop. In organic horticulture, the source material in the fertilizer must originate from organic farming to exclude the presence of pesticide residues. Likewise, there are regulations specifying the origins of raw manure (but not of composted manure).

Since the supplied N is bound in organic substances, the N availability to plants depends on the mineralization rates of the organic matter, and this cannot be predicted under field conditions. Therefore, the timely supply of sufficient plant-available N can be a problem in organic agriculture, resulting in lower yields. The rate of N mineralization differs markedly between organic fertilizers. The mineralization process also depends on temperature, humidity, pH and available NO_3 in the soil.

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Plate 6

Organic tomato crop

From an environmental point of view, organic fertilizers require less fuel to produce (compared with inorganic fertilizers produced using the Haber–Boss process) and there is a concomitant reduction in CO_2 emissions. On the other hand, organic fertilizers used in organic cropping systems are associated with increased rates of organic matter decomposition, which may enhance N_2O and CO_2 emissions compared with conventional cropping systems. Nevertheless, the reduced amount of N supplied to crops in organic agriculture gives a net reduction of N_2O emissions. Furthermore, while the application of manure or other organic materials may result in slightly increased emissions of CH_4, emissions are nevertheless low.

Soil organic matter and soil fertility

The presence of organic matter in the soil is crucial for the:

- improvement of soil structure (it increases the porosity of clay soils and thus their water permeability, and reduces the pore size in sandy soils thereby increasing their water retention capacity);
- release of nutrients for the plants through its gradual decomposition;
- heat absorption, which increases due to the dark colour of humus; and
- biological activity in the soil.

PLANT NUTRITION AND FERTILIZATION IN SOILLESS-GROWN CROPS

Principles

In soilless culture, all essential plant nutrients should be supplied via the nutrient solution, with the exception of carbon, which is taken up from the air as CO_2. In the preparation of nutrient solutions, inorganic fertilizers supply all the essential nutrients, with the exception of iron, which is added in chelated form, to improve its availability for the plants. Nutrient solutions for soilless culture are mostly prepared with highly soluble inorganic salts, but some inorganic acids are also used. Table 5 lists the water-soluble fertilizers commonly used in soilless culture.

In commercial soilless culture, the fertilizers needed to prepare a nutrient solution are first mixed with water to form concentrated stock solutions. These are then mixed with irrigation water to form the nutrient solution.

Composition of nutrient solution

The composition of a nutrient solution for a certain crop depends on the nutritional requirements of the particular plant species. It is important to gather the necessary data from the results of experiments. Further analysis and data are also required during the cropping period in order to monitor and adjust the nutritional status of the root zone. In recent decades, research on soilless culture has focused on the composition of nutrient solutions and the optimization of nutrition in commercial hydroponics. The pioneer work on the composition of nutrient solutions was carried out by American scientists before the Second World War, resulting in the formula of Hoagland and Arnon (1950), still widely used for research purposes

TABLE 5

Nutrient composition (% w/w) of some standard organic fertilizers originating from waste materials

Fertilizer	Chemical formula	Percentage nutrient	Molecular weight (g)	Solubility (kg litre^{-1}, 0 °C)
Ammonium nitrate	NH_4NO_3	N: 35	80.0	1.18
Potassium nitrate	$5[Ca(NO_3)_2.2H_2O]NH_4NO_3$	N: 15.5, Ca: 19	1 080.5	1.02
Calcium nitrate	KNO_3	N: 13, K: 38	101.1	0.13
Magnesium nitrate	$Mg(NO_3)_2.6H_2O$	N: 11, Mg: 9	256.3	2.79[a]
Nitric acid	HNO_3	N: 22	63.0	–
Monoammonium phosphate	$NH_4H_2PO_4$	N: 12, P: 27	115.0	0.23
Monopotassium phosphate	KH_2PO_4	P: 23, K: 28	136.1	1.67
Phosphoric acid	H_3PO_4	P: 32	98.0	–
Potassium sulphate	K_2SO_4	K: 45, S: 18	174.3	0.12
Magnesium sulphate	$MgSO_4.7H_2O$	Mg: 9.7, S: 13	246.3	0.26
Potassium bicarbonate	$KHCO_3$	K: 39	100.1	1.12
Iron chelates	various types	Fe: 6–13	–	–
Manganese sulphate	$MnSO_4.H_2O$	Mn: 32	169.0	1.05
Zinc sulphate	$ZnSO_4.7H_2O$	Zn: 23	287.5	0.62
Copper sulphate	$CuSO_4.5H_2O$	Cu: 25	249.7	0.32
Borax	$Na_2B_4O_7.10H_2O$	B: 11	381.2	0.016
Boric acid	H_3BO_3	B: 17.5	61.8	0.050
Sodium octaborate	$Na_2B_8O_{13}.4H_2O$	B: 20.5	412.4	0.045
Ammonium heptamolybdate	$(NH_4)6Mo_7O_{24}$	Mo: 58	1 163.3	0.43
Sodium molybdate	$Na_2MoO_4.2H_2O$	Mo: 40	241.9	0.56

[a] At 20 °C.

Savvas *et al*., 2013.

today (Table 6). Efforts later focused on adapting this basic formula to the special needs of individual crop species. This work – supported by new developments in analytical techniques and equipment – resulted in the formulation of specific nutrient solutions for each greenhouse crop species.

In commercial practice, it is not easy to implement these nutrient solution formulae, because the **irrigation water** is an additional factor. First, its mineral composition must be considered and in most cases, the irrigation water contains macronutrients (Ca^{2+}, Mg^{2+}, SO_4^{2-}), micronutrients (Mn^{2+}, Zn^{2+}, Cu^{2+}, B and Cl^-) and other non-nutrient ions (HCO_3^-, Na^+) at appreciably high concentrations. When the concentration of a nutrient element in the irrigation water represents a non-negligible fraction of the target concentration in the nutrient solution, the grower has to deduct the amount that is already available in the irrigation water from the total required amount in the nutrient solution. Second, the concentration of bicarbonate (HCO_3^-) is very important, given that it determines the amount of acid required for pH adjustment. Third, the concentration of Na^+ determines the ultimate electrical conductivity (EC) of the nutrient solution supplied to the crop.

TABLE 6

Composition of standard nutrient solutions as proposed by Hoagland and Arnon (1950) for universal use and Sonneveld and Straver (1994) for commercial cultivation of cucumber and tomato in rockwool

Macronutrient	mmol litre^{-1}			Micronutrient	µmol litre^{-1}		
	Hoagland & Arnon	Sonneveld & Straver (Cucumber)	Sonneveld & Straver (Tomato)		Hoagland & Arnon	Sonneveld & Straver (Cucumber)	Sonneveld & Straver (Tomato)
NO_3^-	14.0	16.00	17.00	Fe	25.00	15.00	10.00
$H_2PO_4^-$	1.0	1.25	1.50	Mn	9.10	10.00	10.00
SO_4^{2-}	2.0	1.375	2.50	Zn	0.75	5.00	4.00
K^+	6.0	8.00	8.00	Cu	0.30	0.75	0.75
NH_4^+	1.0	1.25	1.00	B	46.30	25.00	20.00
Ca^{2+}	4.0	4.00	5.25	Mo	0.10	0.50	0.50
Mg^{2+}	2.0	1.375	2.00				

Selection of target values for the nutrient solution

- EC (electrical conductivity) in dS m^{-1} – a measure of the total salt concentration in the nutrient solution.
- pH.
- Levels of K, Ca and Mg – introduced either as mutual ratios (K : Ca : Mg on a molar basis, denoted by X : Y : Z) or as fixed concentrations (mmol litre^{-1}).
- Level of N – defined by specifying one of the following:
  - total nitrogen to potassium ratio (total-N/K denoted by *R*) in combination with an ammonium to total nitrogen ratio (NH_4^-N/total-N denoted by N_r), both on a molar basis;
  - total nitrogen to potassium ratio (total-N/K on a molar basis, denoted by *R*) in combination with a fixed NH_4^-N concentration (mmol litre^{-1});
  - fixed NO_3^-N concentration (mmol litre^{-1}) in combination with an ammonium to total nitrogen ratio (NH_4^-N/total-N on a molar basis, denoted by N_r);
  - fixed NO_3^-N concentration (mmol litre^{-1}) in combination with a fixed NH_4^-N concentration (mmol litre^{-1}).
- Concentration of $H_2PO_4^-$ (mmol litre^{-1}).
- Concentrations of micronutrients (µmol litre^{-1}) – specifically Fe, Mn, Zn, Cu, B and Mo.

The concentration of these various nutrient and non-nutrient ions varies depending on the irrigation water used. Growers must, therefore, do their own calculations to determine the amounts of fertilizers required to prepare a nutrient solution with a standard composition.

Plate 7
Stock solutions used for preparation of nutrient solutions

Another problem is that single-nutrient fertilizers (with the exception of N) are not available and it is not possible to supply a certain amount of just one macronutrient. For example, soluble potassium (K^+) may be added to an aqueous solution either as KOH or as a salt (KCl, KNO_3, KH_2PO_4, K_2SO_4 etc.), but KOH supplies not only K but also OH^- ions, causing the pH of the solution to reach levels harmful to plants. Similarly, potassium salts supply an additional element in the form of an anion at a fixed molar ratio (depending on the valence of the anion, but normally either 1 : 1 or 2 : 1).

Data input for the nutrient solution

- EC, pH and concentrations of nutrients (K, Ca, Mg, NO_3^-N, SO_4^-S, Mn, Zn, Cu, B, Cl) and non-nutrient ions (Na^+ and HCO_3^-) in the irrigation water used to prepare the nutrient solution.
- Percentage of Fe in the Fe-chelate used as iron source.
- Available source of soluble P (KH_2PO_4 or H_3PO_4) and percentage of pure H_3PO_4 in the commercial-grade H_3PO_4 if the latter is used as P fertilizer (commonly 85%).
- Percentage of pure HNO_3 in the commercial-grade HNO_3 if the latter is used for pH adjustment when preparing the nutrient solution.
- Available source of B (see Table 4).
- Available source of Mo (see Table 4).
- Volume of stock solutions (m^3).
- Desired concentration factor – defined for a particular fertilizer as the ratio of its concentrations in the stock solution and the solution supplied to the crop (commonly 100, dictated by the least solubility of the fertilizers used).

To overcome these complications and avoid laborious repetition of work, computer programs have been developed to calculate the amounts of individual fertilizers required to prepare a given nutrient solution taking into account also the specific composition of the irrigation water. The program proposed by Savvas and Adamidis (1999) can be easily applied.[1]

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[1] Operates via a Microsoft EXCEL® platform and is freely accessible on the Internet at http://www.ekk.aua.gr/excel/index_en.htm.

If the desired composition of a nutrient solution is given in terms of fixed target concentrations, the EC of this solution is also fixed and can be calculated using the following relationship (Savvas and Adamidis, 1999):

$$C = 9.819\,E - 1.462 \qquad (1)$$

where E depicts the EC ($dS\,m^{-1}$) and C the concentration sum of cations ($meq\,litre^{-1}$) in the nutrient solution, including also non-nutrient macro cations, particularly the Na^+ concentration.

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Plate 8
Preparation of nutrient solution for soilless-cultivated plants using an automatic fertigation head to control EC and pH of outgoing solution

Consequently, when only macronutrient concentrations but no macronutrient ratios are given to define the nutrient solution composition, it is meaningless to select a target EC, since only one fixed EC, specifically that calculated by equation (1), is feasible. In contrast, if the desired composition of the nutrient solution is defined by selecting target macronutrient ratios, it is possible to select any desired EC.

The output comprises the mass of fertilizers (kg for macronutrients and g for micronutrients) to be added in the two stock solution tanks (A and B) for the given volume. If the target composition includes macronutrient concentrations (as opposed to ratios), the target EC is also calculated. The target values of EC and pH are then introduced to the controlling system of the fertigation head used to automatically prepare fresh nutrient solution by diluting the stock solutions.

Macronutrient sources are generally as follows:

- **Ca:** calcium nitrate (calcium phosphates and sulphates have low solubility, and calcium chloride would result in undesirable concentrations of chloride).
- **Mg and SO_4^{2-}:** magnesium sulphate (extra Mg with magnesium nitrate and extra sulphate with potassium sulphate).
- **P:** monopotassium phosphate (or phosphoric acid, depending on the concentration of bicarbonates in the irrigation water).
- **NH_4^+:** ammonium nitrate.
- **K:** potassium nitrate (but deducting any K added in the form of potassium sulphate and monopotassium phosphate).
- **Nitrate-N:** calcium nitrate, magnesium nitrate, potassium nitrate, ammonium nitrate and nitric acid (the NO_3^-N requirement depends on the target concentrations of Ca, Mg, K, SO_4^{2-}, $H_2PO_4^-$ in the nutrient solution and the concentration of bicarbonates in the irrigation water; a certain amount of phosphoric acid is sometimes used with nitric acid to lower the pH).

The concentration of HCO_3^- in the irrigation water dictates the amount of HNO_3 required to control pH and also determines the addition of H_3PO_4. When preparing fresh nutrient solution by diluting stock solutions with irrigation water, the pH is adjusted by converting the bicarbonates contained in the irrigation water to CO_2 (Savvas and Adamidis, 1999); to achieve this, acid is added at an $H^+ : HCO_3^-$ molar ratio of 1 : 1.[2] The target P concentration in nutrient solutions rarely exceeds 1.5 mmol $litre^{-1}$ and the amount of phosphoric acid added must take this limit into account. However, the bicarbonate concentration in most sources of irrigation water in Mediterranean countries is much higher than 1.5 mmol $litre^{-1}$. Therefore, if the concentration of bicarbonate in the irrigation water exceeds the target P concentration by 0.5–1.0 mM, nitric acid should be used to adjust the target pH (either in addition to phosphoric acid, or as a sole source of H^+). High HCO_3^- concentrations are essentially accompanied by equally high concentrations of cations (particularly Ca^{2+} and Mg^{2+}). Thus, when preparing a nutrient solution using tap water with a high HCO_3^- concentration, an increased addition of NO_3^- (in the form of HNO_3) to control the pH is compensated for by a decreased supply of NO_3^- in the form of $Ca(NO_3)_2$. If a high HCO_3^- concentration in the tap water is accompanied by a high Mg^{2+} concentration, less Mg^{2+} is added in the form of $MgSO_4$. The SO_4^{2-} requirement is provided in the form of K_2SO_4, resulting in reduced addition of NO_3^- in the form of KNO_3. Consequently, even when the HCO_3^- concentration in the tap water is high, there is no risk of adding too much NO_3^- to the nutrient solution when HNO_3 is used to adjust the pH.

Micronutrient sources are generally as follows:

- Fe: chelated Fe
- Mn, Zn and Cu: their respective sulphate salts
- B: sodium tetraborate, sodium octaborate and borax (in soilless culture)[3]
- Mo: sodium molybdate and ammonium heptamolybdate[3]

In the last two decades, silicon has been included in the nutrient solution for the nutrition of soilless-grown plants in greenhouses. When silicon is supplied via the nutrient solution in hydroponics, it improves the growth of plants subjected to both abiotic and biotic stress conditions, although it seems to have no effect under non-stress conditions. Silicon is added to the nutrient solution in the form of liquid potassium silicate ($SiO_2 \cdot 2KOH$), which has a strong alkaline reaction and should, therefore, be supplied to the plants from a separate stock solution tank. The high alkalinity of potassium silicate is controlled by enhancing the HNO_3 injection dosage during the process of nutrient solution preparation. The increased

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[2] There should be a slight excess so that the pH reaches a level at which the buffering effect of phosphates will actually stabilize the pH.

[3] The selection of the B or Mo fertilizer depends on current availability or on market prices and not on the addition of any other nutrient or the composition of the irrigation water.

supply of nitrogen (in the form of HNO_3) and of K (in the form of $SiO_2{\cdot}2KOH$) is compensated for by a reduction in (KNO_3).

When the drainage solution is recycled, it is important to ensure an adequate nutrient supply avoiding accumulation. The injection rate of each individual nutrient to the closed-cycle cultivation system should, therefore, be more or less equal to the rate of removal via plant uptake (Sonneveld, 2002). Several models and approaches have been proposed to adjust the supply to the uptake in closed hydroponic systems. Such models may effectively control the supply of nutrients in closed-cycle cultivation systems, provided that they are calibrated on the basis of reliable and representative experimental data. The total nutrient concentration in the recycled solution may thus be maintained close to a target level.

Control of pH and nitrogen nutrition in soilless culture

The optimum pH in the root zone of most crop species grown hydroponically is 5.5–6.5, although values between 5.0–5.5 and 6.5–7.0 may be acceptable, depending on the crop (Adams, 2002). However, in soilless culture, when marginal values of the optimum pH range are maintained, there is an increased risk of exceeding or dropping below these values due to the limited volume of nutrient solution per plant that is available in the root zone. Most plants exposed to external pH levels of > 7 or < 5 show growth restrictions (Sonneveld, 2002). Nevertheless, some plant species (e.g. gerbera and cut chrysanthemums) perform better at low pH due to the higher susceptibility of these species to chlorosis induced by Fe, Mn, Zn and Cu deficiencies.

Overall, a pH of > 7.0 (sometimes even > 6.5) can quickly result in the appearance of P-, Fe- and Mn-deficiency symptoms (and sometimes Cu and Zn). The appearance of P deficiency at pH > 6.5–7.0 is attributed to the increasing transformation of $H_2PO_3^-$ into HPO_3^{2-}, which is not readily taken up by the plants. Furthermore, the precipitation of calcium phosphate at pH > 6.2 is an additional reason to maintain the pH below this level in the root zone of soilless-grown plants. The occurrence of Fe, Mn, Zn and Cu deficiencies at pH > 6.5–7.0 is associated with the increased precipitation of these nutrients.

The composition of the nutrient solution in the root zone changes gradually, due mainly to selective ion uptake by the plants in accordance with their nutrient requirements. In periods of sufficient light intensity and rapid growth, the anion uptake usually exceeds the cation uptake, as a result of elevated nitrate absorption and utilization. In terms of electrochemical potential, a higher anion uptake is compensated for by the release of HCO_3^- and OH^- by the roots. As a result, the pH of the nutrient solution in the rhizosphere increases. However, under poor light conditions, nitrate reductase activity declines, thus imposing a depression of nitrate utilization by the plant and concomitantly lower NO_3^- uptake rates. Consequently, the total anion uptake is reduced. On the other hand, a more rapid uptake of cations is compensated for by release of H^+ from the roots. Hence, under poor light conditions, the root zone pH does not tend to increase rapidly, and in some cases it may even decrease.

If the pH of the nutrient solution in the root zone drops below the optimum range, KOH, $KHCO_3$ or K_2CO_3 may be used to adjust it – injected from a separate stock solution tank to avoid phosphate and carbonate precipitation. The control of pH in the root environment of soilless cultivated plants requires measures to prevent high (rather than low) pH. If the percentage of drainage solution is relatively low, an increase in irrigation frequency and/or water dosage at each irrigation cycle might restore normal pH levels within the root zone. However, if the adjustment of the irrigation schedule fails to reduce the pH to normal levels, it may be necessary to increase the ammonium supply. Nitrogen is the only nutrient that can be supplied to plants via fertigation in both anionic (NO_3^-) and cationic (NH_4^+) forms, while the uptake rates of both N forms are influenced by their external concentrations. Thus, the manipulation of NH_4^-N/NO_3^-N in the supplied nutrient solution without altering the total-N concentration may considerably modify the total cation–anion uptake ratio. However, changes in this ratio have a profound impact on the pH of the root zone. Indeed, the imbalance of total cation over anion uptake in the rhizosphere originating from enhanced NH_4^+ uptake is electrochemically compensated for by the release of protons, resulting in a lowering of the medium pH. Similarly, an excess of anion uptake due to increased supply of NO_3^- is compensated for by H^+ influx or equivalent anion extrusion, which increases the pH of the external solution.

As a rule, the use of NH_4 as a sole or dominating N source impairs growth and restricts yield due to the high toxicity of ammonia at an intracellular level. Therefore, the current recommendation for soilless culture is that NH_4^-N should not exceed 25% of the total nitrogen supply (Sonneveld, 2002), although individual species differ in their response to the NH_4^-N–total-N supply ratio and root zone pH. In soilless-grown crops of leafy vegetables (e.g. lettuce and rocket), a partial substitution of NH_4^+ for NO_3^- in the nutrient solution may restrict the accumulation of NO_3^- in the edible leaves. Furthermore, an increase of the NH_4^-N supply to solanaceous vegetable fruits may increase the incidence of blossom-end rot and other Ca-related disorders in fruits (Savvas *et al*., 2008). While tomato is tolerant of high pH, it is susceptible to low pH in the root environment caused by high ammonium supply, because this impairs Ca uptake. On the other hand, insufficient NH_4 supply may induce chlorosis in tomato due to micronutrient deficiencies. To maintain the root zone pH within the target range, the NH_4^-N/total-N supply fraction should be adjusted properly. Under SEE conditions, and depending on the type of substrate, a NH_4^-N/total-N range of 0.05–0.15 can be considered a standard for adjustment in tomato crops.[4]

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[4] Note that 15% is too high for substrates like rockwool that lack CEC.

GAP recommendations – Plant nutrition management in smallholder farms

Soil cultivation

- Note that the ability of the soils to adsorb and exchange cations is quantitatively expressed as "cation exchange capacity".
- Note that the uptake of nutrients contained in the soil solution results in the reduction of their concentration in the root environment.
- Maintain the correct balance: excessive application of one or more nutrients is accompanied by an inadequate supply of other nutrients.
- Monitor carefully the supply: errors in fertilization may induce physiological disorders which result in non-marketable produce. Typical physiological disorders related to plant nutrition are blossom-end rot (BER), colour spots or flecks, and fruit cracking of tomato and pepper.
- Apply nitrogen with care: while nitrogen supply is crucial for yield and quality of greenhouse vegetables, excessive N fertilization may result in delayed maturity and formation of disease-sensitive plant tissues. Nitrogen is the only nutrient that can be supplied to plants via fertigation in both anionic (NO_3^-) and cationic (NH_4^+) forms, while the uptake rates of both N forms are influenced by their external concentrations.
- Ensure that (for most greenhouse vegetables) NH_4 does not exceed 15% of the total nitrogen supply. As a rule, the use of NH_4 as sole or dominating N source impairs growth and yield due to the high toxicity of ammonia at an intracellular level.
- Adjust the soil pH to ensure the supply of micronutrients: for an adequate supply of Fe, Mn, Zn and Cu, the soil pH should be 6–6.8.

Soilless cultivation

- Supply all essential nutrients via the nutrient solution, with the exception of carbon, which is taken up from the air as CO_2.
- Adopt special computer programs for the calculation of the amounts of individual fertilizers required to overcome the complications and avoid laborious repetition of work.
- Prepare a nutrient solution with a given composition using irrigation water with a specific composition.
- Include silicon in the nutrient solution for soilless-grown plants in greenhouses.
- Adjust the pH for hydroponically grown crops: the optimum pH in the root zone of most crop species grown hydroponically is 5.5–6.5, although values of 5.0–5.5 and 6.5–7.0 may not cause problems in many crops.
- Use suitable dosing pumps or injectors to maintain optimal nutrient concentrations in the irrigation water.

GAP recommendations – Soil conservation and irrigation in smallholder farms

Soil conservation

- Manage with care ion exchange capacity, organic matter content, soil salinity and acidity to maintain and enhance soil fertility, optimize soil texture, porosity and hydraulic properties, and maintain levels of plant available nutrients.
- Implement measures to prevent erosion and salinization of the soil and to maintain a high organic matter content to maintain soil fertility.
- Avoid soil compaction.
- Minimize the use of agrochemicals and use good quality irrigation water.
- Return organic matter to the soil on a continual basis.
- Pay attention to topsoil – the most fertile soil layer, being the richest soil fraction in organic matter and clay minerals.

Irrigation

- Ensure that the rate of water supply to greenhouse crops exceeds that of consumption, in order to ensure leaching out of salts from the root environment through the excess water that runs off.
- Avoid salinization of the soil: note that in protected cultivations, salinization is mostly favoured by low quality irrigation water, over-irrigation using marginal quality water, and poor drainage.

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3. Irrigation management: challenges and opportunities

S. De Pascale,[a] G. Barbieri,[a] Y. Rouphael,[a] M. Gallardo,[b] F. Orsini[c] and A. Pardossi[d]

[a] *Department of Agricultural Sciences, University of Naples Federico II, Italy*
[b] *Department of Agronomy, University of Almería, Spain*
[c] *Department of Agricultural Sciences, University of Bologna, Italy*
[d] *Department of Agriculture, Food and Environment, University of Pisa, Italy*

ABSTRACT

Water, in terms of both quantity and quality, is crucial to the success of horticulture greenhouse production. This chapter covers the following aspects of irrigation of greenhouse vegetable crops:

- Water-use efficiency and water-saving strategies
- Micro-irrigation
- Irrigation scheduling
- Water quality management

Each section provides a critical overview of the principles, methods and tools used for vegetable crops in greenhouses, the main systems/components, the basic knowledge required for proper management and practical guidelines to deal with the most common issues faced by farmers.

WATER-USE EFFICIENCY AND WATER-SAVING STRATEGIES

To sustain the rapidly growing world population, agricultural production needs to increase. One means of achieving this is greenhouse cultivation, providing large quantities of high quality produce all year round and with an efficient use of resources (e.g. fertilizers and water). The last three decades have seen protected cultivation develop rapidly in many regions around the world, in particular in the South East European (SEE) countries with the production of a range of vegetable crops.[1] As water is rapidly becoming a scarce resource in several European countries, its sustainable use is an increasingly important issue among greenhouse

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[1] See Part I, Chapter 2.

Key questions

- Is water availability an issue?
- How can I understand if water is safe for irrigating crops?
- Is the installation of a micro-irrigation system expensive?
- How can I reduce water needed for cultivation?
- How can I increase the water-use efficiency?
- How should I decide when and how much to irrigate?
- Which is the appropriate technology to assist me in applying sufficient (not too much) water at the right frequency?
- Is water quality important?
- How can I check the water quality?
- What kinds of tools are needed to measure water quality for irrigation?

vegetable farmers. The traditional focus has been on maximizing total production (tonnes ha^{-1} or kg m^{-2}), but growers must now justify their water consumption. They must be prepared to use less water, improving the methods, techniques and management practices currently applied in the processes related to horticultural production. The concept of water-use efficiency (WUE), is a key term in the evaluation of sustainable use of water in greenhouse vegetable production. WUE (measured in kg m^{-3}) is defined as the ratio of marketable yield (Y_a), expressed on a fresh basis for vegetables, to the volume of water consumed by crop evapotranspiration (ET_c) (Molden, 2003).

Evapotranspiration (ET) refers to water lost by soil evaporation or crop transpiration during the growing season. Since there is no easy way of distinguishing between these two processes in soil culture, they are generally combined under the single term, ET. Evapotranspiration and irrigation volumes are generally measured in millimetres, as for rainfall: 1 mm corresponds to 1 litre m^{-2} or 10 m^{3} ha^{-1}.

In comparison to the open-field crops, protected cultivation of vegetables is normally characterized by greater WUE (up to five times) for three main reasons:

- Reduced potential evaporation due to the lower solar radiation, less wind and greater relative humidity inside the greenhouse.
- Higher crop productivity attributed to better control of plant diseases and climatic parameters, in particular global radiation and air temperature.
- Localized irrigation and application of micro-irrigation and closed-loop soilless culture.

High water-use efficiency in greenhouse vegetable production can be achieved by modifying both terms: yield and water consumed. An optimal control of the cultural practices and environmental parameters will lead to higher productivity while reducing water loss. It is important to consider all climatic factors potentially affecting plant water uptake. For example, increased relative humidity inside the greenhouse will decrease the vapour pressure deficit and transpiration, leading to an increase in the WUE. Numerous interventions are possible to **increase WUE**:

- Efficient water delivery systems and irrigation methods (e.g. micro-irrigation) have a major impact. Measured efficiency varies from 25–50% in furrow-irrigation systems, to 50–70% with sprinkler systems, and 80–90% with drip irrigation. In situations of limited water supply, sprinkler and drip methods can increase the irrigated area by 20–30% and 30–40% compared with furrow irrigation.
- Irrigation scheduling can potentially halve crop water consumption (De Pascale *et al*., 2011). Irrigation scheduling aims to synchronize water delivery and crop demand, reducing water lost through runoff and drainage.
- The choice of appropriate crops/cultivars makes a difference, together with the implementation of strategies to identify the best match between crop type and time of cultivation for a specific environment.
- Mulching or bag culture reduce soil evaporation.
- Measures leading to rapid and uniform crop establishment (e.g. transplanting, choice of suitable plant density and architecture) have a positive impact.
- The introduction of closed soilless systems (reducing water loss due to drainage and runoff, by recycling part of the nutrient solution) can improve WUE in vegetable greenhouse production by as much as 70% (Savvas, 2002).
- Rainwater is of high value for crops and should be collected with effective gutter systems, stored properly and utilized. However, rainwater contamination can occur when deposits on the greenhouse roof (or lime and water whitewash) are washed off with the rain or if uncoated galvanized structures leach zinc into the water. It is, therefore, essential that quality parameters for irrigation water be respected.
- In areas with limited fresh water supply, alternative options may be explored at a watershed or regional level – for example, utilization of alternative water sources (e.g. surface water recycled from production areas, treated and untreated wastewater, desalinated water). Note that these sources may require additional treatments.

MICRO-IRRIGATION

This section presents the basic concepts of micro-irrigation to familiarize vegetable growers with the main advantages and disadvantages, and with the components, functioning and management of the principal micro-irrigation systems.

Micro-irrigation – also known as trickle or localized irrigation – is widely adopted in greenhouse vegetables in SEE countries. Studies of several vegetable crops have reported higher yields, improved WUE and higher produce quality with micro-irrigation compared with other irrigation methods. Micro-irrigation entails the slow and regular application at low pressure (< 2 bar) of water directly to the root zone of the crops through a network of valves, pipes, tubing and emitters (Barbieri and Maggio, 2013).

Micro-irrigation has numerous **advantages**:

- **Improved crop productivity.** Slow, regular, uniform application of water and nutrients to all plants improves product quality and uniformity, and increases yield.
- **Water and fertilizer savings.** Water and fertilizer losses are minimized, and fertilizer costs are thus reduced and farmers can irrigate more crop area per unit of water used.
- **Labour savings.** The labour requirements for irrigation, weeding and fertilizer application are less than for other irrigation systems.
- **High flexibility.** Micro-irrigation can be easily repaired, maintained or modified to suit changing needs.
- **Reduced risk of pathogen attacks.** The small wetted area results in both low air humidity and limited weed growth, which also results in reduced disease incidence.
- **Energy saving.** Most micro-irrigation systems are operated with low horsepower pumps, reducing energy demand for irrigation; furthermore, since humidity is low, less energy is needed to heat the greenhouse (more energy is needed to heat humid air than dry air).
- **Tolerance to salinity.** Due to slow and regular application of water by micro-irrigation, concentration of salts in particular in the root zone is reduced (provided the supply of the nutrient solution is well managed).

The numerous advantages can, however, be nullified if the delivery points become clogged. To help counteract this problem, the following measures should be considered:

- Installation of a reliable filtration system for the irrigation system.
- Regular inspection of all watering points to check for blockages, which in turn can lead to isolated dry spots in a crop.
- Regular flushing or washing of filters.

- Flushing of the whole system (ideally at least once a year) with clean water to remove any debris.
- Rinsing with a weak solution of chlorine nitric or phosphoric acid. For on-line drippers, nozzles can be removed, washed clean in a bleach solution, and then replaced. Similarly, nitric or phosphoric acids are injected in the drip lines (integrated dripper) at the end of the growing season for 24 hours in order to break up all the mineral and organic deposits before being flushed.

However, while drip irrigation systems typically result in lower water consumption because of a reduced leaching fraction, the soil or substrate moisture content may become inadequate in organic crop production for soil biological activity and the appropriate mineralization rates of organic fertilizers.

Micro-irrigation systems can be grouped into **five categories:**

- **Systems with drip lines.** This category includes the common perforated hoses, consisting of a thin tube of polyethylene (PE), diameter 0.15–0.20 mm, with holes at fixed distances. The operating pressure is 0.5–2.0 bar, the flow rate 0.5–4.0 litre h^{-1}.
- **Systems with drippers.** These systems consist of low density polyethylene (LDPE) tubes, diameter 16–25 mm, on which drippers are inserted at a proper distance based on the crop requirements. The operating pressure is 0.5–2 bar, the flow rate 1–4 litre h^{-1}.
- **Systems with intermittent drippers.** These systems are characterized by a high unitary flow rate of 6–30 litre h^{-1}, with an operating pressure of 1–3 bar. Due to the higher operating flow rate, the probability of clogging is very low.
- **Systems with capillary tubes.** These systems comprise a PE tube, 20–25 mm diameter, on which are inserted capillaries, internal diameter 0.5–1.5 mm, of sufficient length to reach the point of dispensing. The operating pressure is 1–2.5 bar, the flow rate 0.7–7 litre h^{-1}.
- **Subsurface drip irrigation.** Drip hoses are positioned 15 cm underground in order to reduce water evaporation.

Components of a micro-irrigation system

A micro-irrigation system comprises many components, each one playing an important part in the operation of the system. The main components of micro-irrigation systems are described below:

Pump

Unless the water at the source (municipal or other) is supplied at an adequate rate and pressure, a pump is needed to push the water through the pipes and drippers. Most irrigation applications comprise a centrifugal pump – a rotodynamic pump that adds energy to the water by means of a rotating impeller. It may be either horizontal- or vertical-shaft (including submersed pumps). Horizontal pumps are generally used to pump water from surface sources such as ponds.

Filter

Effective filtration prevents the irrigation water from clogging the drippers and is essential for good operation and long-term performance. The most commonly used filters in micro-irrigation are media filters (gravel or sand), disk filters and screen filters. A well-planned micro-irrigation system comprises two stages:

- **Primary filtration**
    - Filters relatively large particles near the water source.
    - Comprises a media or disk filter.
    - Includes a hydrocyclone sand separator placed before the main filter in cases where sand or other heavy particles (≥ 50 micron) are present in the source water.

- **Secondary filtration**
    - Filters relatively small particles remaining after the main filtration stage.
    - Comprises a screen or disk filter.

Pipes (main, sub-main, distribution)

Pipelines carry water through the entire irrigation system, from the pump through the filters and valves, and onwards to the drippers. All pipelines and fittings should be properly sized to withstand maximum operating pressures and to convey water without excessive pressure loss or gain. Polyvinyl chloride (PVC) piping may be used throughout the system. PVC, polyethylene (PE) or flexible pipes are used for sub-mains and distribution pipes.

Water meters

Water meters provide information about water application that is essential for irrigation scheduling and the monitoring of dripper clogging. Propeller meters are the most common type in horticultural applications.

Pressure gauges

Pressure gauges provide vital information about the irrigation system. The data gathered are used to help detect leaks and clogging, manage the filters and chemical injectors, and keep the system within its operating range. To ensure that data are as accurate as possible, always use a pressure gauge with a scale representing the pressure range of the system. The typical pressure in the system should be around the mid-point of the gauge's scale.

Valves

Precise control of the water flow rate and pressure throughout the irrigation system is important to ensure efficient and timely water application. It is, therefore, imperative to select the right valves and position them correctly. Valves play a key role in controlling pressure, flow and distribution under different conditions to optimize performance, facilitate management and reduce maintenance requirements.

Dripper lines (lateral)

Dripper lines are at the heart of a micro-irrigation system. In any irrigation system, the design process starts at the plant and proceeds to the dripper lines. There are numerous important considerations when designing the dripper lines: dripper line selection, wall thickness, dripper flow rate, spacing between drippers, and spacing between dripper lines.

Drippers

Drippers are evenly spaced along the dripper line and deliver water and nutrients directly to the plant root zone. A typical micro-irrigation system includes thousands of drippers. Each dripper should be durable and resistant to clogging and designed to emit the same amount of water. Wide water passages guarantee long-term trouble-free performance. The flow rate and spacing of the drippers determine the wetting pattern and the prevention of runoff or deep percolation. A properly operated and maintained micro-irrigation system provides water and nutrients to the crop root zone without runoff or deep percolation. Two types of integral drippers are available:

- Non-pressure-compensating drippers (which supply a flow rate on the basis of the working pressure)
- Pressure-compensanting drippers

GAP recommendations – Irrigation systems

- Ensure high water-use efficiency in greenhouse vegetable production through optimal control of cultural practices and environmental parameters.
- Adopt micro-irrigation when possible, as it is the most efficient system for vegetable irrigation under greenhouse conditions.
- Include a filtering apparatus upstream of the distribution line in micro-irrigation in order to avoid clogging of the nozzles.
- Rinse out the system with weak solution of chlorine nitric or phosphoric acid (when necessary, depending on the chemical and biological properties of the water).

IRRIGATION SCHEDULING

Irrigation scheduling determines the amount of water applied to the crop (irrigation dose) and the timing of application (irrigation frequency). The principal methods of irrigation scheduling in soil-bound crops and soilless growing systems are very similar:

- Water balance (determines crop water requirements from climatic data)
- Use of soil or plant sensors

Water balance method

The water applied at each irrigation event must compensate for the crop water uptake between two successive irrigations and should correspond to the maximum oscillation in the available water (AW, m^3/m^3 or percentage) in the soil or substrate – the so-called "management allowable depletion" (MAD) or "pre-irrigation soil/substrate water deficit" (PISWD). The amount of available water is defined as the water that the crop can absorb without suffering water stress (which would reduce yield) and it depends on the soil properties, for example, it is greater in loamy soil than in sandy soil. As a general rule, the MAD is calculated as a fraction of the AW (30–50% in soil-bound crops, 10% in soilless culture), while the irrigation dose is calculated by multiplying the MAD by the scheduling coefficient (SC) to account for the salinity of the water and the uniformity of application. Typically, irrigation water should be applied when the accumulated daily ET_c for the periods between irrigations approaches the MAD.

The SC is a measure of the extra water required because of non-uniform water application, inter-plant differences in leaf transpiration and, more importantly, to prevent salt accumulation in the root zone. Over-irrigation is crucial in container culture as the absence of a significant cation exchange capacity in most substrates allows buildup of high concentrations of ions in the rhizosphere. It ranges from 1.15 (uniform crop and water distribution; use of irrigation water with relatively low salinity; high crop tolerance to salinity) to 2.0 (large inter-plant variability in crop evapotranspiration; poor irrigation uniformity; use of saline water; salt-sensitive crop), that is a drain fraction (water leached/water applied) of 13–50%. An SC of 1.30 (drain fraction = 23%) is suitable in most conditions. For example, with MAD = 40 mm and SC = 1.3, the irrigation volume would be 40 × 1.3 = 52 mm and the drain fraction would be 12/52 × 100 = 23%.

Most irrigation control methods determine the frequency of irrigation and use fixed irrigation doses. As crop evapotranspiration (ET_c) in greenhouse accounts for > 90–95% of the water absorbed by the roots, irrigation frequency can be computed as ET_c divided by MAD. If ET_c is expressed on a daily basis, the result is the number of irrigation events in a day. For example, a crop grown in substrate culture with MAD = 1.0 mm, SC = 1.3 and daily ET_c = 5.0 mm would be irrigated five times a day with an irrigation dose of 1.3 mm.

Determining evapotranspiration

To determine the crop water requirements of greenhouse vegetable crops, it is possible to adopt the FAO-56 Penman–Monteith method, which estimates crop evapotranspiration (ET_c) as the product of:

- reference evapotranspiration (ET_o) – equivalent to the evapotranspiration of a grass crop and quantifies the effect of climate on crop water demand; and
- crop coefficient (K_c) – quantifies the effect of crop species and stage of development.

The FAO-56 Penman–Monteith method is recommended for estimating ET_o inside greenhouses when radiation, air temperature and atmospheric humidity data are available; wind speed is negligible inside greenhouses. Simple equations can be used to estimate ET_o from the air temperature and/or radiation inside the greenhouse, and the results are easily implemented in irrigation control. The principal challenge is to determine K_c (related to leaf area).

K_c varies with species, development stage and crop management practices (vertically supported or not). For greenhouse-grown vegetable crops, there is wide variability in planting dates and lengths of crop cycles, depending on market prices, weather conditions and farm management considerations. For this reaon, the standard FAO method of calculating ET_c – using three constant K_c values, one for each fixed-length crop stage – is unsuitable for these crops. It is therefore recommended to use mathematical models that estimate K_c values as a function of thermal time inside the greenhouse. Crop coefficient (K_c) values for the main greenhouse-grown vegetable crops are presented in Table 1.

TABLE 1
Crop coefficient (K_c) values determined for the major greenhouse-grown vegetable species in Almeria, Spain

Species	Initial K_c	Maximum K_c	Final K_c[a]
Supported crops			
Sweet pepper	0.2	1.3	0.9
Tomato	0.2	1.6	
Melon	0.2	1.3	1.1
Cucumber	0.2	1.2	
Eggplant	0.2	1.2	
French bean	0.2	1.4	1.2
Non-supported crops			
Melon	0.2	1.1	1.0
Watermelon		1.1	1.0
Courgette	0.2	1.1	

Note. Values presented are the initial K_c value for transplanted seedlings, maximum K_c values, and final K_c values where appropriate.

[a] Many out-of-season crops are finished early because of low prices; in these cases final K_c values equal maximum K_c values.

Orgaz *et al*., 2005.

For greenhouses, simplified (empirical) models for predicting ET_c have been developed. These models consider global solar radiation, vapour pressure deficit and specific crop parameters, such as the leaf area index (Baille *et al*., 1994).

One example is the method proposed by Gallardo *et al*. (2013), where the ET_c is estimated from daily values of maximum and minimum temperature inside the greenhouse, and of external solar radiation. These parameters are all easily available to farmers. ET_o is calculated using a local radiation equation calibrated for plastic greenhouses in Spain from external solar radiation measured in a nearby weather station. The crop coefficient (K_c) is estimated using simple models based on thermal time. Since the climatic variability in greenhouses is very low, historical climate data may help farmers to adopt simple irrigation scheduling techniques. Once ET_c is calculated, the irrigation frequency can be determined based on the water balance or by simple sensors (e.g. tensiometers).

Calculations can be done manually or special software can be adopted (e.g. PrHo v2.0, developed by the Research Station of the Cajamar Foundation of Almeria). For a detailed explanation of the methodology, see Gallardo *et al*. (2013).

Use of sensors

Soil moisture sensors can be used to control the frequency of irrigation and, possibly, the water dose by continuously monitoring the moisture content of the growing media, expressed as moisture tension (in kPa – a negative value) or volumetric water content (as a percentage or in m^3/m^3). The tension measures the force of retention of soil water by the soil particles and indicates the availability of soil water for crops. The volumetric water content is the ratio of soil volume occupied by water. Sensors allow irrigation to be implemented on the basis of the characteristics of individual greenhouses and specific cropping conditions.

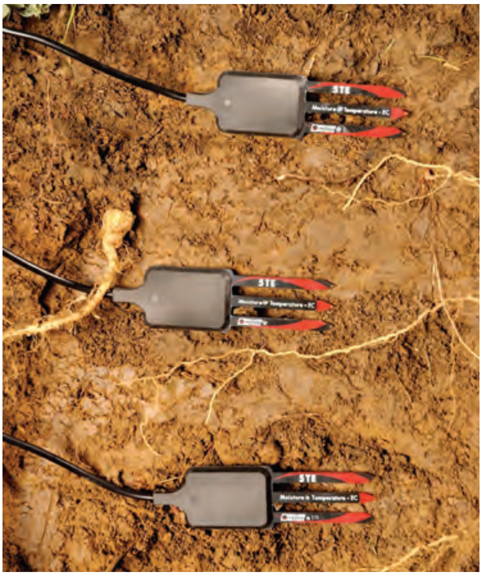

GALLARDO

Plate 1
Manual tensiometer

Nowadays, a variety of simple irrigation controllers are on the market, interfaced with one or more soil moisture sensors, usually using wireless radio technology. New kinds of soil moisture sensor have been developed to measure soil dielectric properties. These sensors are cheaper and require less maintenance and user expertise compared with traditional water-filled tensiometers. However, while the interpretation of moisture tension data for irrigation management is straightforward, the interpretation of volumetric water content requires protocols or site-specific experience. Most tensiometers usually have a working range of between 0 and –80 kPa, basically covering the range of soil moisture tension found in drip irrigated crops.

Sensors, such as 5TE (Decagon Devices) or WET (Delta-T Device), have also been developed for simultaneous measurements of temperature, moisture content and salinity (EC) in soil or soilless media. These sensors provide the possibility of controlled fertigation.

When sensors are used for irrigation scheduling (IS), there are two important considerations: replication (≥ 2–3 sensors per crop); and location (representative of the crop). Other practical considerations include: cost, ease of use, preparation and maintenance requirements, technical support, ease of data interpretation, availability of irrigation protocols, working language, and the user-friendliness of any software.



LAB-FERRER

Plate 2
Decagon probes installed in soil, placed at three different depths to measure volumetric soil moisture, soil temperature and electrical conductivity

Growing systems

The approaches to irrigation scheduling are relevant to both soil culture and soilless culture, but there are some differences between the two growing systems.

Soil culture

When calculating the water requirements of soil-bound crops, decision support systems (DSS) can assist growers and advisors. For example, the software PrHo v2.0 has been developed to calculate daily crop water requirements for the principal greenhouse vegetable crops, for cropping cycles specified by the user.[2]

Irrigation management with soil water sensors is based on maintaining the soil water between two limits: a lower limit (drier value) indicating when to start irrigating and an upper limit indicating when to stop. The difference between the two limits indicates the volume of irrigation required. Generally, the lower limit permits depletion of soil water without stressing the crop; and the upper limit prevents excessive drainage from the root zone (Figure 1).

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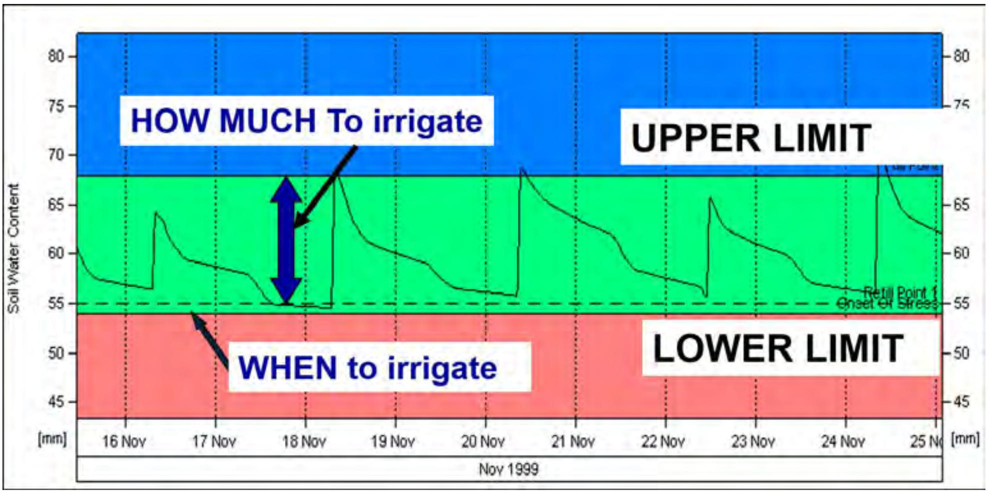
[2] Available at http://www.publicacionescajamar.es/series-tematicas/centros-experimentales-las-palmerillas.

FIGURE 1

Example of irrigation management using a soil sensor to maintain soil water content between upper and lower limits, and their use for deciding the time of irrigation and volume to apply



Note:
Upper limit: volume of irrigation. Lower limit: date of irrigation.

Soil water sensors can be used with different configurations depending on the crop, irrigation system, cost and the characteristics of the sensors. One sensor should be placed in the zone of maximum root concentration. Additional sensors can be placed at different depths, for example, below the roots to control drainage or to the side of the plants to control the size of wetting bulbs from drip irrigation. The most widely used sensor configurations are: 1) one sensor within the zone of major root concentration; and 2) one sensor within the zone of major root concentration complemented by one or more deeper sensors.

When using tensiometers, the recommended upper and lower limits of moisture tensions are –10 and –20 kPa, –10 and –30 kPa, and –15 and –40 kPa, for soils of coarse, medium and fine texture, respectively.

Soilless culture

Either open or closed irrigation systems are used for substrate culture. In **closed systems**, the drainage water is captured and re-used following the adjustment of pH and nutrient concentration and, when necessary, disinfection to minimize the risks of root-borne diseases.

Accurate irrigation scheduling is crucial in **open systems**, as the substrate used determines the seasonal use of water and the pollution resulting from leaching of agrochemicals. However, over-irrigation or deficit irrigation can also affect crop growth and yield in closed systems, for example, by increasing incidence of physiological disorders (such as blossom-end rot in tomato and pepper) or susceptibility to root diseases.

In soilless culture, a wide range of growing media are used. For irrigation management, the ideal medium should be characterized by high porosity (> 80%) and homogenous distribution of air (oxygen) and water in order to sustain root activity.

The amount of available water ranges from 7 to 35% of total substrate volume and tends to increase with increasing substrate porosity and bulk density and with decreasing container height: the taller the container, the more drainage and the less capacity media will have to hold water. Table 2 reports values of water and air content at container capacity ($_{CC}$) and AW for different types of container and growing media widely used in greenhouse horticulture. The container AW is defined as the difference between the container water content calculated at 0 and –10 kPa matric potential at the bottom of the container (Incrocci *et al*., 2014). AW is calculated on the basis of the water retention curve of the substrate determined in the laboratory and the geometry of the container (Bibbiani, 2002).

A good estimation of the available water in the container (AW_{cont}) can be obtained by applying the following equation:

$$AW_{cont} = + 0.64\ AW + 0.30\ P - 67\ h + 4.1$$

where AW (%) is the available water derived from the water release curve (difference between the volumetric water content at –1 and –10 kPa) of the substrate, P (%) is its porosity and h (m) is the container height.

Compared to soil culture, plants grown in substrate are generally irrigated many times during the daytime, beginning early in the morning. More than 90% ET_c occurs during the light period (i.e. ≤ 10 hours in autumn–winter and 12–14 hours in spring–summer). In heated greenhouses and in dry seasons and regions, irrigation may sometimes be necessary in the middle of the night.

Frequent watering means that the irrigation of soilless culture is generally under automatic control entailing the adoption of the following:

- Timer (based on the grower's estimate of ET_c).
- Weather station or simple light sensor (based on the grower's estimate of ET_c).
- Weighing gutter (or similar devices) to measure gravimetrically ET_c (and possibly the growth) of a few test plants over a short time (minutes or hours).
- Tray system (a similar concept to the weighing gutter method). A water level sensor is placed in a small tray where the volume of water is in

TABLE 2

Water ($_{CC}$) and air (A_{CC}) content at container capacity, and AW in different containers filled with various growing media[a]

Substrate	Porosity	AW		Unit	Slab	Bag 1	Bag 2	Bench 1	Bench 2	Bench 3	Pot 16	Pot 24	Pot 32
	%	%	height	m	0.075	0.15	0.20	0.20	0.30	0.40	0.14	0.21	0.29
			length	m	0.15	0.20	0.20	1.00	1.00	1.00	0.16	0.24	0.32
			width	m	1.00	1.00	1.00	0.40	0.30	0.40			
			volume	litre	11.25	30.0	40.0	80.0	90.0	160.0	2.81	9.50	23.31
Peat	88.0	37.0	$_{CC}$	%	82.0	76.3	72.8	72.8	66.0	60.7	77.0	72.1	66.7
			A_{CC}	%	6.0	11.7	15.2	15.2	22.0	27.3	11.0	15.9	21.3
			AW	%	47.1	41.4	38	38	31.3	26.1	42.1	37.3	32
Perlite	90.0	13.0	$_{CC}$	%	69.4	53.2	48.3	48.3	42.8	39.7	54.5	47.5	43.2
			A_{CC}	%	20.6	36.8	41.7	41.7	47.2	50.3	35.5	42.5	46.8
			AW	%	47.4	31.2	26.3	26.3	20.8	17.7	32.5	25.5	21.2
Pumice	55.0	6.0	$_{CC}$	%	49.8	45.5	44.0	44.0	42.0	40.7	45.9	43.8	42.2
			A_{CC}	%	5.2	9.5	11.0	11.0	13.0	14.3	9.1	11.2	12.8
			AW	%	14.8	10.7	9.2	9.2	7.3	6.1	11	9	7.5
Coconut	90.0	35.0	$_{CC}$	%	82.5	75.6	71.8	71.8	64.7	59.2	76.4	71	65.4
			A_{CC}	%	7.5	14.4	18.2	18.2	25.3	30.8	13.6	19	24.6
			AW	%	47.6	40.7	37	37	30	24.7	41.5	36.2	30.6
Rockwool	94.0	78.0	$_{CC}$	%	89.5	82.9	75.6	75.6	59.0	45.9	84.1	74.1	60.7
			A_{CC}	%	4.5	11.1	18.4	18.4	35.0	48.1	9.9	19.9	33.3
			AW	%	85.6	79	71.8	71.8	55.3	42.3	80.3	70.3	57
Peat-perlite	66.0	24.0	$_{CC}$	%	61.5	57.4	55.2	55.2	51.3	48.3	57.9	54.8	51.7
			A_{CC}	%	4.5	8.6	10.8	10.8	14.7	17.7	8.1	11.2	14.3
			AW	%	31.6	27.6	25.5	25.5	21.6	18.7	28	25.1	22
Peat-pumice	77.0	19.0	$_{CC}$	%	67.3	59.3	56.5	56.5	52.7	49.9	60.1	56	53
			A_{CC}	%	9.7	17.7	20.5	20.5	24.3	27.1	16.9	21	24
			AW	%	35.3	27.5	24.7	24.7	21	18.3	28.2	24.3	21.3

[a] The porosity and AW (as calculated from the water retention) for each substrate are also shown.

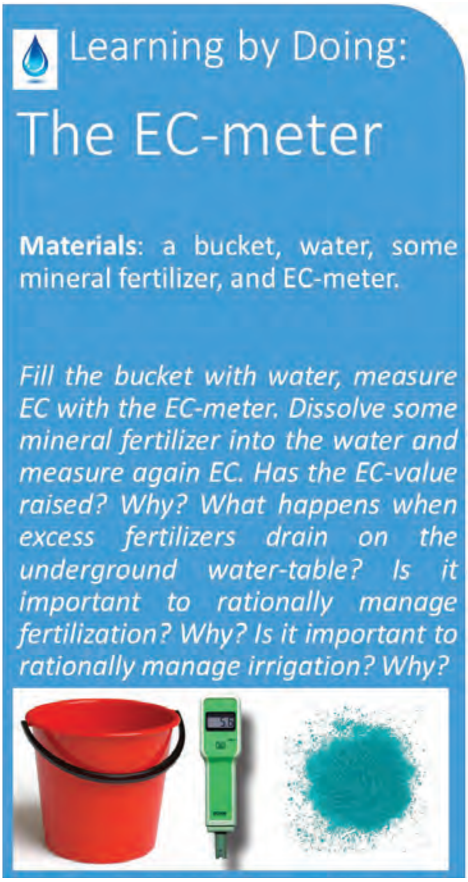
equilibrium with the water content in the substrate. When crop uptake causes the water level in the tray to decrease to the level of the sensor, the crop is irrigated.

- Soil moisture sensor(s). The sensor position is adjusted by the grower during the season on the basis of measured drainage volumes and experience.

The threshold values for moisture tension depend on crop species and growing media; typical values range from –4 to –10 kPa in substrate growing systems. This value can be converted to volumetric water content from the water release curve. For example, a moisture tension of –5 kPa corresponds to a volumetric water content of around 40% in coconut and peat and about 30% in perlite and pumice.

In substrate culture, frequent monitoring of pH and EC in the root zone is crucial in order to adjust irrigation and fertigation. The grower should, therefore, check the pH and EC of the drainage water (every 1–3 days) and of the substrate (every 4–6 weeks). When the quality of the irrigation water is poor, monitoring should be more frequent.

FIGURE 2
EC meter



Learning by Doing:

The EC-meter

Materials: a bucket, water, some mineral fertilizer, and EC-meter.

Fill the bucket with water, measure EC with the EC-meter. Dissolve some mineral fertilizer into the water and measure again EC. Has the EC-value raised? Why? What happens when excess fertilizers drain on the underground water-table? Is it important to rationally manage fertilization? Why? Is it important to rationally manage irrigation? Why?

GAP recommendations – Irrigation scheduling

General recommendations

- Determine both irrigation dose and frequency.
- Calculate the irrigation dose on the basis of soil or substrate hydraulic properties, crop species, water quality and irrigation system, which determine the values of the MAD (%) of the available water in the root zone and the scheduling coefficient.
- Determine irrigation frequency (either automatically or manually) on the basis of irrigation dose and ET_c, which depend, respectively, on the physical properties of the growing medium (including the volume explored by the roots) and on climatic conditions. Soil moisture sensors (tensiometers or capacitance sensors) may also be used.
- Adopt professional systems when possible to ensure optimal irrigation efficiency.
- Contact irrigation designer and company for cost-effective irrigation systems.

Soil culture

- Ascertain crop evapotranspiration ($ET_{c)}$ in crops grown in greenhouses as the product of reference evapotranspiration (ET_o) and crop coefficient (K_c) values. (Software is available to calculate ET_c.)
- Calculate crop coefficients using available models based on temperature inside the greenhouse.
- Place one soil moisture sensor in the zone of maximum root concentration. Place additional sensors at different depths (e.g. below the roots to control drainage), and to the side of the plants to control the size of wetting bulbs from drip irrigation.

Soilless culture

- Install automatic control because frequent watering is necessary.
- Adopt affordable and consistent tools (weighing gutter, tray system) for direct measurement of ET_c.
- Maintain the scheduling coefficient at ≤ 1.5 (which would result in a drain fraction of 33%).
- Check pH and EC of drainage water daily and substrate every 4–6 weeks. Intensify monitoring if poor-quality irrigation water is used.

IRRIGATION WATER QUALITY PARAMETERS

The characteristics of irrigation water depend on the source. Irrigation water can be classified on the basis of its origin as:

- surface water (from rivers, canals, natural or artificial lakes);
- subterranean water (from springs, wells etc.); or
- wastewater (from urban and industrial drains, subjected to various kinds of purification treatments).

For example, subterranean water in coastal zones may be of marginal quality for agricultural use because of the high content of dissolved salts, while municipal wastewater may also be of marginal quality because of the associated health hazards. The **parameters** characterizing irrigation water quality fall into three categories (FAO, 2013):

- **Physical:** temperature, suspended solids (soil particles, impurities etc.).
- **Chemical:** gaseous substances, pH, alkalinity, soluble salts (salinity), and concentration of sodium, chloride and toxic elements.
- **Biological:** algae, bacteria, various micro-organisms.[3]

Physical

For irrigation purposes, the **temperature** of the water must be as close as possible to that of the plants and the layer of substrate containing the root systems. Water is considered cold when its temperature is below three-quarters the air temperature. Cold water is unsuitable for irrigation as it can cause physiological disorders, especially in more delicate crops. Operative measures should be adopted, such as storing the water in basins to encourage the temperature to rise. Warm water, on the other hand, can have the dual benefits of warming the crops and supplying their irrigation requirements. Water at > 35 °C is, however, dangerous to plants. Water temperature is a particularly important consideration when growing foliage plants, because extreme water temperature (whether hot or cold) can cause leaf spotting, which reduces the value of the produce.

The **suspended solid** substances (e.g. soil particles as a result of erosion, different types of suspended matter disposed of in water courses by various industries, particulates contained in unpurified or partially purified municipal wastewater) found in water do not generally cause direct damage to the crops. However, problems may arise when plants and commercial products are stained, leading to their depreciation in terms of appearance and overall sanitary conditions, and this is particularly important in the case of flower crops. Furthermore, solids suspended in irrigation water can clog the irrigation nozzle and damage the

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[3] See Part II, Chapter 9.

distribution equipment, especially in the case of micro-irrigation systems. When the presence of solid particles in the water causes the emitters in trickle irrigation systems to become obstructed, maintenance costs rise and their utilization can become compromised. Moreover, the use of wastewater containing suspended organic solids can lead to health and hygiene hazards.

Chemical

A number of **gaseous substances** may be present in the water. The presence of O_2 depends on the water temperature and the presence of biodegradable substances. Given the low solubility of air in water, however, it does not reach a high concentration, and rainwater and surface water are therefore preferred. The chlorine used to purify drinking water may be present in a gaseous form, but it becomes volatile when in contact with the environment, due to the combined action of the light and air. Gaseous contaminants (e.g. H_2S, SO_2, CH_4) may also be found and their presence can restrict possibilities to use the water.

The **pH** is an expression of the concentration of hydrogen protons (H^+) in an aqueous solution. The pH varies on a scale of 0 to 14: 7 is neutral, < 7 is acid and > 7 is basic or alkaline. The pH regulates all biological functions and can inhibit certain vital processes if it is unsuitable. The pH of the water and of the soil or various cultivation substrates influences the solubility of the ionic species and, therefore, plant nutrition. Indeed, every nutritional element has a maximum solubility for clearly defined pH intervals. The optimum pH of irrigation water is usually between 6.5 and 7.5. Water with a pH of between 6.0 and 8.0 can be used for irrigation purposes. Decidedly acid ($pH < 5$) or basic ($pH > 8.5$) water is classified as anomalous for irrigation purposes.

While pH is a measure of the hydrogen ion concentration, alkalinity is a relative measurement of the capacity of water to resist a change in pH or the ability of water to change the pH of the growing media. Alkalinity increases as the amount of dissolved carbonates (CO_3^{2-}) and bicarbonates (HCO_3^-) rises. Chemically, it is expressed in parts per million (ppm) of calcium carbonates ($CaCO_3$) equivalents. Irrigation water with high alkalinity (> 100 ppm $CaCO_3$) will tend to raise the pH of the growing media over time and will require more acid to lower the pH of the water to an acceptable level should a grower wish to do that.

Sound confusing? Well, simply stated, alkalinity affects the ability to reduce pH by neutralizing added acids. You may wish to think of alkalinity as the buffering capacity of the water – how well it resists or causes a change in pH.

Irrigation water, particularly if the source is from groundwater, usually contains some quantity of **soluble salts**. The use of saline water for irrigation may have negative effects on the overall soil–water–plant relationship, even drastically restricting the normal physiological activity and productive capacity of the crops.

Some dissolved salts are of great concern to growers, as they are directly toxic to the plants, impede root water uptake and/or cause foliar spotting that lowers the plant value. The use of saline irrigation water can lead to three kinds of problem:

- increase in the osmotic potential of the circulating solution with increasing water absorption problems for the plants (osmotic effect);
- effects on the chemistry and physics of the soil/substrate; and
- phytotoxicity.

The higher a salt concentration, the more it contributes to salinity, particularly if dissociated. The most frequently occurring ions are nitrate, chloride, sulphate, carbonates and bicarbonates of alkaline and alkaline earth elements (sodium, potassium, magnesium, calcium). Salinity can be measured by means of analytical or electrical conductivity methods. Analytical measurements give results expressed in unit of volume (g litre^{-1} or mg litre^{-1}) or as a concentration of mineral salts in parts per million (ppm), with water defined brackish whenever the salt content is > 2 g litre^{-1} (or 2 000 ppm). Electrical conductivity (EC) is expressed in milliSiemens per centimetre (mS cm^{-1}), microSiemens per centimetre (µS cm^{-1}) or deciSiemens per metre (dS m^{-1}) as measured by a conductivity meter at 25 °C (where 1 dS m^{-1} = 1 mS cm^{-1} = 1 000 µS cm^{-1}). The EC is linked to the osmotic pressure that a given saline concentration creates in the solution which, in turn, directly affects the plant's ability to absorb water (i.e. increasing the salinity of water reduces the availability of water for uptake by plants). Water is defined as brackish when the EC is ≥ 3.0 dS m^{-1}. Although a rough classification of plant species on the basis of their level of salinity tolerance is available, the response is highly variable in relation to cultivar, soil/substrate, climate conditions and the agronomic techniques used. By combining suitable agronomic strategies with careful species and cultivar selection, it is possible to minimize yield reductions. Salinity control is particularly important in the root zone, especially during germination and the early phenological phases. It can be achieved by increasing irrigation frequency or by satisfying the leaching requirement (i.e. application of extra water for leaching of salts from the root zone to prevent excessive accumulation of salts that would limit the yield potential of crops). Moreover, drip irrigation is particularly suitable for water of poor quality (saline water).

The presence of particular ions – **toxic elements** – in the water can cause phytotoxicity problems. Such problems may appear as direct toxicity for various physiological processes of the plant or in the form of nutritional imbalances, with different levels of tolerance in different plants. Toxicity problems arise when certain elements in the irrigation water build up in the plant tissue to a level which causes reductions in yield, regardless of the total solute concentration. The elements that may generate toxicity phenomena are generally chloride, sulphur, boron and sodium. Toxicity phenomena manifest themselves in a typical fashion for each element and are apparent on old leaves where the buildup is greater:

Sodium (Na) at high levels is a concern to growers since it can contribute to salinity problems, interfere with **magnesium (Mg)** and **calcium (Ca)** availability in the media and cause foliar burns.

Sulphur (S) and **chlorine (Cl)** are essential elements for plant growth. Some crops (cruciferous, leguminous, potatoes) remove significant quantities of sulphur from the soil (70 kg ha^{-1}). However, if large quantities of this element are present in the irrigation water, it can damage the crops as a result of direct toxicity. Sulphur is generally found in water in the form of sulphate (SO_4^{2-}). However, in reducing environments, sulphate can be converted into sulphide (SO_3^-), which has higher phytotoxic action; indeed, sulphides cause the precipitation of iron, leading to toxicity symptoms in plants. Chloride (Cl^-) in water derives from the dissociation of the chloride salts contained in the water and the chlorination of purified wastewater. Elevated chloride is often associated with an elevated sodium concentration. Chloride toxicity symptoms appear as leaf burning and drying (starting at the tips and continuing along the edges), browning, premature yellowing and leaf drop. The potential for chloride and sulphate to cause damage depends on the sensitivity of the irrigated species and primarily manifests itself when the vegetation is wetted (i.e. sprinkler irrigation).

Boron (B) is an essential element for plants, but it can be toxic even at very low concentrations (> 0.5 ppm). Toxic concentrations of boron are almost exclusively found in soils in arid zones and in well and spring water in geothermal and volcanic regions, while most surface water contains acceptable levels of boron. Irrigation water can sometimes contain significant quantities of boron due to outflows from residential purification plants, as it is a common component of household detergents in the form of sodium perborate. The toxic effects of boron first appear in old leaves in the form of yellowing, chlorotic spots or dried tissue at the tip and edges of the leaf. Seedlings are generally more susceptible than mature plants.

In some cases, well water may be particularly rich in **iron (Fe)**. Acid-loving plants may experience problems when grown in acid soil or substrates and irrigated with ferrous water (where iron in the form of ferrous ions does not precipitate, but increases its concentration in solution and can be toxic). Elevated iron levels (> 5 mg $litre^{-1}$) generally cause aesthetic problems on ornamental plants and greenhouse structures, but may also lead to plugged emitters. In addition to the above elements, many others react with the soil and cannot be removed by means of leaching, causing toxic buildups in the soil and in plants, despite the presence of very low concentrations in the irrigation water (trace elements). Many of these elements are heavy metals, mostly deriving from human activities (industry, traffic).

When using irrigation water with high concentrations of heavy metals, the following risks should be considered: direct damage caused by phytotoxicity, buildup of the element in the substrate or soil, and absorption, transfer and buildup in the plant, with the risk of diffusion through the food chain. In any case, as with all the salinity problems, toxicity problems also increase during the period of greatest environmental evapotranspiration demand, meaning that where good quality water is available, it is best to use it during the hottest period of the irrigation season.

WATER ANALYISIS

Analysis of irrigation water is an essential part of any rational cultivation method. It serves to:

- avoid phytotoxicity phenomena in crops;
- rationalize fertilization (especially in the case of fertigation); and
- determine the necessity (or not) of a special water treatment plant.

Sampling

Analysis may be performed at any time of year, but it is important to bear in mind that there can be high variability in the water characteristics depending on seasonal rainfall (especially in the case of surface water sources). If no information is available about the usual conditions of the well, it is advisable to carry out at least two analyses in order to be able to investigate any changes in water quality: one during a rainy and another during a dry period. It is then sufficient to repeat the laboratory test every 1–3 years, in addition to periodic pH and EC tests using user-friendly portable instruments – an essential part of any farm's equipment.

It is very simple to sample irrigation water, but it is important to follow a few basic rules:

- The well must be in regular use. If new, testing must not be done until it has been used for a few weeks; if out of use for some time, it must be used for a few days before sampling.
- The water should be allowed to flow for a few minutes before the sample is taken.
- A clean polyethylene bottle is required for the sample. The capacity must be ≥ 1 litre (to be filled completely), but a larger volume of water may be required for certain measurements, and it is recommended to contact the laboratory in advance for more detailed information.
- The sample should be sent to the laboratory as soon as possible. A label should indicate details of the farm and the crop, the water source (identified by a code), and the type of analyses to be performed. Storage prior to testing should be kept to an absolute minimum; if in excess of 1–2 days, the laboratory should be contacted for advice on the best storage methods, which may vary depending on the parameters to be investigated.

Selection of parameters to be analysed

When choosing the parameters for analysis, it is necessary to make a compromise between the need for the maximum quantity of data and the cost. A very detailed analysis can cost €100–250 (or more), depending on the geographic location and the type of laboratory. Selection of the parameters is, therefore, not easy and must be made on the basis of:

- previous analytical data;
- reason for the analysis;
- farm characteristics (species grown, cultivation technique etc.); and
- local conditions.

Chemical water characteristics may be divided into four categories:

- pH – EC. They allow an initial assessment of the water. While very important, they are insufficient for an accurate judgement.
- Concentration of calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+), chloride (Cl^-), carbonate (CO_3^{2-}), bicarbonate (HCO_3^{2-}) and sulphate (SO_4^{2-}). They enable classification of the water on the basis of its effects on the soil/substrate, the crop and the plumbing systems. They should always be measured.
- Concentration of macro- (nitric nitrogen [$N\text{-}NO_3^-$], ammoniacal nitrogen [$N^-NH_4^+$], phosphates [HPO_4^{2-}, PO_4^{3-}] and potassium [K^+]) and micronutrients (iron [Fe], manganese [Mn], copper [Cu], zinc [Zn], boron [B] and molybdenum [Mo]). They reveal the "fertilizing power" of the water and indicate the potential toxicity risks associated with the concentration of micronutrients, which also depends on the pH of the water (the risks increase as the pH falls). They permit accurate fertilization management and are necessary when the area presents particular risks.
- Concentration of toxic substances (e.g. heavy metals, anionic tensioactives contained in detergents, fluorides) and total suspended solids (TSS). They are not generally present in hazardous quantities in water, but they can present a problem. Heavy metals, for example, may be of geological origin, but can also be the result of human activity. Inorganic (sand, lime, clay) or organic suspended solids can create blockages in the plumbing. They should be measured only if pollution is suspected.

Make reference to official analysis methods when analysing water!

Table 3 presents the criteria for choosing the appropriate type of analysis. The general suggestions should be adapted to suit the individual situation. It is not possible to indicate in advance a suitable analysis type for every situation and expert advice should be sought.

TABLE 3
Guidelines for choosing the water analysis parameters

Parameter		Meaning	When to do it[a]			
			First analysis	Intensive farming	Fertigation	Water treatment system planning
pH		Expresses acidity (< 7) or basicity (> 7) of water.	*	*	*	*
Salinity	EC	Relates to the overall salt content, which in turn is linked to the osmotic pressure.	*	*	*	*
Calcium	Ca^{2+}	Absorbed in considerable quantities by plants; at high concentrations may react with carbonates and bicarbonates to form limescale and can create nozzle obstruction.	*	*	*	*
Magnesium	Mg^{2+}		*	*	*	*
Sodium	Na^{+}	Indispensable at low concentrations; tends to build up in the soil or substrate with toxic effects for plants, worsening the physical characteristics of the soil.	*	*	*	*
Chloride	Cl^{-}	Indispensable at low concentrations; tends to build up in the soil or substrate with toxic effects for the plants.	*	*	*	*
Carbonate/ Bicarbonate	CO_3^{2} HCO_3^{2-}	Also referred to with the term "alkalinity".	*	*	*	*
Sulphate	SO_4^{2-}	At high concentration cause an increase in salinity; leaf deposits may form.	*	*	*	*
Nitric nitrogen	$N\text{-}NO_3^{-}$	Indispensable for plant growth, should be taken into account in the fertilization plan.			*	*
Ammoniacal nitrogen	$N\text{-}NH_4^{+}$				*	*
Phosphate	HPO_4^{2-}, PO_4^{3-}				*	*
Potassium	K^{+}				*	*
Iron	Fe	Indispensable for plant growth; may become toxic at high concentration.	*	*	*	*
Copper	Cu			*	*	*
Zinc	Zn			*	*	*
Boron	B		o	*	*	*
Molybdenum	Mo		o	o	o	o
Toxic substances	Tensioactives, Heavy metals, Fluorides (F^{-})	May be toxic to humans and/ or plants.	o	o	o	o
Total suspended soils	TSS	Can create drip emitter blockage.				*

[a] * = always recommended; o = to be performed in zones at risk.
De Pascale *et al*., 2013.

Interpreting a laboratory report

The interpretation of an analysis certificate can appear complex:

- **Identification of "threshold values"** – i.e. the concentrations above which a certain substance can become harmful – is not simple. Cultivated species have different levels of tolerance and the growing techniques adopted affect these thresholds. For example, a given salt content may be dangerous for a greenhouse crop, but not for a field crop, which is periodically washed by the rain.
- **Assessment of irrigation water quality** involves the examination of the relationships between the various parameters. For example, a given salt content may be tolerated if the ions present are primarily calcium and magnesium, but it may be harmful if sodium and chloride predominate. The opinion of an expert with detailed knowledge of the farm in question is more reliable than fixed thresholds. The threshold values for greenhouse crops given in Table 4 are therefore indicative and are only sufficient for the purposes of an initial assessment.

TABLE 4
Assessment of water analysis results

Parameter	Unit	Threshold	Possible intervention
pH		6.0–8.0	Acidification if too high, addition of bicarbonate if too low
EC	dS m^{-1} (25 °C)	< 0.750	Reverse osmosis, dilution
Ca^{2+}	ppm	< 150	Reverse osmosis, acidification, dilution
Mg^{2+}	ppm	< 35	
Na^{+}	ppm	< 50	Reverse osmosis, dilution
Cl^{-}	ppm	< 50	
Alkalinity	ppm	< 250	Acidification
SO$_4^{2-}$	ppm	< 50	Reverse osmosis, dilution
Fe	ppm	< 1.0	Reverse osmosis, dilution, oxidation tanks, removal systems
Mn	ppm	< 0.6	
Cu	ppm	< 0.3	Reverse osmosis, dilution
Zn	ppm	< 0.3	
Bo	ppm	< 0.3	
Mo	ppm	< 0.05	Dilution
Tensioactives	ppm	< 0.5	
Flourides (F^{-})	ppm	< 1.0	Reverse osmosis
Cadmium (Cd)	ppm	< 0.01	
Chromium (Cr)	ppm	< 0.1	
Nickel (Ni)	ppm	< 0.2	
Lead (Pb)	ppm	< 5.0	
Mercury (Hg)	ppm	< 0.002	
TSS	ppm	< 30	Filtration

De Pascale *et al*., 2013.

- The **units of measurement** used to express the results may differ, making it difficult to compare different analyses or an analysis and a series of threshold values. Few farms have their own laboratory and, indeed, it is not essential. However, a pH meter and a conductivity meter (to check the pH and EC levels on a regular basis) are indispensable. They are portable instruments, easily available on the market at a wide range of prices, affordable for all farms.

When using these instruments it is important to follow some fundamental rules to ensure that the readings are reliable!

GAP recommendations – Water quality

Water quality

- Ensure water quality – it is critical to successful horticulture greenhouse production.
- Know your water quality in order to plan for water treatments and avoid problems such as poor plant growth, staining, clogged watering pipes and other undesirable effects.
- Greenhouse irrigation water comes from a number of different sources and its quality varies. Nevertheless **apply the following general rules:**
  - Test water using an accredited laboratory before cultivation.
  - Seek expert advice, as it is not possible to indicate a suitable analysis type for every situation in advance.
  - Repeat analytical testing of irrigation water over time to identify composition variations which sometimes occur and may have negative effects on the crop.
  - Refer to official analysis methods when analysing water.
  - Perform periodic on-farm water pH and EC measurements as an essential part of any rational cultivation method.
  - Use portable instruments for measuring irrigation (or fertigation) water pH and EC (they are affordable, user-friendly and an essential part of correct management of greenhouse crops) and follow the fundamental rules to ensure the reliability of readings.
  - Adjust low quality waters corrected through desalination, pH correction, acidification, addition of bicarbonates and filtration.

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4. Crop diversification, management and practical uses

Y. Tüzel and G.B. Öztekin

Ege University, Faculty of Agriculture, Department of Horticulture
Izmir, Turkey

ABSTRACT

Greenhouse horticulture is an intensive production system creating favourable conditions of climate control and the increased efficiency of resources. However, monoculture remains an important problem with a very limited number of high-value crops grown in greenhouses. Crop diversification means a wider choice of crops/varieties and reduced risks for the grower. Crop diversification is an important tool for food security, income growth, efficient use of natural resources, sustainable development, and environmental and ecological management/improvement. In greenhouses, crop diversification could be enhanced through intraspecific genetic diversity, cultivation of new (alternative) crops, cultivation of mixed crops (i.e. intercropping, trap plants) and crop rotation. Numerous strategies are available for increased diversification in greenhouse production.

INTRODUCTION

The world population has reached over 7 billion and continues to increase steadily. An increase of 34% is forecast by 2050, mostly in developing countries. The demand for food, feed, fibre and biofuel will consequently increase, resulting in growing pressure on already scarce agricultural resources. Agriculture will also be required to respond to other issues, for example, adapting and contributing to the mitigation of the adverse effects of climate change, helping preserve natural habitats and maintaining biodiversity. Farmers will, therefore, need to adopt innovative technologies to maintain adequate levels of productivity.

Greenhouse cultivation involves modification of the natural environment to improve plant growth. Modifications may be in aerial or root environments and aim to increase crop yield, permit plant growth for out-of-season production and/or extend the growing season. Different crops can be cultivated depending on the season and species, taking into account the milder climatic conditions under cover (Maloupa, 2007). In fact, greenhouse horticulture is an intensive production system creating favourable conditions for climate control and increased efficiency of resources (i.e. land, labour, water, fertilizers, energy). Indeed, limited water resources and rapid population growth are the major factors drawing attention towards the use of intensive–protected agriculture. Protected cultivation has expanded all over the world and has an important role also in South East European countries, where the total protected cultivation area is about 104 560 ha and is dominated by vegetable crops.[1] Fruit vegetables include various cultivars of tomato, pepper, eggplant, melon, cucumber, squash, watermelon, strawberry and green bean (Maloupa, 2007). Investment costs are high – whether for low- or high-tech structures – while the returns are good on high-value crops grown as off-season production, but of which there are a relatively limited number. This situation results in monoculture, which is one of the most important problems in greenhouses, and there is a need for crop diversification.

Cultivar

Cultivar means **"cultivated variety"**. It has desirable characteristics for cultivation and is selected through:

- specific hybridization;
- plant selection; or
- mutation of a plant.

When hybridization produces successful results, the plant is usually given a cultivar name and released commercially. In this regard, a successful hybrid is also a cultivar.

For easy retrieval and comparison of information, refer to **"Hortivar"** FAO's database on the performance of horticultural cultivars (www.fao.org/hortivar/).

In addition to the advantages of crop diversification highlighted in the box, it can also be adopted to enhance resilience to abiotic and biotic stresses which have a major impact on agricultural production systems and threaten yield and crop sustainability (Tables 1 and 2). In more diverse agrosystems, it is easier to control pests and diseases and to protect from climate variability (Keatinge *et al.*, 2012).

The elements of diversified agroecosystems (Ebert, 2014) are not all applicable to greenhouse crop cultivation, whether in commercial, economic or practical terms. However, some practices can be adopted – such as intraspecific diversity with grafting on rootstock or crop rotation with a limited number of crops – in consideration of the crop intensification requirements.

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[1] See Part I, Chapter 2.

TABLE 1
Benefits of different types of diversification on crops for either greenhouse or open-field conditions

Increases	Decreases	Balances
• Income • Fodder for livestock animals • Resilience to poor weather conditions • Tolerance/resistance to biotic and abiotic stresses • Conservation of natural resources • Food security (by spreading the risk over a range of crops and cultivars)	• Environmental pollution • Off-farm inputs • Pest, disease and weed problems • Effects of increasing extremes of climate • Dependence on off-farm inputs	• Food demand • Price fluctuation

TABLE 2
Potential benefits of diversification in greenhouse conditions

Type of diversification	Nature of diversification	Benefits
Genetic diversity in monoculture	Growing mixed varieties of a species in monoculture	Disease suppression Increased production stability
Crop rotation	Temporal diversity through crop rotation	Disease suppression Increased production
Polyculture	Growing ≥ 2 crop species	Disease suppression Product diversity

Lin, 2011 (adapted).

CROP DIVERSIFICATION IN GREENHOUSES

Crop diversification in greenhouse cultivations is increasingly important, given its vital role in maintaining the economic sustainability of greenhouse production and improving the performance of farmers who have introduced protected cultivation in new areas (Maloupa, 2007). Crop diversification is an effective tool that allows greenhouse cultivation to:

- take advantage of the increasingly close links between agricultural production and economics;
- adopt new production technologies and systems;
- implement new technologies in processing, preserving and marketing; and
- respond to trends in market requirements due to changes in consumer habits.

In particular, changing consumer habits and demands requires producers to be innovative. Consumer demand continues to change as a result of:

- improved living standards;
- new recipes;
- less time available for cooking;
- greater prevalence of eating out;

Crop diversification

- Increases food security.
- Improves income growth.
- Uses natural resources efficiently.
- Promotes sustainable development.
- Supports environmental and ecological management/improvement.
- Gives a wider choice in the production of different crops/varieties.
- Reduces risks for the grower.

- growing interest in new foods;
- increased awareness of quality; and
- greater interest in health effects and nutritional value.

As a result, greenhouse vegetables need increasingly to respond to a call for “not more, but better” or “not more, but more variation” (Maloupa, 2007). However to achieve “more variation”, it is necessary to face the challenge of adapting new crops to greenhouse conditions while ensuring that they remain competitive from an economic point of view. There are some new crops that perform well agronomically, but they are not in high demand on the market (La Malfa and Leonardi, 2001).

There are four main approaches for enhancing crop diversification in greenhouses:

- intraspecific genetic diversity;
- cultivation of new (alternative) crops;
- cultivation of mixed crops (i.e. intercropping, banker plants); and
- crop rotation.

Intraspecific genetic diversity

Genetic variation within the same species is used in greenhouse cultivation, in particular in the cultivation of tomato (La Malfa and Leonardi, 2001). Over the years, genetic diversity in tomato and its wild relatives has evolved, resulting in the improvement of new typologies, varieties and rootstocks. For example, once truss and cherry type tomatoes had been developed, new cultivars resembling old heirloom varieties were developed.

Colourful bell peppers, beefsteak and cluster tomatoes, and eggplant are all traditional greenhouse vegetable crops. They – together with other species – can provide alternative crop opportunities if greenhouse growers choose to grow non-traditional cultivars, for example: heirloom tomatoes, cherry tomatoes, hot and speciality peppers, unusual types of eggplant, small peppers and eggplants, off-season peppers, immature pea pods, small strawberries, yellow and variegated green bean pods, yellow courgettes, and seedless watermelon or eggplant. These cultivars can represent a great opportunity, particularly for small specialized greenhouse operations (Hochmuth and Cantliffe, 2012; Leonardi and Maggio, 2013).

Plate 1
Diversification in fruit typologies of greenhouse tomato cultivars

For introduction as a new crop, the cultivar should:

- be adapted to the agroclimatic and social conditions;
- meet consumer requirements; and
- be marketable and profitable (Leonardi and Maggio, 2013).

Alternative greenhouse crops

The identification of new alternative crops to introduce into farming systems is important for the economic sustainability of greenhouse cultivation. A crop must be competitive in terms of economic return; this is easier to achieve when crops are adapted to small, simple structures without any climate control (Leonardi and Maggio, 2013).

A "new crop" is different from the crops already available on the market. The "difference" may be related to the characteristics of the vegetable itself or to the supply period. A new crop is not necessarily a new species; it could be a particular form of cultivar of an already-cultivated species. It could also be considered new and innovative because of its period or location of cultivation or the growing system. A crop traditionally grown in the open field may even be considered "new" when it is cultivated in the same period and location, but in a greenhouse (Maloupa, 2007).

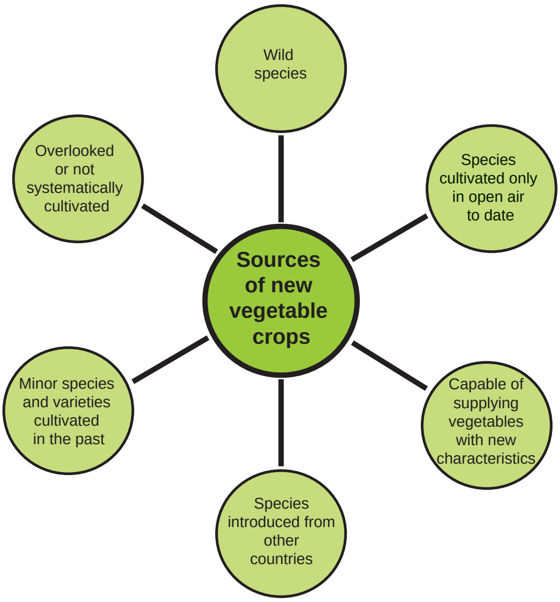
ÖZTEKIN (15 photos)

Plate 2

Alternative crops for protected cultivation

From left to right, top to bottom: Swiss chard, asparagus, purslane, 'Red Batavia' lettuce (Batavia type), green ice lettuce (Batavia type), onion (green), bell pepper, 'Giant Marconi' Italian type pepper, pepino, strawberry, elongated green tomato, cucumber ('Beit Alpha'), summer squash, cos lettuce, cut flowers

FIGURE 1
Sources of new vegetable crops



Maloupa, 2007.

Compared with the open field, protected cultivation means a grower can opt for highly profitable cash crops/species in a given region, since they are produced under a structure regardless of outside conditions. It is imperative to increase the range of crops in greenhouse cultivation in order to increase the economic benefits, meet market requirements and satisfy consumer demand. Growers or breeders can use several sources of new crops introduced in greenhouse productions.

The choice of species and cultivar is also relevant to the sustainability of greenhouse productions. Before making their decision, growers should consider what/when/how they are going to produce and where they will sell their products.

Several factors affect crop and species choice (Table 3), but economic potential tends to be the main conditioning factor. Farmers then develop appropriate protection, growing systems and technologies; alternatively, they select a crop suited to the farm's existing structures. While economic factors (market) and political decisions (subsidies for certain crops in specific areas) affect crop choice, agro-environmental constraints are a further consideration. Cultivar choice

TABLE 3
Effective factors for choice of crop and species

Crop choice	Species choice
• Market requirements • Economic convenience • Economic and social context • Distance from markets • Plant dimensions • Crop characteristics and requirements • Labour requirements • Climatic conditions • Characteristics of protection means • Possibility of active climate control • Soil characteristics and soil-borne diseases	• Environmental conditions • Production type • Consumer demands - easy to use - novel and versatile - good taste - health properties • Properties - yield potential - quality - extended harvesting time - resistance to biotic and abiotic stresses - long shelf-life

depends on farm size (small, medium or large), because medium- and large-scale farms look to national and international markets, while small-scale farms aim simply to meet the family's needs or to make limited profits in local markets (Leonardi and Maggio, 2013).

La Malfa *et al*. (1996) carried out experiments for 4 years on the optimization of protected cultivation. They introduced 23 new crops and concluded that the following crops could be used for diversification of greenhouse production: bottle gourd, cherry tomato, Chinese cabbage, orach, parthenocarpic eggplant, parthenocarpic tomato, snake melon, sweetcorn, watermelon and wild beet.

Hochmuth and Cantliffe (2012) on the other hand – in light of consumer demand for novelties and the consumer's concern to reduce food waste – indicated the following alternative crops for protected cultivation: mini cucumber ('Beit Alpha' or Persian type), lettuces (baby greens and salad types) and other leafy green vegetables (Swiss chard, spinach, kale and mustard), fresh-cut herbs (arugula [*Eruca vesicaria*], basil [*Ocimum basilicum*], purple basil [*Ocimum basilicum*], chervil [*Anthriscus cerefolium*], dill [*Anethum graveolens*], lemon balm [*Melissa officinalis*], sweet marjoram [*Origanum majorana*], oregano [*Origanum vulgare*], parsley [*Petroselinum crispum*], Italian flat leaf parsley [*Petroselinum crispum*], sage [*Salvia officinalis*] and thyme [*Thymus vulgaris*]), Galia muskmelon (*Cucumis melo Reticulatus* group L.), Charentais cantaloupes, strawberry, fresh-cut flowers, mini or "baby" vegetables (baby squash), squash flower, and edible flowers, microgreens (cabbage, beet, kale, kohlrabi, mizuna, mustard, radish, Swiss chard and amaranth) and baby greens (sprouts from almond, pumpkin and peanut).

In SEE countries, a range of protected crops are cultivated; a crop grown in one country may be considered exotic in another country in the same area.[2] Another consideration for farmers in SEE countries is the introduction of rotation crops that are of economic value and in high demand, for example, baby greens or other leafy vegetables and fresh-cut herbs.

GAP recommendations – Selection of species and cultivars

Species

- Research the market requirements.
- Take into account the economic convenience.
- Consider the economic and social context.
- Evaluate the distance from markets.
- Factor in the plant dimensions.
- Allow for specific crop characteristics and requirements.
- Calculate the labour requirements.
- Consider the climate conditions.
- Research carefully the features of the protection structures available.
- Consider the possibility of active climate control.
- Research the soil characteristics and consider the eventuality of soil-borne diseases.

Cultivars

- Take into account the environmental conditions.
- Consider the type of production.
- Research carefully the market requirements, considering that the consumer:
  - wants easy-to-use produce;
  - likes variety and is attracted by novelty and change;
  - prefers good taste; and
  - takes into account the health properties of foods.

- Examine the specific properties, including:
  - yield potential;
  - quality (e.g. cleanliness and safety);
  - extended harvesting time;
  - resistance to biotic and abiotic stresses; and
  - long shelf-life.

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[2] See Part III.

Cultivation of mixed crops

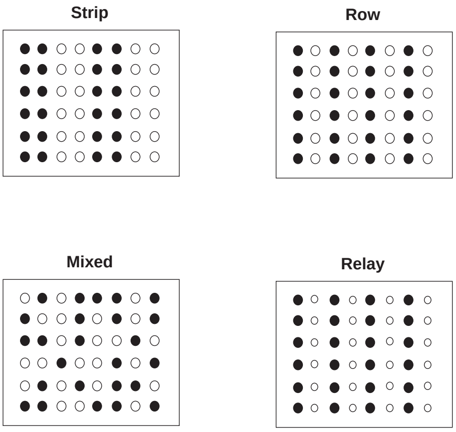
Intercropping

Intercropping – also referred to as mixed cropping or polyculture – entails the cultivation of two or more crops contemporarily in the same area. It is an old agricultural technique using crops of different rooting ability, canopy structure, height and nutrient requirements. Intercropping is based on the complementary use of growth resources by the component crops with the aim of efficiently matching the crop demands to the cultivation and labour resources available (Lithourgidis *et al*., 2011). Each crop must have sufficient space – taking into account spatial distribution (row, strip, mixed, relay intercropping), plant density, harvesting periods and plant architecture – in order to maximize cooperation and minimize competition between crops (Sullivan, 2003). The planting schedule, fertilization, plant protection and the harvesting period should all be effectively managed in order to increase intercropping performance.

There are various intercropping techniques (Figure 2):

- **Mixed:** The plants are totally mixed in the available space without any arrangement in distinct rows.
- **Relay (alternate row):** Two or more plant species are arranged in separate alternate rows and their cultivation is not synchronized.
- **Row:** The component crops are planted simultaneously within the same row in varying seeding ratios.
- **Strip:** Several rows of one plant species are alternated with several rows of another plant species.

FIGURE 2
Different types of intercropping



Intercropping is also suited to the cultivation of a fast-growing crop with a slow-growing crop, so that the first crop is harvested before the second crop starts to mature. This practice requires some form of temporal separation, for example, different planting dates so that the differential influence of the weather (in particular, temperature) on component crop growth can be modified. Temporal separation is also found in relay intercropping: the second crop is sown during the growth – often close to the onset of reproductive development or fruiting – of the first crop, so that the first crop is harvested to make room for the full development of the second crop (Lithourgidis *et al*., 2011).

Plate 3
Row intercropping (tomato–broccoli) in greenhouse

Plate 4
Strip intercropping (tomato–lettuce) in greenhouse

Intercrop performance can be evaluated using the land equivalency ratio (LER). Commonly used to indicate the biological efficiency of an intercropping system, the LER also shows the yield advantage of the intercrop over a sole crop. It is the sum of the division of intercrop yields to the pure crop yields for each crop in the intercrop. It can be calculated using the equation:

$$\text{LER} = \Sigma\ (Y_{int}/Y_{pure})$$

where Y_{int} is the yield of each crop in intercropping and Y_{pure} is the pure yield of each crop (Vandermeer, 1992; Sullivan, 2003).

- If LER = 1, there is no advantage from intercropping.
- If LER > 1, intercropping is considered advantageous.
- If LER < 1, there is a disadvantage from intercropping.

The selection of the appropriate intercropping system for each case is quite complex as the success of intercropping depends on the interactions between the component species, the available management practices, and the environmental conditions. Plant breeding can contribute increased productivity of intercropping systems by investigating and exploiting the genetic variability to intercrop adaptation (Lithourgidis *et al.*, 2011).

Although intercropping has some advantages (e.g. reduced risk of total crop failure), it is not widely practised in greenhouses where the monocultural production of high-value crops is more usual. Nevertheless, it is possible to use intercropping in greenhouses, particularly relay intercropping. For example, leafy vegetables (e.g. lettuce, green onion) and/or some herbs (e.g. basil) could be intercropped with high-value vegetables (e.g. tomato) (Jett *et al.*, 2005). Intercropping may also be more profitable for small-scale greenhouses, because it entails diversification of production.

TABLE 4
Overall advantages and disadvantages of intercropping practices in greenhouses

Advantages	Disadvantages
• Utilizes the available resources more efficiently • Increases yield • Improves soil fertility through biological nitrogen fixation (legume cultivation) • Increases soil conservation (greater ground cover than sole cropping) • Provides better lodging resistance for crops susceptible to lodging • Reduces incidence of pests • Provides insurance against crop failure or against unstable market prices for a given commodity (especially in areas of extreme weather conditions) • Increases financial stability • Maximizes potential of labour-intensive small farms • Reduces inputs (lower fertilizer and pesticide requirements) • Minimizes environmental impacts of agriculture	• Presents difficulties for the selection of the appropriate crop species and the appropriate sowing densities • Increases the workload (preparation and planting of the seed mixture) • Imposes extra work during crop management practices, including harvest .

TABLE 5
Harmonious plants and antagonist plants in greenhouse vegetable production

Vegetable species	Harmonious plants (LER > 1)[a]	Antagonists plants (LER < 1)[b]
Tomato	Chives, onion, parsley, lettuce, asparagus, marigold, nasturtium, carrot, radish, Chinese cabbage, squash	Potatoes, fennel, cabbage
Cucumber	Pole beans, radish, okra, eggplant, beans, corn, peas, radish, sunflower	Potatoes, aromatic plants
Eggplant	Beans, squash, Chinese cabbage, radish	Squash
Lettuce	Carrot, radish, strawberry, cucumber	-
Bean	Potato, carrot, cucumber, cauliflower, cabbage, summer savoury, most other vegetables and herbs	Onion, garlic, gladiolus

[a] Intercropping is considered advantageous.
[b] There is a disadvantage from intercropping.
Jeavons, 1982.

Trap cropping

A companion crop may sometimes be selected as a trap for pests, serving to attract pests and distract them from the main crop. An excellent example is the use of marigold or broccoli to draw root knot nematode away from tomato; the same strategy could be applied for the sustainable non-chemical management of nematodes.

Plate 5
Marigold (left) and broccoli (right) as trap crops accompanying tomato in greenhouse

Crop rotation

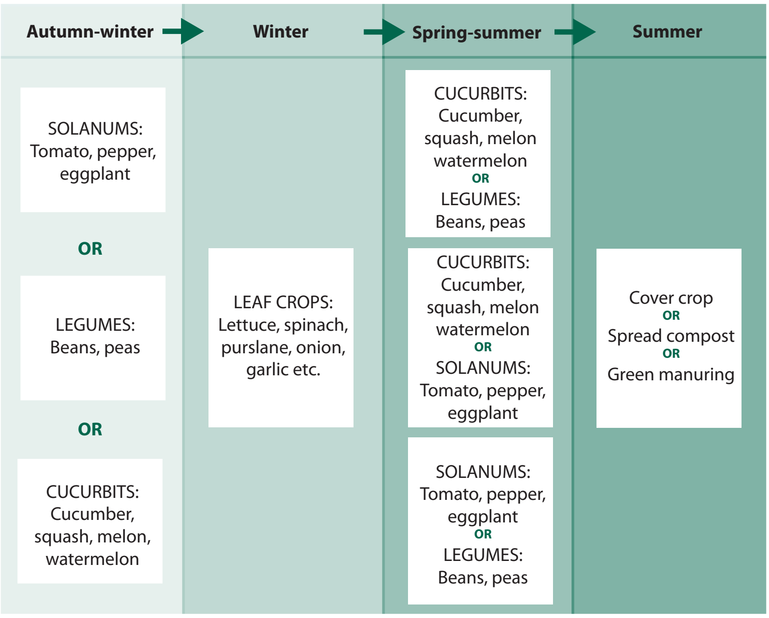
Monoculture cropping has been a growing trend in protected cultivation in recent decades, with the same crop or type of crops grown in the same field. Crop rotation, on the other hand, is the planting of two or more crops, in succession in the same field to maximize land productivity. Crop rotation has many agronomic, economic and environmental benefits compared to monoculture cropping. Crop rotation (in particular with legumes) is an essential practice to support crop diversification in sustainable farming. Another form of crop rotation is the combination of vegetable and flower production, but vegetables and flowers require different investments and knowledge and they are also destined for different markets, factors which do not facilitate the planning and implementation of crop rotation.

Crops should be carefully selected, taking into account their most favourable planting date. Crops of the same botanical family should not be planted in succession to prevent accumulation of pests. For example, eggplant should not follow tomato or pepper because of bacterial wilt, a soil-borne disease. Some crops produce root exudates which may remain in the soil and harm the next crop. Moreover, decomposed residues may damage the next crop. For consumption of all nutrients in the soil, deep-rooted crops should be cultivated in rotation with shallow-rooted crops. Note that the high cropping intensity of a sequential cropping system requires sustained application of compost or manure to replenish the organic matter in the soil and improve its biological and physical conditions (AVDRC, 1990).

On the basis of the above principles, Figure 3 presents a basic sample for unheated greenhouse conditions for two cycles per year. However, summer is the time for soil solarization which may not permit green manuring or cover crop growing.

FIGURE 3

A basic rotation programme for greenhouse crops



Advantages of crop rotation

- **Increased pest, disease and weed control.** Weeds are controlled more efficiently when the soil is used continuously for crop growing, as the weed population increases during the period between crops. If new cropping begins immediately after the previous crop, the land does not remain empty and weeds do not find optimal growth conditions. Moreover, successive crops do not share the same disease or insect problem, and the life cycle of pests can effectively be broken, resulting in a reduction in and easy control of the pest population.
- **Reduced use of pesticides.** Given the lower incidence of weeds and diseases and the decrease in insect and other pest infestations, there is a reduction in pesticide use. Consequently, there is both a decrease in costs and a mitigation of the negative impacts on the environment. There are also beneficial effects on consumers' health.
- **Improved use of residual soil moisture and nutrients.** Following one crop, the residual soil moisture is usually adequate to support the establishment of another crop. Likewise, fertilizers applied to the previous crop can also be utilized by a second crop, resulting in lower costs and increased profit margins.
- **Higher soil fertility.** To maintain the balance of nutrients in the soil, it is important to rotate crops with different nutrient utilization patterns. For example, leguminous vegetables can fix atmospheric nitrogen, returning it to the soil at the end of the season.
- **Improved soil structure.** Sequential crop practices mean that the organic matter in the soil increases and soil degradation decreases, resulting in higher yields and greater farm profitability in the long term. Improved soil structure also improves drainage, reduces the risk of waterlogging during floods, and boosts the supply of soil water during droughts.
- **Decrease in synthetic fertilizer requirements.** Raised levels of soil organic matter enhance water and nutrient retention and decrease synthetic fertilizer requirements. Leguminous crops, in partiular, fix atmospheric nitrogen and bind it in the soil, increasing fertility and reducing the need for synthetic fertilizers.
- **Lower greenhouse gas emissions.** Improved management of nutrients through crop rotation can decrease nitrogen fertilizer. For example, using legume crops in the rotation can reduce the need for additional synthetic nitrogen fertilizer (with biologic nitrogen fixation of 100 kg N ha^{-1} $year^{-1}$). The global warming potential of nitrous oxide is 310 times greater than that of CO_2. Reduced synthetic fertilizer use also leads to the reduction of greenhouse gas emissions associated with the manufacturing process and transportation.
- **Reduced water pollution.** Limiting the input of large applications of synthetic fertilizers decreases water pollution caused by nitrogen. Rotations with a low dependence on pesticides also reduce potential runoff into groundwater.
- **Greater ability to store carbon.** Crop rotation practices can lead to higher soil-carbon content through increased crop cover periods (using catch crops), reduced tillage intensity and frequency. This mitigates the effects of climate change.

GAP recommendations – Crop diversification

Greenhouse vegetables:

Not more:
BETTER!

Not quantity:
VARIATION!

- Recognize the importance of **biodiversity** for sustainable crop diversification.
- Enhance crop diversification in greenhouses through:
  - promotion of intraspecific genetic diversity;
  - cultivation of new (alternative) crops;
  - application of mixed cropping (i.e. intercropping, banker plants); and
  - adoption of crop rotation.

- For small and specialized greenhouse operations, increase profits by growing innovative crops originated from traditional crops (i.e. different in size, colour, shape, taste) based on genetic variation within the species.
- Select species and cultivars, including new crops, carefully. They must be adapted to agroclimatic and social conditions, meet consumer requirements, and be marketable and profitable. Consider the following:
  - bottle gourd, cherry tomato, parthenocarpic eggplant;
  - snake melon, watermelon, Galia muskmelon (*Cucumis melo Reticulatus* group L.), Charentais cantaloupes;
  - wild beet, sweetcorn, strawberry;
  - mini or "baby" vegetables (baby squash, mini cucumber);
  - lettuces (baby greens, microgreens and salad types) and other leafy green vegetables;
  - fresh-cut herbs, fresh-cut flowers, edible flowers (squash flowers).

- Adopt good agricultural practices for planting, fertilization, plant protection and harvesting.
- Adopt intercropping, particularly relay intercropping (cultivation of more than one crop simultaneously during the growing cycle of each crop). For example, intercrop leafy vegetables (e.g. lettuce) or herbs (e.g. basil) with high-value vegetables (e.g. tomato).
- Select companion crops that act as a trap for pests to distract them from the main crop.
- Favour crop rotation over monoculture for its agronomic, economic and environmental benefits. In particular, grow legumes in crop rotation to ensure sustainable farming and support crop diversification.
- Take account of the planting date when selecting crops.

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5. Integrated pest management

S. Masheva,[a] V. Yankova[a] and S.I. Rondon[b]

[a] *Maritsa Vegetable Crops Research Institute, Plovdiv, Bulgaria*
[b] *Oregon State University, Hermiston Agricultural Research and Extension Center, Hermiston, Oregon, United States of America*

ABSTRACT

Sustainable agriculture is a comprehensive term that covers a vast assortment of farming methods focusing on ecology and the interaction between farms and the environment. The objective of sustainable agriculture is to endure in the long term while maintaining profitability and causing minimal damage. The modern concept of integrated pest management (IPM) applied to insects or other pests falls under this umbrella, as it combines biological, biotechnological, mechanical, cultural and agrotechnical measures rather than applying a single means of control in order to keep the pest population under the economic injury level (EIL). IPM is a philosophy and a scientific approach that requires the use of an intelligent decision-making process to determine the ideal combination of control tactics. These tactics are intended to ensure favourable economic, ecological and social consequences. In this chapter, the most frequent pests in protected vegetable and strawberry production are discussed. Descriptions of damage and control methods for each pest are included. This section provides practical information for growers. It outlines the prerequisites for implementation of IPM, including pest identification, knowledge of the biology and ecology of pests and their natural enemies, establishment of EIL, selection of control methods, understanding of the effects and fate of pesticides, selection of compatible control methods, and novel IPM approaches.

INTRODUCTION

It is generally believed that chemical methods are an essential feature of protected agriculture. However, inappropriate use of chemicals can result in contamination and environmental damage, with negative effects on human health. Sustainable agriculture and integrated pest management (IPM) are based on the use of multiple agricultural practices, which in combination are able to alleviate the potential damage of widespread pesticide use while maintaining profitability and yield. This approach is in line with good agricultural practices for sustainable intensification of crop production.

Key questions

- What is IPM?
- What measures are required to produce healthy seedlings?
- Which pests can be effectively tackled using insect nets on the window vent? What are the recommended dimensions?
- Which diseases and pests develop at high air humidity in greenhouses?
- If there are root-knot nematodes in greenhouses, which crops can be grown without soil disinfection?
- What is the effect of drought in greenhouses on the phytosanitary status of the crops?
- What is the best time for spraying plants with plant protection products (PPP)?
- Why should PPP be alternated in plant treatment?
- Is it possible to increase the greenhouse air temperature and reduce the air humidity combined with ventilation to restrict the development of plant diseases?
- Is treatment with PPP harmless for useful species (macro- and microbioagents)?

The adoption of a combination of control measures in an IPM programme limits the application of any single means of control, constrains the adaptation of pests to any one tactic, and maintains pest populations at numbers below the economic injury level (EIL). Multiple decision-making processes, informed by adequate surveying of the pest situation, are used to determine what combination of control methods is most appropriate in a given scenario. Educational outreach directed towards growers can improve pest prevention and increase technical support for IPM programmes.

However, the goals of IPM can be very difficult to meet. Moreover, protected vegetable production typically faces multitudes of pest control challenges which are exacerbated by abiotic differences between regions, inadequate infrastructure and infrastructure capability, lack of qualified personnel and, of course, pest pressure.

Goals and associate strategies for successful crop production

- Minimum risk for human health and the environment
- Maximum protection of non-target organisms
- Sustainable pest control
- Maximum economic returns for producers

PREREQUISITES FOR IPM IMPLEMENTATION

To successfully implement IPM in protected vegetable and strawberry production, growers need the capacity to:

- identify pest(s), understand their bio-ecological characteristics and obtain the necessary data for diagnosis;
- apply biological control and understand the bio-ecological peculiarities and regulatory intricacies of increasing or introducing beneficials;
- implement monitoring programmes to determine population dynamic curves for pests and beneficial organisms that can be used in prediction models;
- establish EIL values – when possible, since this measure can be difficult to quantify;
- understand the selection, use and fate of pesticides in the environment;
- evaluate new control technologies and applications, including precision agriculture; and
- create a roster of available IPM specialists for eventual consultancy.

MANAGEMENT APPROACHES

Improved pest management practices can result in pest reduction by limiting the ability of the pest(s) to reproduce, distribute and/or survive. Soil tillage, irrigation, fertilization, mechanical practices, control of humidity and light, and use of screens can all contribute to the reduction of pest problems. Deep ploughing can push pathogens and pests deeper into the soil where anaerobic conditions are not favourable for their development; elimination of weeds can restrict pests' food and water supply. Extremes of temperature or humidity can have an effect on pests and natural enemies. For example, high soil and air humidity can encourage the development of mildew and grey mould, while hot and dry conditions can favour the outbreak mites. Finally, excess of nutrients and fertilizer can make plants susceptible to pest infestations such as thrips and aphids.

Mechanical and physical control

Mechanical control techniques are usually more practical for small producers when the labour requirements are not excessive; large operations covering a more extensive area, on the other hand, rely on tillage and cultivation. Mechanical control can be effective used singly or in combination with other techniques. Specific procedures can disrupt pest life stages in the soil and kill early season weed seedlings. Cultivation and tillage serve to upset insect life stages through exposure to desiccation or predation. Manual control is useful for removing pests at visible life stages, while shaking plants can dislodge pests and application of soaps or oils can kill pests. Other physical means of control include disinfection with steam, soil solarization, use of protected nets or screens on greenhouse vents, installation of screens for shading and plastic barriers. Under certain circumastances, no-till practices can reduce the pressure of pests and diseases.

Biological control

Biological control entails the use of natural enemies – predators, parasitoids and pathogens – to manage pest problems. Natural enemies are living organisms requiring special consideration. They should be used at the beginning of the growing season, when plants are small and pest density is potentially lower than later in the season, and can be employed as "natural" pesticides (augmentation or inundation) or through conservation (Masheva *et al.*, 2005; Masheva and Yankova, 2012). In protected agriculture, natural enemies have a major role in controlling pest problems. *Encarsia formosa*, *Aphidius colemani* and *Trichogramma* spp. are commonly adopted natural enemies; others include several species of lady beetles, minute pirate bugs and big-eyed bugs. Natural enemies can be used in conjunction with other means of control including chemicals. Biological control practitioners can obtain natural enemies from distributors worldwide.[1] The Association of Natural Bio-control Producers (ANBP) brings together researchers and biological control specialists; many such professional organizations are found around the world. Biocontrol agents are available for all major greenhouse pests, including aphids, gnats, mealybugs, spider mites, thrips and others.[2]


OSU-IAEP SIR

Plate 1
Biocontrol in action

Chemical control

Chemical control is the use of pesticides to significantly reduce the impact of pests on desirable plants by killing, suppressing growth, inhibiting biological functions, and/or disrupting behaviour patterns. Ideally, pest management practitioners use chemicals only as a last resort or in combination with other methods to achieve effective and long-term pest control. Repellants, mating disruptors, insecticides, fungicides, herbicides and miticides are all types of commercially available chemicals. Some may be derived from natural substances, others are synthesized. Chemicals are widely used in industrialized nations because they present several important **advantages**:

- They are very effective when used correctly, and broad spectrum pesticides often control multiple pests.
- They are relatively cheap to produce and apply.
- Their effects are predictable and reliable.

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[1] A list of distributors is available at the Association of Natural Biocontrol Producers (ANBP) site (http://www.anbp.org/).

[2] Not all sources of biocontrol agents are reliable. It is important to verify the validity of any product obtained.

However, chemical control also presents **disadvantages**:

- Most are biologically active against many forms of life and therefore can affect non-target organisms, including humans and other mammals.
- They are hazardous to humans, in particular pesticide applicators and farmworkers.
- They can be highly toxic to beneficial insects, such as pollinators, predators and parasitoids.
- Both pests and non-target insects can develop resistance to insecticides.


OSU-IAEP SIR

Plate 2
Chemical control application

Pesticides should be chosen to minimize damage to humans and the environment. It is essential to read carefully the label and the manufacturer's specifications. Fungicides and insecticides are listed in Tables 1 and 2, respectively (see pp. 182–185).

COMPONENTS OF IPM

Identification of the pest

To effectively manage a pest, it must first be correctly identified. Once identified, information can be gathered on its life cycle, host range, natural enemies, environmental requirements and behaviour. In some countries, extension personnel may be available to resolve identification issues raised by the public or industry. There are various open access resources available online, and in libraries or museums. A telephone consultation with a specialist may be possible on the basis of a description of the damage and collected pest. However, the best and most reliable identification advice can be provided when a good picture or an actual specimen is submitted. Identification is a critical step before selecting any type of control.

Determination of the economic injury level (EIL)

Pest population assessment and decision-making processes are basic IPM concepts, linked to the bio-economic basis of crop production. Concepts originally proposed in the early 1960s are still used today:

- **Economic damage** – "the amount of injury which will justify the cost of control measures" – i.e. the most basic concept.
- **Economic injury level** – "the lowest population density that will cause economic damage" – a theoretical value which measures the destructive status and potential of a pest population.
- **Economic threshold** – "the population density at which control action should be initiated to prevent an increasing pest population (injury) from reaching the economic injury level" – referred to by some IPM practitioners as the actual action threshold.

Since the total eradication of a pest is almost impossible to achieve, IPM practices are designed to turn this challenge into an advantage. A realistic approach is to determine the amount of pest(s) or pest-related damage that can be tolerated by the crop while maintaining adequate levels of the desired product. The "injury level" can refer to either aesthetic injury, applied mainly to plants since it is a question of appearance rather than health (e.g. flowers, strawberries), or economic injury, i.e. pest damage causing monetary loss (e.g. white flies can cause feeding and oviposition injury and can vector serious diseases). To determine the level of action, it is necessary to make an educated guess about the likely impact of numbers of pests where economics are important. Economic thresholds are difficult to come by and vary as a function of crops, pests and location.

Monitoring

Monitoring is considered by many to be the pillar of any IPM programme. Early detection of pests and pest damage allows management decisions to be made before a problem gets out of hand. Plants should be inspected on a weekly basis in all sections of an operation. Many pest monitoring devices are available. Visual observations can be made with the naked eye or with the aid of a hand lens. Indirect observations can be made using traps (e.g. yellow or blue sticky cards for insects and spores), buckets or inverted leaf blowers – useful for winged aphids, leafminer adults, whiteflies, flies and gnats, among others. As a rule of thumb, use one to three cards per 92.9 m^2 in the greenhouse. Ensure that all the information is recorded using data sheets or modern hand-held devices.

The number of samples taken depends on the size of the operation. There are four basic patterns of sampling. Select the most appropriate depending on the pest distribution:

- Even distribution of sampling locations – if the pest is expected to be uniformly spread over the crop (e.g. mildew) – but not the edges (to avoid the so-called "edge effect").
- Sampling in quadrants (one sample per corner) – when pests are more randomly distributed (e.g. aphids, mites, thrips, foliar diseases).
- Focus sampling – when the pest is expected to be concentrated in particular areas of a field (e.g. weeds, cutworms, root rots).
- Sampling at the edges – for pests which typically make their first appearance at the edges (e.g. spider mites).

Pests respond differently to abiotic factors (e.g. temperature, humidity and photoperiod), depending on their lower or upper developmental threshold temperatures. Monitor abiotic factors daily – the information gathered can be combined with pest density and distribution data to develop prediction models to understand pest occurrence and pressure. Once the presence of pests is confirmed and their location identified, it is time to select appropriate control tactics.

GAP recommendations – Integrated pest management

Basic pest management

- Determine whether pests and natural enemies are present in an operation.
- Establish the vulnerable stages of the pest.
- Evaluate the state of plants before, during and after infestation (see "Indicators" below).
- Ascertain whether the observed damage is more or less costly than the control.
- Select a control method. If choosing a chemical control:
  - Verify whether it can be applied in combination with other means of control.
  - Read the label and regulations of pesticide use.
  - Select the pesticide least destructive against natural enemies.
  - Evaluate the level of tolerance and loss that the operation can economically withstand.

- Evaluate whether pests and natural enemies are present following treatment to gauge the degree of success or failure.
- Assess whether the treatment reduced the number of pests below the economic level.
- Evaluate what can be done to improve the effectiveness of your practices.
- Evaluate what changes can be made to improve control if the same problem occurs.

Indicators of plant condition

Plant state	Indicators of plant condition[a]			
	Leaf colour[b]	Rate of growth[c]	Damaged parts[d]	Presence of pest problems[e]
Excellent	Good	Adequate	None to few	No major ones
Good	Good	Slightly reduced	Few to common	A few minor ones
Fair	Poor	Very reduced	Common to abundant	Either major or minor Frequent occurrence
Poor	Poor	Significantly reduced	Innumerable	Both major and minor Frequent occurrence

[a] Crop dependent.
[b] Leaf shape, size and colour vary. Use healthy plant as a control.
[c] Refers to length of new growth for the season, as well as to the number of new leaves and the size of the leaves, flowers or fruit.
[d] For leafy crops, observe leaves: are there leaves with holes, spots or discolorations? For fruit crops, observe flowers, fruits size, number etc.: is damage present on the flowers or the fruits?
[e] A major pest problem is one that has seriously affected or injured the plant and requires management. Secondary pests can also be a problem warranting attention.

Source: University of Nebraska (adapted).

GAP recommendations – Integrated pest management (cont'd)

Always maintain the highest phytosanitary standards!

Preventive measures

Before planting

- Restrict the entrance of unauthorized persons inside greenhouses.
- Install vents and double doors.
- Eliminate plant residues; disinfect farm equipment, greenhouse walls and benches; place bleached mats in front of the entrance door.
- Apply soil disinfection to avoid soil pathogens and nematodes.
- Practise weed control to reduce reservoirs of pests and diseases.
- Install insect nets on vents and doors to restrict the movement of pests inside the greenhouse.
- Purchase certified transplants and/or seed.
- Select resistant or tolerant varieties.

During production

- Adopt crop rotation.
- Implement irrigation and fertilization following local recommendations.
- Eliminate previous crop residues; use clean equipment; remove weeds; follow best agricultural management practices.
- Monitor pests and diseases on a weekly basis – either directly (e.g. visual) or indirectly (e.g. sticky cards, pheromones) – before and after the implementation of selected control methods.
- Select adequate and apply timely control methods (e.g. biological, physical, mechanical, chemical).
- Use selective pesticides that will least affect non-target organisms including pollinators.
- Dispose of pesticides in an appropriate way.

DISEASES

Fungal diseases – soil-borne

Damping-off of seedlings

This disease affects all vegetable crops grown under protected agriculture. It is caused by fungi such as *Rhizoctonia*, *Alternaria*, *Sclerotinia*, *Phytophthora* and *Pythium*. They are typical soil pathogens and are transmitted by seedlings, infected soil, soil tillage, irrigation water etc. Environmental factors (temperature, humidity), extent of infestation, occurrence of mechanical damage to plants by pests and agricultural practices, and lack or excess of nutrients all affect the degree of infestation. Seedlings grown in cool, poorly drained and excessively damp substrates are the most susceptible; the disease is also observed in transplanted plants.

Symptoms:

- Watery or dark necrotic hollowed spots on the plant stem at the root neck.

Control:

- Adopt appropriate agricultural practices (e.g. use certified sterilized seeds, adopt optimal seeding density, clean debris and weeds, avoid overwatering of seedlings).
- Use healthy seedlings coming from healthy or disinfected seeds grown in sterile substrate.
- Maintain optimal soil/air temperature and humidity.
- Use chemical control when necessary (e.g. treat seedlings with a mixture of thiophanate methyl and propamocarb hydrochloride; apply biological fungicide Mycostop to prevent seed of soil-borne diseases).
- Soil disinfection: (a) chemical – use fumigants; (b) physical – employ steaming or solarization.

*Bottom-end rot (*Rhizoctonia solani*)*

Rhizoctonia solani affects many plant species worldwide, including agricultural and vegetable crops, and bottom-end rot is particularly damaging to early season lettuce and endive. *Rhizoctonia solani* is a soil-borne fungus that survives for indefinite periods. Warm, moist weather favours the development of bottom-end rot, which asppears in lettuce and endive as the heads begin to form.


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Plate 3
Bottom-end rot in lettuce

Symptoms:

- Early symptoms – brown, sunken lesions on the midribs in contact with the soil.
- As the disease progresses – infection of leaves inside the head.
- Soft rots, due to secondary decay organisms, developing on bottom-rot infection sites, resulting in collapse of the head.

Control:

- Adopt crop rotation: use non-hosts (e.g. brown mustard as an intermediate crop to reduce inoculum in the soil prior to sowing lettuce); sow a cover crop during winter adopting appropriate soil tillage.
- Plant in soil with good drainage.
- Remove all residues from previous crop.
- Avoid planting lettuce in fields with a history of bottom-end rot.
- Use chemical control when necessary (e.g. treat with flutolanil, tolclofos-methyl or mepronil).

Corky root rot (*Pyrenochaeta lycopersici*)

This is an important economic disease in tomato. It also affects other Solanaceae crops, including pepper and eggplant. Cucumber is also affected, but symptoms may not be visible, in which case it is necessary to test using polymerase chain reaction (PCR). The temperature interval for pathogen development is 8–32 °C, with an optimum temperature of around 26 °C. The fungus stays in the plant residues and in the soil for 3–4 years, where it can be found at a depth of ≤ 50 cm. Damage is greater in cold and heavy soils. Losses caused by the disease can reach 40–70%. Resistant varieties are not available. The disease affects the root system, but the initial symptoms can be observed in the above-ground parts.

Symptoms:

- First symptoms – stunting, slow growth, brightening of infected plants, young leaves becoming chlorotic.
- As the root system becomes more damaged – branches turn dark and corky with noticeable spots.
- If uncontrolled, spots increasing to cover almost the entire root.
- Withering under summer conditions.
- Fruits small and few in number.

Control:

- Use healthy certified seed and seedlings for prevention.
- Use grafted plants (e.g. rootstocks: ‘Maxifort’, ‘Beaufort’, ‘Body’, ‘Robusta’, hybrid *L. esculentum* × *L. hirsutum*).
- Maintain the pH of the soil at > 6.5–7 to depress the pathogen.
- Physical control: disinfect the soil with steam; use solarization of the soil in appropriate weather conditions and then apply bioproducts (e.g. based on *Trichoderma*).
- Chemical control: use fumigants (e.g. dazomet).

Fungal diseases – Fusarium diseases

Fusarium wilts (*Fusarium oxysporum *f. sp.* lycopersici*;* Fusarium oxysporum *f. sp.* cucumerinum*)

This disease affects tomato and cucumber grown in greenhouses. Severe damage is observed in tomato and cucumber as the pathogen blocks water causing the plant to wilt and eventually die. Some tomato varieties are resistant to this disease; resistant cucumber varieties are not available.

Favourable conditions for pathogen development are high temperatures (28 °C), high soil humidity, acidic soils and over-fertilization with ammonium nitrate. The pathogen survives in the soil for many years even when the host is not available. The disease is transferred to new seedlings: via irrigation; during soil tillage using infected tools or contaminated substrate; and by using infected seedlings. Plants can be infested at any time during their development.

Symptoms:

- First symptom – yellowing of lower leaves followed by growth delay.
- Yellowing and wilting of leaves on one side of the plant gradually spreading upwards.
- Final stage – darkening of conductive vessels observed in cross-section of stem and branches.
- Wilting and death of entire plant.

Control:

- Use disinfected/clean tools.
- Use disinfected/clean substrate (when applicable).
- Use 3–4 year crop rotation when possible.
- Select resistant varieties when available.
- Use healthy or certified seed and transplants.
- Use grafted plants (e.g. against Race 1 – 'Anchor-T', 'Survivor', 'Aegis'; against Race 2 – 'Maxifort', 'Beaufort', 'Anchor-T', 'Survivor', 'Aegis', 'Body', 'Robusta').
- Remove weeds.
- Use antagonists for biocontrol.
- Physical control: disinfect soil with steam; use solarization of the soil in appropriate weather conditions followed by application of bioproducts.
- Chemical control: use fumigants (e.g. dazomet).

Fusarium wilt of pepper and eggplant (*Fusarium oxysporum *var.* vasinfectum *(pepper),* Fusarium oxysporum *f. sp.* melongenae *(eggplant)

Fusarium wilt in solanaceous crops is caused by several different types of the fungus *Fusarium oxysporum*. *Fusarium* wilt pathogens tend to be specific to their hosts. They are warm weather organisms.

Symptoms:

- **Pepper:** decay of roots and base of stem; wilting of entire plant; base of plant becoming dark brown and sunken.
- **Eggplant:** wilting spreading from lower to upper leaves; collapse of plant.

Control:

- Control is as for tomatoes. Note that *Fusarium*-resistant varieties of eggplant and pepper are not available.

*Fusarium root and stem rot of tomato and cucumber (***Fusarium oxysporum** *f. sp.* **radicis-lycopersici***;* **Fusarium oxysporum** *f. sp.* **radicis-cucumerinum***)*

Fusarium oxysporum f. sp. *radicis-lycopersici* (FORL) has a greater host range than *F. oxysporum* f. sp. *lycopersici*. It affects not only tomato, but chilli pepper, eggplant, peanut, bean and pea, among others. *Fusarium oxysporum* f. sp. *radicis-cucumerinum* can infect cucumber, melon, watermelon and other cucurbits. The fungus can survive for several years in soil or in plant debris and develops rapidly in cool soil (17–20 °C). At higher substrate temperatures, the disease is asymptomatic. Both fungi can colonize sterile rockwool substrates in hydroponic systems.

Symptoms:

Tomato:

- Yellowing and wilting of plants, growth stunted, internal stem tissue discoloured.
- Yellowing of oldest leaves as fruit reaches maturity.
- During the warmest times of the day – wilting of infected plants, which then recover at night.
- Adventitious roots above infected parts.
- Root damage, rapid wilting and death.
- Yellowish brown discoloration of vascular tissues and rotting of roots and stem.

Cucumber:

- First symptoms 6–8 weeks after sowing – pale yellow lesions at stem base.
- Expansion of lesions causing root and stem rot.
- As disease progresses – stems colonized by fungus leading to a breakdown of cortical tissues.
- Browning and eventual death of plants, especially when grown under high temperatures.

Control:

- Use disinfected tools and substrates.
- Adopt 3–4 year crop rotation.
- Use healthy or certified seed and transplants.
- Use grafted plants (e.g. *Cucurbita ficifolia*, and *C. maxima* × *C. moschata* F1).
- Remove weeds.
- Use biocontrol using antagonists (*Fusarium oxysporum* saprobes).
- Physical control: disinfect soil with steam; use solarization of the soil in appropriate weather conditions followed by application of bioproducts.
- Chemical control: use fumigants (e.g. dazomet).

*Fusarium wilt of radish (***Fusarium oxysporum** *f. sp.* **raphani***)*

The host range of *F. oxysporum* f. sp. *raphani* is limited to radish. It survives in the soil between hosts. It can be spread by wind- or water-borne soil, or by soil carried by equipment, tools or footwear.

Symptoms:

- First symptoms – yellowing of lower leaves, sometimes one-sided or V-shaped.
- When flowering starts – wilting of plants and yellowing spreads to younger leaves.
- Death of entire plant.
- Dark brown to blackish discoloration around the vascular elements in the roots (radish bulb), followed by wilting symptoms.

Control:

- Use pathogen-free seed in pathogen-free soil.
- Remove and destroy infected plants.
- Adopt long rotations to get rid of infested ground.
- Use biocontrol with antagonists (*Fusarium oxysporum* saprobes).
- Physical control: disinfect soil with steam; use solarization of the soil in appropriate weather conditions followed by application of bioproducts.
- Chemical control: use fumigants (e.g. dazomet).

*Fusarium wilt of spinach (***Fusarium oxysporum** *f. sp.* **spinaciae***)*

Fusarium wilt, caused by the fungus *Fusarium oxysporum* f. sp. *spinaciae*, has been reported in all spinach-growing areas of the world. This soil-borne fungal disease can result in crop loss of 100%. Fusarium wilt of spinach occurs annually, when soil temperatures are 25–30 °C. It is favoured by acidic soils, and soils with a pH of around 8 tend to suppress the disease. Severe symptoms are most often found in full-size spinach. *Fusarium oxysporum* can also cause damping-off in spinach seedlings.

Symptoms:

- First symptoms – stunting, wilting of the older leaves, necrosis and plant death.
- As disease progresses – discoloration of vascular tissue of the root from white to dark brown.
- Blocking of vascular system, reducing the plant’s ability to uptake water.
- Severe wilting during the hottest part of the day – possible recovery at night of moderately infected plants.

Control:

- Use pathogen-free seed in pathogen-free soil.
- Remove and destroy infected plants.
- Use less susceptible cultivars (e.g. 'C2606', 'Sardinia', 'POH-6116' and 'Carmel').
- Select clean sites.
- Apply lime to adjust the pH to the target of 8 to suppress disease.

Fungal diseases – Verticillium diseases

*Verticillium wilt of tomato, cucumber, pepper, eggplant and strawberry (*Verticillium albo-atrum*;* Verticillium dahliae*)*

Verticillium wilt can be caused by two different soil-borne fungi: *Verticillium albo-atrum* or *Verticillium dahliae*. These fungi have a very broad host range, infecting up to 200 species of plants, including tomato, cucumber, eggplant, pepper, watermelon, artichoke, bean, strawberry, raspberry and a number of weedy plants. The pathogens are sensitive to soil moisture and temperature. Soil temperatures must be moderate or cool for infection to take place; 24 °C is the optimum temperature for disease development.

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Plate 4
Verticillium wilt of tomato

Symptoms:

Tomato (usually on lower leaves):

- Wilting during the warmest part of the day, with recovery at night.
- Characteristic V-shaped lesions at edge of leaf, spreading gradually, browning, then death of whole leaf.

Cucumber (similar to those of fusarium wilt):

- Initial symptoms – wilting of lower leaves, with recovery at night.
- As the disease progresses – development of interveinal chlorosis on lower leaves and characteristic V-shaped yellow lesions.
- Browning of vascular tissues in the stem.
- Premature death.

Pepper/eggplant:

- Yellowing and drooping of leaves on a few branches or the entire plant.
- Inward curling of leaves, followed by foliar wilting.
- Severe stunting with small leaves turning yellow–green (aggressive strains of *V. dahliaeare*).
- Browning of the vascular tissues observed in cross-section of stem.

Plate 5
Verticillium wilt of strawberry

Strawberry:

- Older leaves drooping, wilting, drying, becoming reddish yellow or dark brown at margins and between veins.
- Poor development of new leaves (few in number) and stunting of leaves.
- Stunted and flattened appearance of plants, with small yellowish leaves.
- Brown–blue or black streaks/blotches on runners or petioles.

Control:

- Use disinfected tools free of pathogens.
- Apply 3–4 year crop rotation.
- Use healthy or certified seed and transplants.
- Use resistant varieties.
- Use grafted plants (e.g. resistant rootstocks: for tomatoes – 'Maxfort', 'Beaufort', 'He-Man', 'Unifort', 'Natalya', 'Spirit'; for eggplant – *Solanum torvum*, 'Hikyaku', 'Emperador', 'King Kong').
- Remove weeds.
- Use biocontrol with antagonists (e.g. based on *Bacillus* spp. and *Trihoderma* spp. bioproducts).
- Physical control: disinfect soil with steam; use solarization of the soil in appropriate weather conditions followed by application of bioproducts.
- Chemical control: use fumigants (e.g. dazomet).

*Black root disease of radishes (***Aphanomyces raphani***)*

The pathogen attacks only radishes and infection can occur at any stage. Early infection (seedling stage) can result in plant death. Cool wet soil favours development of the pathogen.

Symptoms:

- Severe stunting and blackening of the fleshy root tissues.
- Lesions on younger roots restricting growth in that area.
- In the early stages – darkened areas small, superficial and located in the immediate vicinity of the point of emergence of secondary roots.
- "Black" tissue when the pathogen has penetrated deeply in the plant tissue.
- Dark, lead-coloured strands of infected tissue extending irregularly through neighbouring healthy white tissues.
- Severe infection – uniform blackening of internal root tissue and collapse of plant.

Control:

- Plant on a raised bed in well-drained soil.
- Use resistant varieties (e.g. ‘Fancy Red’, ‘Far Red’, ‘Sommerwunder’).
- Rotate crops.
- Minimize irrigation in cool and moist seasons.
- Apply optimal fertilization.
- Systemically remove and destroy infected plant material (including culled crops).
- Do not apply fungicides.

Fungal diseases – Stem and foliar diseases

*White mould (***Sclerotinia sclerotiorum***)*

This disease is widespread with a host range of > 400 crops and weeds. Tomato, cucumber, pepper and lettuce grown under protected cultivation are all affected.

The sclerotia (dark rounded bodies) is the infective stage, which remains in plant residues in the soil until the arrival of the next crop. The rounded bodies can survive several years in the soil. They remain dormant or quiescent during the stressful period and then germinate when conditions are more favourable. The optimum temperature for infestation is 15–20 °C.

Symptoms:

- Water-soaked lesions on stems, leaves and fruits.
- Loss of turgor and yellowing in infested plants.
- Mycelium growing from sclerotia producing a creamy mass that gradually darkens until it becomes black.

Control:

- Adopt optimal agricultural practices including appropriate plant density, regular ventilation of the facilities, humidity control.
- Apply crop rotation (crops other than tomato and green pepper may reduce levels of initial inoculum).
- Physical control: disinfect soil with steam; use solarization of the soil in appropriate weather conditions followed by application of bioproducts.
- Chemical control: use fumigants (e.g. dazomet).

*Leaf drop of lettuce and endive (***Sclerotinia sclerotiorum***)*

The pathogen attacks lettuce and endive and can be found on broccoli, cabbage, cauliflower, carrot, bean, tomato and others. The fungi can survive in soil as sclerotia or in plant debris. These sclerotia can survive in dry soil for up to 10 years. In wetter conditions, it can be less prominent after 3–4 years in the absence of a host.

Symptoms:

- Wilting of plants at various stages of maturity, outer leaves dropping to the ground while remaining attached to the plant.
- Petioles affected with fungus spreading to the centre of the head until the plant is unmarketable.
- Fluffy white mycelium and large, dark, oval or round sclerotia (observed when plant pulled up).
- Stem infections at soil level on senescent cotyledons or in leaf axils.
- Large black sclerotia, often lying in a mass of white mycelium.

Control:

- Adopt crop rotation using non-host crops (e.g. broccoli has been shown to reduce the number of sclerotia in the greenhouse).
- Physical control: disinfect soil with steam; use solarization of the soil in appropriate weather conditions followed by application of bioproducts.
- Chemical control: use fumigants (e.g. dazomet).

*White mould disease of carrots (***Sclerotinia sclerotiorum***)*

Sclerotinia disease on carrots is an economic disease in many vegetable-growing areas. Significant losses can occur during storage. The fungal pathogen has a very wide host range, including canola, sunflower, soybean, bean and several vegetable crops. Sclerotia – the hard dark resting body of certain fungi and comprising a mass of hyphal threads capable of remaining dormant for long periods – overwinter in soil and crop residue.

Symptoms:

- Early signs – water-soaked lesion at base of foliage; when humidity is high, cottony white mycelial growth on carrots and crop residue.
- During storage – rapid growth of white mycelium.

Control:

- Adopt crop rotation using non-host crops (e.g. broccoli has been shown to reduce the number of sclerotia in the greenhouse).
- Improve air movement in the crop through humidity control, weed removal, increased row-row spacing, cultivation on ridges or raised beds and removal of excess foliage between rows using mechanical cutters.
- Treat with plant protection products (biological or chemical) when necessary.

Grey mould (*Botrytis cinerea*)

This disease affects several crops in all phases of their development. The most frequently affected greenhouse crops are tomato, pepper, lettuce and strawberry. Damage in cucumbers caused by grey mould is rare and therefore of no economic importance. Infestation in protected facilities come from wounds inflicted during pruning. When conditions are favourable for pathogen development, the whole plant could be defoliated if no adequate measures are taken. Symptoms are difficult to notice (stem damage is the most conspicuous resulting in semicircular rings) and when noticed it may be too late. The optimum temperature for disease development is 22–25 °C.

Symptoms:

- In young plants – dry brown spots at bottom of stem.
- Penetration of circular system restraining sap flow, resulting in death of plant.
- Spots covered with heavy grey brown mycelium and fungus spores.
- Leaf surface of plants severely threatened by pathogen attacks when high air humidity (90%) is combined with temperatures of 13–18 °C.
- Bright brown elongated spots on petioles and top of leaves, resulting in death.

Control:

- Remove suckers – during sunny weather free of dew.
- Prune the lower leaves to open the canopy to improve air circulation and reduce humidity.
- Remove and bury infested crop residues.
- Control air humidity and ventilation.
- Increase greenhouse temperature and ventilate (especially in the morning); however, note that while this practice is effective, it has energy and environmental implications.
- Remove weeds.
- Chemical control: fungicides can provide effective control, but they should be used alternating mode of actions to avoid the buildup of resistant strains.

*Tomato downy mildew (***Phytophthora infestans***)*

This disease most commonly affects potatoes, but can also affect tomatoes under cool, over-irrigated and humid conditions. In open fields, it is observed in tomato and potato all over the world. Fungus development occurs year around. Crops under plastic can be severely affected since dew forms under such conditions. Therefore, it is not recommended to grow seedlings in such facilities. Heating greenhouses at night reduces the significance of this disease. Depending on the conditions, the incubation period is 3–10 days. Favourable conditions for this disease: over-irrigation, high relative air humidity (> 75%), overcast conditions, average day temperature around 16 °C (min. 10–12 °C; max. 18–25 °C). Retention of water drops for > 4 consecutive hours on the plant surface is a prerequisite for disease development.

Symptoms:

- Blighting on all above-ground parts of the plant.
- Dark lesions on leaves and sporangia (i.e. seeds of the pathogen) on undersides of leaves, resulting in a whitish/purplish appearance. These sporangia can be transported for long distances via wind currents or air ventilation.
- Blackened lesions on stems late in the season.
- Downy mildew on green and ripe tomato fruit.
- In fruits, dark, greasy areas that enlarge rapidly, covering the entire fruit.
- White masses (sporangia and mycelium) on leaves and fruit.

Control:

- Apply fungicides to protect transplants in the greenhouse.
- Control air humidity and ventilation.
- Remove cull or volunteer potatoes, tomatoes or petunias.
- Chemical control: fungicides can provide effective control, but use in rotation to avoid buildup of resistant strains.

*Cucumber downy mildew (***Pseudoperonospora cubensis***)*

This disease affects cucurbit crops such as cantaloupe, cucumber, pumpkin, squash and watermelon. It is an important pathogen, especially in areas with high humidity, and one of the most important diseases in cucumber production. It is a highly destructive foliar disease where successful breeding for resistance provides a control alternative. The optimum temperature for infestation is 16–22 °C. The disease is exacerbated by high humidity as found in structures with a plastic coating.

Symptoms:

- Early symptoms – angular yellow spots on upper leaf surfaces of lower and older leaves.
- Spots on undersides of leaves.
- Purple–grey fungal growth with high relative humidity or moist conditions.
- As the disease progresses – enlarging of yellow spots, becoming necrotic or brownish until the whole leaf burns.

Control:

- Use resistant varieties (e.g. 'Palermo F1', 'SV3462CS' and 'SV4719CS', 'Diva', 'Tasty Jade', 'Marketmore 76', 'Olimpian', 'General Lee F1', 'Amiga F1', 'Jackson Classic F1').
- Adopt crop rotation with non-hosts (e.g. non-Cucurbitaceae family species).
- Increase ventilation and control irrigation to reduce humidity.
- Increase night temperatures if possible, to prevent condensation on leaves.
- Adopt chemical control, as this is an aggressive and destructive disease. Apply both contact and systemic products. Fungicides are most effective when applied prior to infection and reapplied at 5- to 7-day intervals.

*Phytophthora blight of pepper (***Phytophthora capsici***)*

Phytophthora blight is an important disease worldwide. It damages mainly pepper and to a lesser extent eggplant and tomato. The fungus develops at an optimum temperature of 25 °C. The pathogen usually attacks the root system and lower leaves. The fungus may be air-borne or can also enter the greenhouse via infected seedlings or soil from infested areas. Hydroponic system production is particularly prone to the rapid spread of *P. capsici* zoospores (motile asexual spore that uses a flagellum for locomotion). Adding a non-ionic surfactant to the nutrient solution can eliminate zoospores and help achieve 100% control of the spread of the root pathogen. It is mostly found where water pools or splashes.

Symptoms (depend on crop and involve roots/crowns/leaves/fruits):

- Lesions on lower stems resulting in rapid death.
- Development of crown or fruit rot, and/or foliar lesions on mature plants (most common symptoms are crown and fruit rot regardless of host).
- Pepper: black lesion just above soil line; wilting and progressive death.
- Rotting of fruit, particularly if fruit are in direct contact with soil.
- Dark and concentric lesions, but not in pepper, where rot appears as moist, cream-coloured suppressed growth.
- No symptoms at harvest of fruit infected in greenhouse, but rotting a few days later, resulting in substantial economic losses.

Control:

- Clean and disinfest greenhouses at the end of the growing season.
- Use resistant varieties (e.g. 'Paladin', 'Aristotle', 'Revolution', 'Conquest', 'Declaration', 'Emerald', 'Isle').
- Use certified seed.
- Grow pepper on raised beds and in well-drained soils.
- Disinfect hydroponic systems at the end of vegetation.
- Use chemicals when needed. Always check local recommendations.

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Plate 6
Lettuce downy mildew

Downy mildew of lettuce and endive (**Bremia lactucae*****)***

This pathogen affects lettuce in both protected facilities and the open field. It also affects many other plants, including *Centaurea*, *Cineraria*, *Gaillardia* and globe artichokes. The disease develops rapidly under wet, cool conditions with moisture on the leaves. The spores germinate at approximately 10 °C.

Symptoms:

- Chlorotic spots on leaves limited by the veins.
- Underside of leaf covered by loose, white coating (the spores of the fungus).
- Similar spots on leaves and stalks, becoming necrotic.
- Browning and eventual death of infected tissues.

Control:

- Use resistant varieties when available (e.g. 'Adriana', 'Harmony', 'Nancy', 'Optima', 'Red Cross', 'Bamby', 'Claremont', 'Defender', 'Green Star', 'Antago', 'Garrison', 'New Red Fire').
- Disinfect seeds.
- Use certified seed.
- Maintain optimal air humidity regime (night temperature of 4–6 °C and day temperature of 6–10 °C; humidity around 70%).
- Manage irrigation to reduce leaf wetness and humidity to reduce severity of the disease.
- Use chemicals when needed. Check local recommendations.

Plate 7
Onion downy mildew

*Downy mildew of onions (*Peronospora destructor*)*

Downy mildew is a major disease in onions, but it rarely damages chives and leeks. The pathogen can persist as mycelium, systemically infecting onion bulbs in the soil for several years as oospores (thick-walled sexual spore that develops from a fertilized oosphere), but it is not transmitted by onion seed. Under moist conditions, the pathogen sporulates on the affected tissues and spreads to other plants. The disease developes rapidly in cool, wet weather. The optimum temperature for sporulation is 7–15 °C.

Symptoms:

- Grey–violet local lesions on leaves and stalks.
- Death of infected leaves.
- Yield poor and quality compromised by the presence of distorted bulbs.

Control:

- Rotate crops (3 years).
- Use of healthy bulbs for planting (heat treatment eliminates the pathogen).
- Ventilate the facility.
- Remove and destroy crop residues at the end of the cropping season.
- Apply balanced N fertilization.
- Apply optimal plant density.
- Treat bulbs for planting with fungicide and spray the foliage with fungicide if infection is observed.

*Downy mildew of radishes and Brassicaceae (*Peronospora parasitica*)*

The disease affects both seedlings and mature plants. It penetrates the tissues under wet cool conditions and spreads to other Brassicaceae by wind and rain. The pathogen is more prevalent in the spring, affecting young plants in greenhouses. This disease is specific to brassicas, including cabbages, cauliflowers, Brussels sprouts, radishes, swedes and turnips, as well as some ornamental and wild relatives.

Symptoms:

- Yellowish patches of discoloration on upper surfaces of leaves, often angular and limited by veins.
- On the corresponding lower surface, fuzzy whitish outgrowth of pathogen.
- Shrivelling, death and drop of affected tissues.
- Leaf damage accompanied by internal browning of tissue.

Control:

- Remove wild host plants (e.g. shepherd's purse *Capsella bursa-pastoris*, member of the Mustard family).
- Remove and destroy infected material to avoid resting spores contaminating soil.
- Use crop rotation.
- Maintain optimal air humidity regime.
- Use watering methods that will not wet the leaves.
- Use balanced N fertilization.
- Use chemicals when needed. Check local list for recommendations.

Downy mildew of spinach (Blue mould) (**Peronospora farinosaf.** ***sp.*** **spinacae*****)***

Downy mildew is a very common and destructive disease of spinach during cool, wet conditions. The pathogen is disseminated by wind and splashing. The pathogen survives on dead spinach plants, crop residues, volunteer spinach and some weeds, and in infested seed.

Symptoms:

- First symptoms – pale yellowish spots with a grey to purple downy growth on leaf undersides, especially during wet weather.
- Coalescing of individual lesions.
- Stunting or death of severely infected plants.

Control:

- Use resistant varieties (e.g. 'Admiral F1', 'Avon F1', 'Baker F1', 'Carmel', 'Catalina F1', 'Hunter', 'Melody', 'Olympia', 'Scarlet').
- Rotate crops.
- Ventilate to reduce humidity and leaf wetness.
- Remove and destroy infected material to avoid contaminating the soil with spores.
- Maintain optimal air humidity regime.
- Use watering methods that will not wet the leaves.
- Use chemicals when needed. Check local list for recommendations.

*Early blight (*Alternaria solani*) of tomato*

Early blight is the most widespread and frequent disease in tomato and other solanaceous crops grown under protected agriculture. The optimum temperature for development is 26–28 °C. A prerequisite for disease development is high relative humidity of the air. The pathogen prefers older leaves and the most susceptible stage is during fruit formation.


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Plate 8

Early blight of tomato

Symptoms:

- Small, watery spots on oldest leaves and later on whole plant.
- Enlargement of spots, developing concentric, target-like rings.
- Spots developing on fruit and stems, potentially covering the entire plant.
- Spots on fruits starting at pedicels, causing dropping of fruits and consequent yield loss.

Control:

- Disinfect seeds.
- Remove and destroy crop debris at the end of the vegetation.
- Use disinfected substrate.
- Ventilate properly in order to adequately manage temperature and humidity in the facility.
- Use chemicals when needed. Check list of local recommendations.

*Purple blotch of onion (*Alternaria porri*)*

Purple blotch in onion is caused by *Alternaria porri.* This fungus is also a pathogen of leek, garlic and chive. The initial infection is from previous crop debris and is favoured by high temperatures and humid conditions. The optimum temperature for development is 21–30 °C.


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Plate 9

Purple blotch of onion

Symptoms:

- First symptoms – small, water-soaked lesions with white centres on older leaves.
- As the disease progresses – spreading of lesions, becoming purplish with light yellow concentric rings on the margins.
- As severity increases – leaves turning yellow–brown and wilting.

Control:

- Use healthy seedlings.
- Remove plant debris and eradicate wild plants.
- Use balanced N fertilization.
- Ventilate properly the facility.
- Apply optimal plant density.
- Use chemicals when needed. Check list of local recommendations.

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Plate 10
Black rot of carrot

***Black rot of carrot* (Alternaria radicina)**

Alternaria radicina is widespread in carrot crops. It is known to cause black rot of carrot roots and also foliage blight. Other hosts are celery, parsley and parsnip. Disease development requires high humidity. It is transmitted by seed and soil. Infection can develop even at 0 °C.

Symptoms:

- Dry black rotting of both crown and root.
- First symptoms – at base of petiole, dark, usually shallow, lesion spreading into crown and moving to the root.
- When severely damaged – withering, covered with olive black patches of conidia (chlamydoconidia are asexual, non-motile spores, asexual “chlamydospores”).
- Development of lesions below ground coinciding with cracks.
- Development of dry mealy rot during storage.

Control:

- Use healthy and treated seeds.
- Rotate crops.
- Remove diseased plants and eradicate wild plants.
- Ventilate properly the facility.
- Use chemicals when needed. Check list of local recommendations.

*Alternaria leaf spot (Black spot, Grey spot) (***Alternaria brassicae***) of kale*

Hosts are all Brassicas including wild species and ornamentals. Development is favoured by cool wet conditions.

Symptoms:

- Early symptoms – small dark spots on leaves turning brown to grey.
- Round or angular lesions, sometimes with purple–black margin.
- Later stages – lesions forming concentric rings, becoming brittle and cracking in the centre.
- Development of dark brown elongated lesions on stems and petioles.

Control:

- Use healthy pathogen-free seed.
- Rotate crops.
- Use chemicals when needed. Check list of local recommendations.

*Leaf mould (***Fulvia fulva***)*

Leaf mould affects mainly tomato. Mycelium and spores of this disease overwinter in plant residues in the soil. The conidiospores can survive in greenhouses. Spreading is favoured by airflows. The spores germinate in high air humidity (> 95%). Optimum temperature for pathogen development is 20–25 °C. The disease is not common on the fruit. In the absence of control and immediate intervention, the foliage can be severely damaged, resulting in significant yield losses. Resistant varieties are available. Check with your local seed company.

Symptoms:

- Large, pale irregular-shaped spots and unclear margins on upper leaf side.
- Infected tissue becoming yellowish brown, withering of leaves which eventually fall off the plant.
- Withering and death of whole plant.

Control:

- Remove and destroy crop residue at the end of the vegetation.
- Ensure good ventilation.
- Regulate temperature and humidity.
- Use resistant varieties.
- Use chemicals if needed. Check local recommendations.

*Powdery mildew of tomatoes (***Leveillula taurica** *and* **Oidium neolycopersici***)*

Tomato grown under protected agriculture is mildly affected by powdery mildew *Leveillula taurica*. The other powdery mildew *Oidium neolycopersici* is more prevalent and damaging in autumn–winter and it is very important for tomatoes in protected cultivation. Optimal conditions for *Leveillula taurica* are temperature > 25 °C and humidity < 60%; it is typical of the arid areas of the Mediterranean region. Optimal conditions for development of *Oidium neolycopersici* are temperature 25 °C, relative humidity 70–85% and poor light.

Symptoms:

***Leveillula taurica*:**

- First symptoms – bright yellow spots on lower leaves.
- Spots enlarging and eventually turning brown.
- As infection progresses – withering and death of entire leaf, which remains attached to the stem.
- No symptoms on stems or fruits.

***Oidium neolycopersici*:**

- Above-ground plant parts affected; fruits not affected.
- Development of disease on upper leaf surface without penetrating the mesophyll.
- Spots with loose, white coating on affected tissues.
- Severe infestation producing leafy chlorosis, premature ageing and decreased fruit quality.

Control:

- Use resistant varieties (e.g. ‘Granadero F1’, ‘Massada F1’, ‘Olivade F1’).
- Increase air humidity.
- Use chemicals if needed. Check local recommendations.

*Powdery mildew of greenhouse peppers (***Leveillula taurica***)*

This disease affects pepper, tomato and eggplant. Its development can be observed throughout the season and is favoured by dry and hot weather (25 °C) and low relative air humidity (60%). It develops mainly in the second half of the summer and in the autumn during dry and hot days. Spores can be in the facility or directly in plant residues in the soil; they spread by airflow.

Symptoms:

- Small, light, yellowish angular spots on upper leaf side, at times limited by veins.
- Underside of leaves covered with loose, white fungous coating from spores.
- Later stages – development and merging of spots.
- Spore coating on upper side.
- Dropping of infected leaves and, in severe cases, loss of all leaves.

Control:

- Grow resistant varieties.
- Increase air humidity in protected facilities.
- Treat with bioproducts when necessary.

Powdery mildew of cucumbers (**Podosphaera xanthii*****)***

This disease is widespread in protected facilities and in open fields. Infestation is observed on the leaves and stalks, more rarely on the stems. Favourable conditions for progress are: inconsistency in the temperature–humidity regime (decreased soil and air humidity, temperature fluctuations); unbalanced nitrogen fertilization; decreased lighting. It is more prevalent in greenhouses during the winter months (Dec.–Jan.). Plants close to the doors and vents are more susceptible, due to temperature fluctuations. Optimum temperature for development is 23–26 °C.

Symptoms:

- First symptoms – small angular-shaped spots on leaves.
- "White coat" or powdery coating resulting from proliferation of spores.
- Later stage – emergence of spots and burning of leaves. Spots on both top and underside of upper and lower leaves and on leaf stalks – sometimes on stem, but without causing serious damage.
- In strong infestations – plants leafless, fruits small and deformed, yield strongly reduced.

Control:

- Grow resistant varieties (e.g. 'Delano F1', 'Euphya F1', 'Kalunga F1', 'Defens F1', 'Hudson F1', 'Pasandra F1', 'Rodeo F1', 'Jazzer F1', 'Ekron F1', 'Palermo F1', 'Tribuno F1', 'Vigorex F1').
- Eliminate plant residues from the previous vegetation.
- Apply balanced nitrogen fertilization.
- Maintain optimal temperature–humidity regime.
- Treat first symptoms with chemical and biological products (Masheva *et al.*, 2012).


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Plate 11
Strawberry powdery mildew

*Powdery mildew of strawberries (***Sphaerotheca macularis***)*

Powdery mildew prefers dry and warm conditions. This pathogen tends to cause more problems in greenhouses and high tunnels. It affects both yield and quality. It infects wild and cultivated strawberry, affecting leaves, flowers and fruits.

Symptoms:

- First symptoms – small, white powdery colonies on undersides of leaves.
- Enlargement of colonies to cover entire underside of leaf, causing edges of leaves to curl.
- Purple reddish blotches on top and underside of leaves.
- Deformed fruit produced by infected flowers.
- Severely infected flowers – completely covered by mycelium and later killed.
- Infected fruits hardened and desiccated.

Control:

- Grow resistant varieties (e.g. ‘Hood’, ‘Totem’, ‘Benton’).
- Remove leaves from transplants during harvest and packing.
- Apply balanced nitrogen fertilization.
- Avoid overhead irrigation.
- Apply fungicides at the first sign of disease.
- Apply native sulphur or insecticidal soap (acceptable practice on organically certified strawberries).

*Powdery mildew of carrot (***Erysiphe heraclei***)*

This pathogen affects members of the Apiaceae family, including carrot, parsnip, parsley, dill and wild carrot. Some cultivars (e.g. ‘Nantes’ and ‘Imperator’) are more susceptible. Weed hosts have not been observed. The disease appears typically in summer and autumn, affecting foliage, stems and umbels or flower clusters.

Symptoms:

- Patches of white fluffy mycelium on lower leaves, spreading to upper leaves.
- Entire leaves covered with white mycelium and powdery spores.
- Infected foliage brittle, turning brown, shrivelling and dying.
- Diseased pedicels turning brown, resulting in premature death of florets.

Control:

- Remove leaves from transplants during harvest and packing.
- Apply balanced nitrogen fertilization.
- Avoid overhead irrigation.
- Apply fungicides at the first sign of disease.

Powdery mildew of lettuce (**Erysiphe cichoracearum*****)***

The host range is broad, ranging from different wild Asteraceae species and Lactuca species to cultivated species. Powdery mildew on lettuce can seriously affect quality. This disease is favoured by warm and dry conditions. Spores are dispersed in the air via wind currents. On cultivated lettuce in greenhouses, symptoms of powdery mildew infection are typically observed on 7- to 8-week-old plants.

Symptoms:

- White, powdery growth on both sides of the leaf.
- Small circular pustules on leaves, gradually enlarging, coalescing and converging to cover entire leave surface.
- Affected tissue chlorotic and leaves deformed.
- Severely infected leaves necrotic, drying out and dying.
- Retarded plant growth, even causing plant death.

Control:

- Grow resistant varieties (e.g. ‘Jericho’).
- Eliminate the plant residues from the previous crop.
- Maintain optimal regime for temperature and humidity.
- Treat with plant protection products at the appearance of the first spots.

Septoria blight of endive (**Septoria lactucae*****)***

The disease affects not only endive, but lettuce and escarole. *Septoria lactucae* survives in lettuce seed, crop debris and on wild lettuce hosts. It is spread by splashing water.

Symptoms:

- Early symptoms on older leaves, consisting of small, irregular chlorotic spots.
- Lesions enlarging, turning brown, drying out and falling, giving the leaves a tattered appearance.

Control:

- Use disease-free seed.
- Avoid overhead irrigation.
- Plough plant debris into soil after harvest to hasten decomposition.
- Rotate crops.
- Control wild lettuce weeds.
- Avoid working in fields when plants are wet.
- Apply fungicides at the first sign of disease.

*Anthracnose of strawberry, lettuce and endive (***Colletotrichum acutatum, Microdochium panattonianum***)*

Colletotrichum acutatum has a very wide host range but is of economic importance for strawberries (*Fragaria ananassa*). It affects mainly mature fruits. Infected plants and soil are the primary source of inoculum. Disease is dispersed in the field by wind-driven rain, splashing water, insects and workers. Disease spreads and develops in cool and dry conditions. The spread of the disease is often so rapid that by the time symptoms are noticed, the crop is in serious danger. *Microdochium panattonianum* affects lettuce and endive plants. Fungus survives in crop debris in soil.

Symptoms:


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Plate 12
Anthracnose of strawberry

Strawberry:

- Fruit and petiole rotting, with sunken, water-soaked enlarged spots covering the whole fruit within 2–3 days.
- Fruits turning dark brown, producing pink spore masses.
- Leaves: small brown and/or blackish spots forming on edges and apex of leaf blade.
- Flowers and flower buds: rapid withering and collapse; dark tissue gradually moving down the stalk.
- Fruits: light brown water-soaked spots becoming brown–black.

Lettuce:

- Small water-soaked spots on outer leaves.
- Spots – usually irregular and angular in shape – enlarging, turning yellow.
- Centres falling out of mature lesions giving the plant a shot-hole appearance.
- Under cool, moist conditions – white to pink spore masses on lesions.

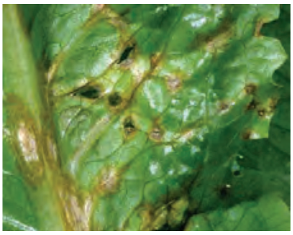
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Plate 13
Anthracnose of lettuce

Endive:

- Small circular or irregularly shaped, grey to straw-coloured, dry spots, on leaves.
- Death of leaf when spots are numerous.
- Lesions coalescing to form large necrotic patches causing leaves to turn yellow and wilt.
- Lesions splitting or cracking in dry centres.

Control:

- Grow resistant varieties (e.g. strawberry – 'Sweet Charlie', 'Bish'; lettuce – 'Hyper Red Rumple Waved', 'Merlot', 'Red Deer Tongue').
- Eliminate plant debris.
- Apply balanced nitrogen fertilization.
- Maintain optimal growing conditions for temperature and humidity.
- Apply chemical treatment of soft fungicides (e.g. thiophanathe metyl or azoxistrobin).

Anthracnose of spinach (**Colletotrichum** *spp.)*
The fungus survives as a mycelium in infected plant debris. Wet conditions, along with dense leaf canopy limits air movement and favours infection and disease development.

Symptoms:

- Initial symptoms – small, circular, water-soaked lesions on young and old leaves.
- Lesions enlarging, turning chlorotic and then becoming brown to tan in colour.
- Brown lesions becoming dry, thin and papery in texture.
- Lesions coalescing, resulting in blighting of foliage.

Control:

- Use disease-free seed.
- Remove plant debris from the previous crop.
- Avoid sprinkler or overhead irrigation when possible.
- Maintain optimal temperature–humidity regime.
- Apply chemical control at first sign of spots on leaves.

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Plate 14
Bean anthracnose

*Anthracnose of beans (brown spot) (***Colletotrichum lindemuthianum***)*

Anthracnose is an important fungal pathogen of bean, *Phaseolus vulgaris*. It affects yield, seed quality and marketability. Hosts include beans, pea, lentil, vigna and soybean.

Symptoms:

- Cotyledons: small, dark brown to black lesions.
- Petioles, leaves and leaf veins on older plants: small, angular, brick red to purple spots, becoming dark brown to black.
- Pod: flesh- to rust-coloured lesions; in periods of low temperature and high moisture, lesions may contain a gelatinous mass of pale salmon pink conidia; at the severely infected stage, young pods shrivel and dry up; the fungus can invade the pod, and infect the cotyledons or seed-coat of the developing seeds.

Control:

- Use pathogen-free seeds.
- Adopt crop rotation using non-susceptible crops (e.g. ‘Advantage’, ‘Boone’, ‘Caprice’, ‘Dart’, ‘Espada’, ‘Matador’).
- Remove plant debris from the previous crop.
- Maintain optimal growing regime for temperature and humidity.
- Chemical control: treat at first sign of leaf spots.

*Bean rust (***Uromyces appendiculatus***)*

Hosts include various species of *Phaseolus*, vigna and soybean. Wet and cool weather conditions during flowering and pod formation are conducive to development of this disease. The disease cycle may be repeated every 10–14 days under favourable conditions during the growing season. Leaves are generally affected, but green pods, and occasionally stems and branches, may also become infected and develop typical rust pustules. However, bean rust is not seed-borne.

Symptoms:

- Small white specks under leaf epidermis.
- Rust-coloured pustules mainly on underside of leaf and surrounded by a circle of chlorosis.
- Elongated pustules on pods, stems and petioles.
- Pustules blackening as teliospores form and overwinter, usually on older leaves.
- Leaves curling upwards, drying up, turning brown and dropping prematurely.

Control:

- Rotate crops.
- Remove plant debris.
- Use resistant varieties (e.g. 'Boone', 'Concesa', 'Crockett', 'Jade Lewis', 'Hickok').
- Maintain optimal temperature–humidity regime.
- Chemical control: apply treatment at first sign of the disease.

*White rust on radish (***Uredo candida***)*

Uredo candida causes white rust or white blister diseases in above-ground plant tissues. Hosts are beet (garden and sugar), Brussels sprouts, cabbage, Chinese cabbage, cauliflower, collard, garden cress, kale, lettuce, mustard, parsnip, radish, horseradish, rape, salsify, spinach, sweet potato, turnip, watercress and water-spinach. Autumn and spring conditions favour the dispersal and consequent infection of white rust. New infections form and spread under cool, moist conditions.

Symptoms:

- Chlorotic lesions and galls on upper leaf surface with corresponding white blister-like dispersal pustules of sporangia on underside of leaf.
- Branches and flower parts deformed.

Control:

- Minimize irrigation under cool and moist conditions.
- Remove infested plants, culls and weeds that can served as alternative host.
- Use resistant varieties when available.
- Use chemical treatment when necessary.
- Apply balanced fertilization.

Bacterial diseases

Bacterial canker (*Clavibacter michiganense *subsp.* michiganensis*)

The main host of economic importance is tomatoes, but the pathogen has also been reported on other *Lycopersicum* spp. and on wild Solanaceous plants. The main source of infestation is infected soil through plant residues from infected plants and seeds. The bacteria penetrate in the plants through wounds caused by pricking, transplanting or soil tillage. The strongest infestation in tomatoes in the greenhouse is observed during pruning of the crop. The incubation period depends on the variety and conditions of the environment and varies from 13 to 38 days. There are very few resistant varieties. Losses caused by the disease vary from 20 to 80%.

Symptoms:

- Early symptoms – wilting, followed by drying up of leaf blades situated on same side of leaf petiole. Remaining blades stay fresh and green, with leaf petiole twisting in direction of withered blades.
- Long cracks on leaf petioles (i.e. the damaged conducting vessels).
- Upper layers progressively covered.
- Fruits penetrated through the fruit stalks causing the conducting vessels to darken.

Control:

- Apply 3-year crop rotation.
- Grow resistant varieties when available.
- Use healthy, disinfected seeds.
- Sow seeds in sterile substrate.
- Use soil solarization.
- During pruning, avoid making or touching wounds.
- Disinfect agricultural tools by soaking them in a 2–3% solution of copper sulphate.

Bacterial wilt (*Pseudomonas solanacearum *syn.* Ralstonia solanacearum*)

There are numerous hosts that can stay for a long period in the host rhizosphere. Infestation begins through root wounds caused mainly by agricultural practices. The bacterium moves from the root to the vascular system of the plants destroying it. Infected plants wither and die. The pathogen penetrates the fruit through the fruit stalks where it can also infect superficially the seed. Pathogen transfer can be facilitated by pruning. The temperature and humidity regime in protected facilities contribute to disease development. The bacterium is susceptible to acid medium. It develops at 35–37 °C.

Symptoms:

- Early symptoms – yellowing of leaves.
- Conducting vessels becoming brown but not destroyed; exudate flowing from vessels if vascular system pressured.
- Difficulty for plant sap to move in infected plants, resulting in formation of additional adventitious aerial roots.
- Fruits from infected plant light and milky white.
- Weakened connection with fruit stalk, falling easily when touched.

Control:

- As for bacterial canker.

Angular leaf spot (*Pseudomonas syringae *pv.* lachrymans*)
This disease affects cucumber grown under protected agriculture and in the open field. It also affects watermelon, melon and pumpkin. The bacterium stays in the soil for 2 years. In wet weather, water drops transmit the pathogen. The incubation period is 5–6 days. The disease penetrates fruits through wounds. The bacterium can survive in the seeds for up to 3 years. Infected seeds are a serious source of infestation.


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Plate 15
Angular leaf spot

Symptoms:

- Leaf: Small water-soaked, yellowish spots with angular shape, limited by veins; in wet weather, small droplets of bacterial exudates on underside of leaves; as concentration of bacteria increases, the centre burns and falls off; angular-shaped, perforated spots on leaves.
- Fruit: Bacteria penetrate deeply in the tissues reaching and infecting the seed; fruits die as a result of wet rot.
- Cotyledon: Greasy spots germinated from infected seeds appear; they cover the cotyledons and the plants die.

Control:

- Use resistant varieties (e.g. ‘Ashley’, ‘Cobra’, ‘Cortez’, ‘Diamante F1’, ‘Diva F1’, ‘Green Finger F1’, ‘Impact’, ‘Python’).
- Apply 2-year crop rotation.
- Grow seedlings in isolated, disinfected facilities.
- Disinfect the soil in protected facilities.

- Reduce air humidity to 80–90%.
- Remove and destroy infected leaves upon appearance of the first spots.
- Treat the remaining plants with chemical products containing copper.

Halo blight (*Pseudomonas savastanoi *pv.* phaseolicola*)

Halo blight of bean is a bacterial disease caused by *Pseudomonas savastanoi* pv. *phaseolicola*. The main hosts are lima bean, red kidney bean, cranberry yellow eye field bean, snap bean, scarlet runner, kudzu vine and common bean *Phaseolus vulgaris*. The development of the pathogen is highly favoured by cool temperatures – unlike other common bacterial blights.

Symptoms:

- Small water-soaked spots on leaves.
- Spots gradually turning dark brown and surrounded by a wide greenish yellow halo.
- Necrotic spots small – unlike in common blight.
- Water-soaked spots on vegetative pods.
- When lesions become severe on pods – wrinkling of seed and formation of yellow patches on seed-coat.
- If disease spreads – curling, yellowing and eventual death of young leaflets.

Control:

- Use resistant varieties (e.g. ‘Boone’, ‘Cabot’, ‘Capris’, ‘Contesa’, ‘Crocket’, ‘Lewis’).
- Apply 2-year crop rotation.
- Remove infected material from the greenhouse.
- Apply chemical control based on copper products.

Bacterial soft rot of carrots (*Pectobacterium carotovorum *subsp.* carotovorum*)

Pectobacterium carotovora is a soil-borne bacterium. It has a wide host range, including carrot, potato, tomato, leafy greens, squash and other cucurbits, onion, and green pepper. The bacterium enters carrots through wounds. High humidity and temperatures around 30 °C favour development and decay.

Symptoms:

- Soft, watery, slimy decay of the root.
- Fast decay surrounding core of carrot, epidermis remaining intact.
- Foul odour from decayed tissue.
- Yellowing, wilting and collapse of leaves.

Control:

- Grow in well-drained soil.
- Rotate crops.
- Avoid injury to plant tissues.
- Apply balanced fertilization.
- Apply optimal irrigation.

Bacterial soft rot of endive (**Erwinia** ***spp.)***

This bacterium is a common pathogen on lettuce, endive and chicory. It affects most vegetable crops and some weeds. Bacteria are easily spread through infected tools and by irrigation water. Disease emergence and development is favoured by warm and moist conditions. Bacteria enter the plant through wounds.

Symptoms:

- Water-soaked lesions.
- Lesions expanding to form large rotted mass of cream-coloured tissue on leaves.
- Cracking of lesions, which exude a slimy liquid turning tan, dark brown or black when exposed to the air.

Control:

- Rotate crop.
- Plant in well-draining soils or raised beds.
- Harvest heads when they are dry.
- Avoid damaging heads during harvest.

Black rot (leaf spot) on kohlrabi and kale (**Xanthomonas campestris*****)***

Black rot is one of the most destructive diseases of crucifers. Cauliflower, cabbage and kale are among the crucifers most susceptible to black rot. Broccoli, Brussels sprout, Chinese cabbage, collard, kohlrabi, mustards, rape, rutabaga and turnip are also susceptible. Several cruciferous weeds are also hosts. In warm and wet conditions, black rot losses may exceed 50% due to the rapid spread of the disease. The disease is prevalent in areas where plants remain wet for long periods. The pathogen spreads via infected seed or by splashing water and insect movement. Symptoms can be observed in plants at any plant growth stage.

Symptoms:

- Wilting of plant parts and leaves turning yellow–brown.
- Yellow, V-shaped lesions on mature leaf margins.
- Dark rings visible in cross-section of stem.

Control:

- Use certified pathogen-free seed.
- Treat seed with hot water.
- Rotate crops every 2 years or less (non-brassica).
- Use resistant varieties when available.
- Control cruciferous weed.
- Control insects.
- Avoid sprinkler irrigation.

Common scab of radishes (**Streptomyces scabies*****)***

Streptomyces scabies can infect tuber and tap root crops. It causes common scab on potato, beet, carrot, parsnip, radish, rutabaga and turnip. The disease can live on plant debris decomposing in the soil and does not require a host to remain alive.

Symptoms:

- Brown–yellow circular irregular lesions on roots.
- Lesions eventually merging and affecting the plant through tissue cracks.
- Lesions erumpent, russet and pitted.
- Lesions swollen and defined as superficial corky tissue covering the tuber surface.
- Pitted lesions dark in colour and found on surface or deep inside tissue.
- Scab lesions on tuber surface; scab affecting young tubers and lesion expanding as tuber matures.
- More than one type of lesion present on a single tuber.

Control:

- Include crops other than root crops in rotation schemes.
- Avoid soils with high pH; if necessary, lower the pH by using acid-producing fertilizers such as ammonium sulphate. Avoid or limit the use of alkaline-producing amendments, such as lime, ashes, fresh barnyard manure, fertilizer or other materials that increase the soil's alkalinity (pH 5.2 is sufficient to prevent development of the scab organism).
- Use resistant cultivars when available.
- Apply optimal irrigation.

Viral diseases

Tomato mosaic virus (ToMV)

The disease is caused by specific races of ToMV. There are more than 150 host species, including vegetables (tomatoes, peppers and others), flowers and weeds. The virus can survive in dry leaves for 25 years. It is seed-transmitted. Infected leaves and roots debris are the common sources of inoculum. It can also be spread by contaminated tools and the clothing and hands of workers during routine activities. Low temperatures, poor light and high nitrogen content in the soil are favourable prerequisites for development of the disease. Temperature over 30 °C, high light intensity and high phosphorus and potassium rates in the soil delay development of the disease. The incubation period is 10–14 days.

Symptoms:

Tomato (symptoms influenced by environment):

- Mottling on leaves, with alternating yellowish and darker green areas.
- Leaves fern-like in appearance with pointed tips; younger leaves twisted.
- Fruit distorted, with yellow blotches and necrotic spots on both ripe and green fruit.
- Internal browning of fruit wall.
- Dwarfing of entire plant and discoloration of flowers.

Pepper:

- Mosaic-type symptoms on top leaves and deformation.
- Fruits smaller with a rough surface.
- Delayed growth.
- Black long necrotic strips on the tops, ultimately causing wilting of vegetative apex.

Control:

- Use resistant cultivars (e.g. ‘Armando F1’, ‘Barbarian F1’, ‘Big Beef F1’, ‘Brillante F1’, ‘Celebrity F1’, ‘Golden Rave F1’, ‘Hermosa’, ‘Maxifort F1’, ‘Primo Red F1’, ‘Sakura F1’, ‘Samurai F1’, ‘Mamirio F1’, ‘Gravitet F1’, ‘Panekra F1’, ‘Sprigel F1’, ‘Parvati F1’, ‘Belle F1’, ‘Vedetta F1’, ‘Velasco F1’, ‘Mondial F1’, ‘Monroe F1’, ‘Buran F1’, ‘Velocity F1’, ‘Rally’).
- Use healthy seeds and planting material.
- Use heat-treated seeds when growing susceptible varieties.
- Remove plant debris and weeds.
- Before and during the handling of the seedlings, wash your hands with soap to inactivate the virus.

Cucumber mosaic virus (CMV)

The virus has a large range of hosts (1 200 species) including cucurbits, pepper, tomato, spinach, lettuce, bean and celery. Most damage to tomato and pepper is in the open field. The disease is associated with the vector: leaf aphids. There are over 200 species of aphids. Among them, the common peach leaf aphid. The virus cannot be transmitted by seeds, by contact or by the soil; it cannot survive in the plant debris. During the off-season, the virus survives on weed hosts.

Symptoms:

- Cucumber: first symptoms visible at early crop development as uppermost leaves of infected plants show mosaic-type damage and later curl; plants become small, the internodes short, fruits small.
- Tomato: uppermost leaves show mosaic-type damage, sometimes strongly deformed, elongated, reduced or fibrillar; filamentary or shoestring-like leaf blades are very characteristic of CMV, and should not be confused with symptoms of ToMV; severely affected plants produce few fruits – small, often mottled or necrotic, with delayed maturity.
- Pepper: mosaic-type damage on leaves, which become deformed since the central nerve becomes a zig-zag; plants experience growth delay and internodes shorten; fruits are deformed and sometimes show ring-shaped necrosis.

Control:

- Grow resistant varieties (e.g. ‘Amiga F1’, ‘Cobra’, ‘Concquistador’, ‘Impact’, ‘Python’, ‘Turbo F1’, ‘Delano F1’, ‘Defense F1’, ‘Hudson F1’, ‘Jazzer F1’).
- Control leaf aphids using systemic insecticides.
- Apply insecticides and mineral oil sprays for non-persistent vector-transmitted viruses.
- Use certified, virus-free seed.
- Keep crops aphid-free.
- Eliminate alternative hosts.

Tomato spotted wilt virus (TSWV)

There are over 271 hosts of this virus. The disease is of great economic importance for vegetables (mainly tomato and pepper), ornamentals, tobacco and other crops. The virus cannot be carried by seed and it does not survive in the soil. It is transmitted by small insects called thrips. Thrips move the pathogen when they suck the plant sap during feeding. At present, there are nine reported vectors: *Frankliniella occidentalis* (western flower thrips); *F. schultzei*; *F. fusca* (tobacco thrips); *Thrips tabaci* (onion thrips); *T. setosus*; *T. moultoni*; *F. tenuicornis*; and *Scirtothrips dorsalis*. The first four are the most important vectors of this disease and are commonly found in greenhouses. The virus overwinters in the roots of weed plants and in the system of the viruliferous vectors (persistent). It is transmitted by adult insects and immature thrips larvae. The duration of the incubation period (8–12 days) depends on the conditions of the environment.

Symptoms:

- Tomato: small ringlets and superficial spots on uppermost leaves; bronze spots and necrotic strips on leaves, later appearing on stems; when necrotic areas become larger, leaves look burned and weaken; big orange concentric rings of 2-cm diameter are observed on ripe fruits, but they do not penetrate the pericarp.
- Green pepper: stunting and yellowing of whole plant; leaves chlorotic or mosaic-type with necrotic spots; necrotic streaks appear on stems extending to terminal shoots; yellow spots with concentric rings or necrotic streaks observed on ripe fruits, making them not marketable.
- Lettuce: infection starts on one side of plant; later it becomes chlorotic with brown patches; the stunting on one side of the plant is characteristic.

Control:

- Isolate seedling beds from ornamental plants in flowering or susceptible crops.
- Remove weeds inside and outside of glass or plastic greenhouses.
- Use fine mesh netting to exclude thrips.
- Apply systemic insecticides to control vectors.
- Remove plants showing typical symptoms.

Tomato infectious chlorosis virus (TICV)

The wide host range includes tomato, pepper, potato and artichoke, ornamentals and weeds species. TICV is transmitted by the whitefly *Trialeurodes vaporariorum* in a semi-persistent manner. It is a phloem-transmitted virus. There are no resistant tomato varieties available at present.

Symptoms:

- First symptoms – yellowing of bottom leaves between the vein.
- At later stage – reddish spots between the yellow sections.
- Curling of leaves, which then become solid and crispy.
- As disease progresses – similar symptoms in upper layers (Pasev *et al.*, 2012).
- Severe infestation – damage to fruits, negatively affecting quality and yield.

Control:

- Use healthy seedlings.
- Control the vector – the greenhouse whitefly.
- Use *Encarsia formosa* to successfully control *T. vaporariorum* in the greenhouse.

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Plate 16
Cucumber yellow virus

Cucumber yellows virus (Beet pseudo-yellows virus – BPYV)

This virus affects cucumber, melon, lettuce, tobacco and some weeds. It does not stay in the soil and/or plant debris and it is not transmitted by contact. The greenhouse whitefly (*T. vaporariorum*) carries the virus. The incubation period is about 2 months.

Symptoms:

- On petioles of older leaves – tissue between veins becomes lighter in colour and yellow, veins remaining dark green.
- Infected leaves yellow, curling down and becoming tender.
- Disease gradually moving to upper layers of plant.
- Fruits remaining green, but abortion of part of sets (Hristova *et al.*, 1983), with yield decreases of 40–50%.

Control:

- Apply greenhouse sanitation, adopt crop rotation and establish an ornamental-free zone around the greenhouse.
- Remove weeds inside and outside the greenhouses.
- Use healthy seedlings.
- Apply vector control.
- Install insect-proof nets on doors and vents.
- Use yellow sticky traps under the vents and near the doors.

Pepper yellow mosaic virus (PepYMV)

Pepper yellow mosaic also affects tomato. Many species of aphids transmit this virus in a non-persistent manner.

Symptoms:

- Vein banding, blistering and bright yellow mosaic pattern.
- Distortion of leaves and stunting of plants.
- Development of mosaic pattern on and distortion of fruit.

Control:

- Use resistant varieties (e.g. 'Aliance F1', 'Cortes F1').
- Control leaf aphids using systemic insecticides.
- Apply insecticides and mineral oil sprays for non-persistently transmissible viruses vector control.
- Use healthy certified aphid-free seedlings.
- Remove weeds around the greenhouse.

Strawberry crinkle cytorhabdovirus (SCrV)

SCrV has a narrow host range among species of *Fragaria*, both cultivated and wild. The virus is spread around the world, including Europe. It is transmitted to strawberry by aphids, including the strawberry aphid *Chaetosiphon fragaefolii*. The infectivity of aphids is life-long. The length of a transmission cycle depends on temperature conditions. At lower temperatures the incubation period is longer. Symptoms vary in relation to strain and strawberry cultivar.

Symptoms:

- Leaves distorted and crinkled.
- Uneven development of leaflets in size and shape.
- Small, irregularly shaped chlorotic spots often associated with the veins.

Control:

- Use virus-free plants.
- Control vectors including *Chaetosiphon fragaefolii*.
- Eliminate diseased plant material.

Bean viruses: bean common mosaic virus (BCMV) and bean yellow mosaic virus (BYMV)

These viruses attack beans, alfalfa, clover, rye, other legumes and flowers, such as gladiolus. BCMV is seed-borne, but not usually found in wild legumes. It is transmitted by at least 12 aphid species. BYMV is not seed-borne in beans; it overwinters in hosts such as clover, wild legumes and some flowers, like gladiolus. It is spread by more than 20 aphid species.

Symptoms:

- BCMV: Symptoms vary depending on the bean variety and disease strain. An irregular mosaic of light yellow and green or dark green appears on the leaves along the veins on an otherwise green leaf; foliage may pucker and warp in size, often causing the leaf to roll up. Seeds are affected by BCMV.
- BYMV: Symptoms vary depending on the virus strain, growth stage and bean variety. Contrasting yellow or green mosaic markings appear on the foliage; sometimes the plant has yellow spots on the foliage and leaflets often become droopy, followed by curling foliage, glossy leaves and stunted plant size. The number of seeds per pod are significantly reduced.

Control:

- Destroy infected plants.
- Use disease-free seeds.
- Rotate crops if there has been any infection in the past.
- Control aphids with an insecticidal soap or neem oil.

Onion viruses: iris yellow spot virus (IYSV) and onion yellow dwarf virus (OYDV)

Hosts of IYSV are onions, garlic, leek, iris, lisianthus and some weeds. The virus is transmitted only by the onion thrip, *Thrips tabaci*. The disease has the potential to spread rapidly in the greenhouse if large numbers of viruliferous thrips are present. The virus is not seed-borne and it is not found in bulbs or soil. It can survive on various host plants, such as overwintering onions, iris, alstroemeria and leeks, but also in infected thrips. OYDV has a narrow host range (onions, garlic, shallots and a few ornamental alliums). It survives in bulbs and can be transmitted during vegetative reproduction. It is spread by the green peach aphid *Myzus persicae* and some other aphids.

Symptoms:

- IYSV: Diamond-shaped lesions on leaves; lesions often have a green centre. Seedlings can be killed. Severely infected plants have a stunted appearance.

- OYDV: Yellow streaks at the base of the first true leaves; later-developing leaves show symptoms ranging from yellow streaks to complete yellowing of leaves. Leaves become crinkled and flattened and can fall. Bulbs become undersized.


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Plate 17
Onion yellow dwarf virus

Control:

- Remove infected plants.
- Do not grow onions in close vicinity of other *Allium* crops.
- Use only disease-free seeds.
- Keep the crops aphid- and thrip-free: apply insecticidal soap or neem oil.
- There is no chemical control for this disease, but there are efficient insecticides against vectors.

Onion viruses: garlic mosaic virus (GMV) and leek yellow stripe virus (LYSV)
GMV hosts are onion and garlic. It spreads vegetatively and can also be transmitted by various aphid species. LYSV hosts are onion, garlic, leek and *Drimia maritima*; it is transmitted by aphids.

Symptoms:

- GMV: Mosaic, chlorotic mottling, striping and streaking of leaves; symptoms are more pronounced in young leaves; infected plants are stunted and bulb size is reduced.
- LYSV: In leek – irregular yellow striping of the whole lamina especially at its base; whole leaves may become yellow and affected plants are smaller and weigh less than normal. In garlic – the chlorotic to yellow striping or streaking of leaves is similar to that in leek.

Control:

- Remove infected plants; this activity may reduce secondary spread within the crop.
- Use virus-free seed.
- Keep the crops aphid-free.
- Isolate crops from infested crops of the same species.
- Use systemic insecticides for they are effective against non-persistent aphid-transmitted viruses.

Big-vein diseases: mirafiori lettuce big-vein virus (MiLBVV) and lettuce big-vein virus (LBVV)

Big-vein disease of lettuce has been attributed to infection by lettuce big-vein virus (LBVV), vectored by the soil fungus *Olpidium brassicae*. The discovery of a second soil-borne virus in lettuce, mirafiori lettuce virus (MiLV), has recently led to a re-investigation of the role of LBVV in the big-vein disease complex. Foliar symptoms are similar for both diseases and they occur in major lettuce-growing areas with cool to temperate temperatures, but also in subtropical areas.

Symptoms:

- Veins widening, lightening and showing yellow discoloration.
- Leaves becoming puckered or ruffled, ultimately thickening.
- Outer leaves becoming upright.

Control:

- Grow resistant cultivars when available.
- Use disease-free healthy seeds.
- Drench the field with chloropicrin or dazomet solution. Check local recommendations.

Spinach viruses: cucumber mosaic virus (CMV), beet curly top virus (BCTV), tobacco rattle virus (TRV) and tomato spotted wilt virus (TSWV)

These viruses have extensive host ranges comprising many agronomic crops and weed species. CMV is vectored by aphids; BCTV is vectored by the beet leafhopper; TSWV is vectored by thrips; and TRV is vectored by soil-borne nematodes. All viruses can cause substantial damage in early autumn-planted spinach.

Symptoms:

- CMV: Slight chlorosis of younger leaves and narrow or "puckered" young leaves; in advanced stages of infection, plants often appear stunted and the crown leaves may become completely blighted, killing the growing point.
- BCTV: Leaf stunting and chlorosis; younger leaves in the centre of the rosette are often very chlorotic, extremely curled, and rigid; plants usually die a few weeks after symptoms appear.
- TRV: Yellow and necrotic spotting, mottling, and leaf crinkling on spinach leaves.
- TSWV: Ringspots, circular leaf spots and necrotic spotting on foliage.

Control:

- Remove and eliminate infected plants.
- Keep greenhouse aphid- and thrip-free: use an insecticidal soap or neem oil.
- There is no chemical control for virus disease but there are good insecticides against vectors.
- Eliminate alternative hosts.

INSECTS

Aphids (Aphididae family)

Potato aphid (*Macrosiphum euphorbiae*), green peach aphid (*Myzus persicae*), buckthorn aphid (*Aphis nasturtii*) and cotton aphid (*Aphis gossypii*) are commonly present in greenhouse facilities and affect several crops.

Some species present alternation of sexual and asexual parthenogenetic generations. Adults and mature-stage aphids feed by inserting their needle-like mouth parts (stylet) into the plant parts (leaves, stems and fruits). Aphids prefer the young and tender plant tissue usually present on the upper portion of the canopy near stems and branches, and on the undersides of leaves and flower buds. Severe aphid infestation stunts plant growth and development. Aphids secrete a sticky "honey dew" which serves as a medium for development of black saprophytic fungi "sooty mould" that contaminates leaves, flowers and fruits, affecting overall production. Besides the direct feeding and honey dew production, aphids cause indirect damage as vectors of important plant diseases including viruses.

Under favourable mild conditions, aphids develop very quickly and small numbers rapidly reach outbreak proportions. High temperatures and low humidity have a negative effect on aphid populations; adequate conditions for aphid development are mild temperature (22–24 °C) and relatively high humidity (70–80%). Aphids may have several generations per growing season in the greenhouse. Carefully selection of pesticides is recommended to avoid development of resistance.

Control:

- Use certified seeds.
- Eliminate weeds that can serve as reservoir for vectors and pathogens.
- Use sticky cards, buckets or beating sheets to monitor aphid populations.
- Use natural enemies such as several *Aphidius* spp., *Chrysoperla carnea* and *Coleomegilla maculate*, which are commercially available. Revise local regulations related to the release of natural enemies in the field.
- Select pesticides that are compatible with biological control. Comply with all pesticides rules and regulations at national and international level.

Greenhouse whitefly (*Trialeurodes vaporariorum*) and tobacco whitefly (*Bemisia tabaci*) (Hem. Aleyrodidae)

Greenhouse whiteflies are one of the major greenhouse pests around the world. Adults are small insects about 1.5 mm in length covered with white coating scales. Fresh-laid eggs are greenish to waxy yellowish; depending on temperature, they become darker after 2 days. Females lay 60–300 eggs (depending on temperature, food and other factors) located mainly on the underside of the leaf, mostly in groups arranged in a semi-circle. After hatching, the young nymph seeks a feeding spot, loses it legs and stays put.

The greenhouses whitefly has 10–12 generations; each generation lasts 24–47 days depending on temperature. All developmental stages of the whitefly occur on the underside of the leaf. Nymphs and adults damage the plant directly by sucking plant sap from the leaves and petioles, rarely from the stem. They can also cause indirect damage as vectors, transmitting beet pseudo-yellows virus (BPYV) and other virus diseases. Similar to aphids, adult and mature-stage whiteflies secrete a honey dew.

High accumulation of honey dew allows the growth of a black saprophyte fungus or sooty mould. Infected plants slow their development; leaves and affected plant parts become yellow and eventually fall off. The greenhouse whitefly reproduces very quickly and causes significant damage. Eggs, as well as mature-stage and adult whiteflies can be found simultaneously (overlapping generations); this makes control difficult.

Control:

- Use certified seed.
- Eliminate weeds.
- Use insect-proof nets.
- Monitor populations on a regular basis (every 3 days) using visual counts or sticky cards.
- Eliminate plant residues after harvesting to reduce reservoirs of pathogens and to remove alternative hosts for the vector.
- Adopt biological control using, for example, pathogenic fungi, such as *Ashersonia*, *Verticillium lecanii* and *Paecilomyces fumosoroseus*, endoparasitic wasps (*Encarsia* and *Eretmocerus*) and predatory bugs from the genus *Macrolophus* (Loginova and Yankova, 2003).
- Use selective pesticides compatible with biological control (e.g. BioNeem Plus 1,5 EC, Timorex 66 EC) (Yankova *et al.*, 2011).

Onion thrips (*Thrips tabaci*) and western flower thrips (*Frankliniella occidentalis*) (Tripidae family)

Plate 18
Western flower thrips

Onion thrips (*Thrips tabaci*) and western flower thrips (*Frankliniella occidentalis*) are the most common thrips species present in greenhouse vegetable and strawberry production under protected agriculture. Damage occurs directly when adults and immature stages suck sap from leaves and flower buds, or indirectly as vectors transmitting pathogens such as tomato spotted wilt virus (TSWV) in tomato. Affected flowers drop, resulting in decreased fruit production. Mite infestations produce growth stunt. Thrips can be present year round under greenhouse conditions.

Control:

- Use clean certified seedlings or transplants.
- Eliminate weeds.
- Monitor plants and plant parts directly or by using sticky cards; blue sticky traps are recommended.
- Use beneficials: the predatory mite *Amblyseius cucumeris*, the minute pirate bug *Orius* spp. and the fungus *Verticillium lecanii*; or soil-living predatory mites *Hypoaspis miles* and *Hypoaspis aculeifer* control thrips in the ground.
- Apply pesticides if thrips populations are out of control.

Leafminers (*Liriomyza bryoniae* and *L. huidobresis*) (Agromyzidae family)

The tomato leafminer (*Liriomyza bryoniae*) and the South American leafminer (*Liriomyza huidobrensis*) are two of the most common leafminer flies worldwide. The adults are small black flies 1.2–2.3 mm long. Eggs are small elongated milky white ovals, placed singly. The larva is triangular and coloured bright yellow–orange. The pupa is golden yellow to dark brown usually resting in the mines or soil if available. There can be multiple generations per growing season, depending on the temperature. During oviposition, mainly on the upper side of the leaf, adults make numerous punctures, which exudate sap – i.e. their food source. The leaf tissue around the punctures becomes yellow, withered and spotty. Immediately after hatching, larvae enter between the mesophylle of the leaves, creating the characteristic “mines”. As the larvae grow, the mines become larger, diminishing the photosynthetic capability of the plant. Each mine can contain one larva, but in serious infestations several mines are observed on one leaf.

Control:

- Remove remains of previous crops.
- Install insect-proof nets on doors and vents to reduce movement of flies from nearby fields into greenhouses. Adopt biological control: the beneficials *Dacnusa sibirica*, *Diglyphus iseae* and *Opius pallipes*, are good alternatives. Note that leafminer flies are resistant to several classes of insecticides (Yankova *et al.*, 2008).
- Consider chemical control according to pesticide availability: consult your local extension agent and pesticide dealer about the availability of recently developed biopesticides; note that most of the chemicals target immature stages.

Several species of moths (Noctuidae family)

There are several species of moths affecting greenhouse production: cotton bollworm (*Helicoverpa armigera*), silver Y-moth (*Autographa gamma*) and golden twin-spot (*Chrysodeixis chalcites*). All three species are considered defoliators. The cotton bollworm develops three generations per year under continuous production. Caterpillars feed on leaves, and damage blossoms, buds and fruits. The silver Y-moth produces at least three generations per year. Caterpillars feed on younger leaves causing defoliation. Similarly, the golden twin-spot also has several overlapping generations under greenhouse operations.

Control:

- Eliminate crop residues and control weeds.
- Apply regular soil treatments (including tilling when feasible) in greenhouses where the crop is planted directly in the soil or if reusing the soil medium, to help reduce pest populations.
- Adopt biological control: the parasitoid *Trichogramma evanescens* has been used successfully.
- Consider chemical control, selecting chemicals that target the immature stage. Treatment with biopesticides (e.g. *Bacillus turingensis*) can also be applied at the immature stage.

Tomato borer (*Tuta absoluta*; Gelechiidae family)

The tomato borer is a relatively recent problem in greenhouse tomato production. Adults are medium-sized moths approximately 5–6 mm long. Front wings are longer than they are wide, with fringes on the outer edge. They are brownish to silvery, with a black spot on the first pair of wings. The egg is elongated and oval shaped, milky white to yellow. Young larvae are yellowish, later turning yellowish green to bright pink. The head is bright brown. The pupa is spindly, bright brown. Caterpillars of *T. absoluta* mine leaves and stems and also bore inside fruits causing significant damage in solanaceous crops such as tomato, eggplant, pepper and potato. Depending on temperature, the development of one generation of *T. absoluta* ranges from 29 to 38 days, resulting in several populations in greenhouse operations. Adults are active at night; during the day they hide in the crop canopy. Females lay up to 260 eggs during their lifespan. Hatching occurs 4–6 days after egg laying. There are four instars larvae lasting 12–15 days. As long as food is available, they do not enter in diapause (Harizanova *et al*., 2009).

Caterpillars feed inside mines on leaves, stems and fruits. The worst damage is in the fruit because the appearance is ruined. Once feeding is complete, larvae leave the mine for pupation, which can take place in the soil, on the leaf surface or inside mines. The tomato borer can overwinter as an egg, pupa or adult. Populations can overlap during a single growing season. During heavy infestations, affected plant parts dry out and eventually die; fruits can be deformed and unmarketable. Damaged fruits are potential entry points for secondary pathogenic pest problems.

Control:

- Adopt preventive measures such as the use of pest-free seedlings.
- Eliminate weeds.
- Adopt crop rotation using non-Solanaceous crops.
- Apply soil tillage and eliminate previous crop residues to reduce pest populations.
- Install insect-proof nets.
- Use pheromone traps to detect the pest.
- Apply biological control using the two effective agents available for tomato bore control: *Macrolophus caliginosus* and *Nesidiocoris tenuis*.
- Consider chemical control, but take care to apply effective chemicals, as this insect has already shown resistance to several chemical compounds making chemical control challenging.

Mole-cricket (*Gryllotalpa gryllotalpa*, Gryllidae family)

This is a problematic insect in nurseries. It thrives under wet and humus-rich soils. The mole-cricket hollows underground tunnels close to the roots; here the insect mines and feeds on plant seedlings, seeds and stalks. Stand is noticeably reduced. When older plants are affected underground, they eventually wither and die.

Control:

- Use baits with an effective mixture of fresh manure and chemicals.

Two-spotted spider mite (*Tetranychus urticae*, Tetranichidae family)

Two-spotted spider mite adults are small, oval-shaped and with four pairs of legs. They have a winter and a summer form. The winter forms are brick red, the summer yellow–green. Males are smaller than females. Eggs are typical spherical, smooth and transparent, resembling water drops. Immature stages are green–yellow and the first instar presents only three pairs of legs. The proto-nymph and the deuto-nymph are larger couples with four pairs of legs, similar to the adults.


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Plate 19
Two-spotted spider mite adults, nymphs and eggs

Mites thrive under hot and dry conditions. Two-spotted spider mites live and feed mainly on leaves, but they can also be found in other plant parts including fruits. Heavy spider mite infestations cause mites to produce characteristic spider webs. Mites feed by sucking sap; a light green dot-shaped spot can be seen where the puncture is made. Later the spots merge and the leaf becomes marbled. The two-spotted spider mite prefers to feed on older leaves or plant parts that present low water content. Under heavy two-spotted spider mite infestation, plants wither and eventually die.

Control:

- Eliminate weeds and previous crop residues.
- Maintain a balanced irrigation regime.
- Monitor visually the edges of the facility since infestation tends to start close to doors, vents or openings.
- Use the predatory mite *Phytoseiulus persimilis* to control two-spotted spider mite.

Root-knot nematodes (*Meloidogyne* spp.)

The root-knot nematode, *Meloidogyne incognita*, is the most frequent species found in cucumber, tomato, pepper and eggplant. In greenhouse production it can cause severe yield loss. *M. javanica* predominates in warm regions; *M. arenaria* is found on light sandy soils and is often present together with *M. incognita*; *M. hapla* is present in conditions with continental climate and on winter crops. The number of generations varies from 4 to 7 depending on temperature and humidity. The root-knot nematode overwinters as larvae and females in the soil, in plant residues and on some wild hosts. The female lays eggs at 14–31.5 °C. The average fertility is 600–800 eggs per egg mass during the life cycle. The second stage juvenile (J2) – or invasion larvae – hatch from the eggs. Males appear in spring and autumn, after which reproduction is parthenogenetic. Larvae penetrate the plants close to the growing root top, moving to the conducting tissue where they start to feed. Feeding results in mutation of cells of the host – hypertrophy, disappearance of cell membranes and formation of gigantic cells and galls. The galls have anomalous shapes and different sizes. Initially they are white and later become darker. The root system ceases to function properly and the plants wither and die. The leaves become dry from bottom to top. The areas damaged by nematode penetration act as entry points for agents of some diseases; moreover, yields decrease.

Control:

- Use certified seeds.
- Eliminate crop residues and maintain clean equipment using formalin (1 : 50).
- Rotate crops.
- Use resistant tomato varieties (e.g. ‘Buran F1’, ‘Rally F1’, ‘Mondial F1’, ‘Panekra F1’).
- Graft fruiting vegetable onto tolerant/resistant rootstocks (e.g. ‘Maxifort’, ‘Beaufort’, ‘Survivor’, ‘Body’).
- Apply biological control using the soil-borne fungus *Paecilomyces lilacinus*.

Strawberry root weevil (*Otiorrhynchus rugosostriatus*, Curculionidae family)

The strawberry root weevil develops one generation per year overwintering in the strawberry roots as larvae (more rarely as adult weevils). The imago emerged beetles stay in the soil before coming to the surface to then tunnel into the root system.

In a strong infestation, the old leaves – and eventually the whole plant – wither completely. In a slight infestation, the plants blossom and fruits form, but they are small and tasteless and they often become dry at ripening.


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Plate 20
Strawberry root weevil

Control:

- Plant healthy strawberry plants.
- Target chemical applications against adults in the early morning or late afternoon when they are more likely to be moving.

Strawberry blossom weevil (*Anthonomus rubi* Hrbst, Curculionidae family)


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Plate 21
Strawberry blossom weevil

The strawberry blossom weevil develops one generation per year, overwintering as an adult weevil in the surface soil layer under fallen leaves and other plant parts. In early spring it enters the strawberry buds and feeds on the pollen. It damages the leaves, leaf petioles and buds, making bores with its rostrum. It begins egg-laying after supplementary feeding. The female incises the flower stalk and introduces the eggs into the flower buds. The damaged stalks break and after a few days the buds drop off. The larvae grow in the damaged, fallen flower buds. When the flower stalks are only slightly damaged, the buds do not drop off but become dry. The main damage caused by this pest occurs during egg-laying.

Control:

- Carry out control against the adult weevil before egg-laying.

Strawberry mite (*Tarsonemus pallidus* Banks, Tarsonemidae family)

Strawberry mites overwinter as female in the surface soil layer, under the plant residues, in the leaves and buds of strawberry plants. In the spring, strawberry mites, located on the underside of the leaves close to the leaf veins, feed by sucking sap causing the leaves to turn yellow and dry. The mites prefer young and tender leaves, not yet fully developed and rich in water, soluble carbohydrates and proteins. Strongly infested plants continue to grow, but the quality of the produce deteriorates as fruits are smaller with a lower sugar content. The strawberry mite prefers high humidity. The low relative humidity of the air and high temperatures in the summer result in a reduced mite population as they do not like heat.

Control:

- Use planting stock originating from mountain areas (i.e. where there are no mites).
- Select areas with good drainage and at a distance from old plantations.

Plate 22
Allium leafminer

Allium leafminer (*Napomyza gymnostoma*)

Allium leafminer causes damage to *Allium* crops, but the most serious injuries are found in leek. The allium leafminer develops 3–4 generations a year, making control difficult. It overwinters as a pupa in the leek stalks, located in the end of the mine and very rarely in the soil under the plant. Damage is not usually found after harvesting of the crop. Almost straight mines, directed towards the bottom can be observed on the external 3–4 leaves of the false stalk. During growth, the stalks of the damaged plants become cracked lengthways, pathogens enter and they tend to rot. Sometimes the false stalk of the leek, damaged by the fly, becomes rosy and rots during storage. In strongly infested plants, it is possible to find 5–15 larvae and pupae in the stalks.

Control:

- Reduce plant density per unit of area.
- Avoid cultivation over long periods in the same area.
- Apply regular soil cultivation practices.
- Use healthy high-quality planting material.
- Remove plant residues.
- Apply chemical control against the adult flies before they lay their eggs.

Onion maggot (*Hylemyia antiqua*)

This pest attacks especially onion, but also garlic. The onion maggot develops two full generations and a third partial generation. It overwinters as a pupa in the soil at a depth of 10–20 cm. The flies from the first generation start to fly at the end of April. It lays its eggs on the leaves, the bulbs and the soil surface near the plants. The larvae from the first generation cause damage, boring the plants beneath the leaves. They enter the stem lengthways and move to the bulb. Damaged plants have poor development, become flaccid and eventually wilt. The damaged tissue ferments and emits an unpleasant smell of rotten onion. Several larvae may develop in one plant and they attack the stems of the next plants to feed.

Control:

- Plant early as late sowings are more strongly attacked.
- Sow at optimal density.
- Remove plants with symptoms of damage to prevent larvae moving to healthy plants.
- Remove all bulbs from the soil and eliminate the wilting onion, because the development of the fly continues in the bulbs.
- Apply chemical control directed against the adults before they lay their eggs.

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Plate 23
Leek moth

Leek moth (*Acrolepia assectella*)

This pest damages onion, garlic and leek intended for fresh consumption and seed production. It develops two generations annually. It overwinters as an adult and pupa in plant residues and other protected places. It lays eggs one by one on the leaves and racemes of the onion. The larvae bore narrow strips and enter the leaves or flower-bearing stems, boring longitudinal grooves in the leaf parenchyma. The upper epidermis is not affected. During leaf growth, the epidermis becomes cracked. The caterpillars enter the inflorescences and nibble the blossoms; part of the seeds desiccate resulting in reduced yield and quality.

Control:

- Weed regularly and remove plant residues.
- Monitor to ensure that plants have uniform germination and healthy growth.
- Spray the young plantlets in the early stages to avoid damage.

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Plate 24
Carrot fly

Carrot fly (*Psila rosae*)

The carrot fly has two generations a year. This pest overwinters as a pupa in the soil. The larvae make rust-coloured tunnels in the roots. The damaged roots are deformed, tasteless and almost unfit for consumption. The leaves of the damaged plants become red–violet and later yellow and wilted.

Control:

- Rotate crops and isolate.
- Control weeds.
- Remove damaged plants.
- Apply chemical control during flight and laying periods.

Slugs (Limacidae family)

Slugs are polyphagy pests. Their density is greatest in years with a warm and humid spring. This pest develops several generations a year. It is a hydrophilous, night pest. It makes irregular bores on the leaves, tunnels as longitudinal grooves, depositing slime and polluting the produce.

Control:

- Apply regular soil cultivation practices during vegetation.
- Implement an optimal irrigation regime.
- Remove weeds during the vegetation period.
- Use baits to reduce the damage to the plants.

TABLE 1

Fungicides used in greenhouse production

Fungicide (active ingredient)	Targeted diseases	Crops	Comments
		Chemical products	
Azoxystrobin	Late/early blight, downy mildew, powdery mildew	Tomato, cucumber	Systemic fungicide with protective, curative and eradicant action
Benalaxyl	Downy mildew	Cucumber	Systemic fungicide with protective, curative and eradicant action
Benthiavalicarb	Late blight	Tomato	Local systemic fungicide with protective and curative action
Boskalid	Powdery mildew	Cucumber, lettuce	Systemic fungicide with protective and curative action
Chlorotalonil	Early blight	Tomato	Contact fungicide with protective action
Copper calcium sulphate (Bordeaux mixture)	Late blight	Tomato	Contact fungicide with protective action
Copper hydroxide	Late blight, downy mildew	Tomato, cucumber	Contact fungicide with protective action
Copper oxychloride	Late blight	Tomato	Contact fungicide with protective action
Cymoxanil	Late/early blight, downy mildew	Tomato, cucumber, lettuce	Systemic fungicide with protective and curative action
Dazomet	Soil pathogens	Vegetables	Soil fumigant
Difenoconazole	Early blight, powdery mildew	Tomato	Systemic fungicide with protective and curative action
Dimethomorph	Late blight	Tomato	Contact fungicide with protective action
Famoxadone	Late blight, downy mildew	Tomato, cucumber	Non-systemic strobilurin: fungicide with protective action
Fenamidone	Late blight, downy mildew	Tomato, cucumber, onion	Systemic fungicide with protective and curative action
Folpet	Late blight	Tomato	Contact fungicide with protective action
Fosetyl-aluminium	Late blight, downy mildew	Cucumber, tomato, pepper	Systemic fungicide with protective and curative action
Kresoxym-methyl	Powdery mildew	Cucumber	Semisystemic fungicide with protective and curative action
Mancozeb	Late/early blight, downy mildew, anthracnose	Tomato, cucumber, lettuce, onion, strawberry	Contact fungicide with protective action
Mandipropamide	Late blight	Tomato	Contact fungicide with protective and curative action
Mefenoxam	Late/early blight, downy mildew	Tomato, cucumber	Systemic fungicide with protective and curative action
Metam sodium	Soil pathogens	Vegetables	Soil fumigant
Metiram	Late/early blight	Tomato	Contact fungicide with protective action
Penconazole	Powdery mildew	Tomato, cucumber	Systemic fungicide with protective and curative action

Note:

Effects of pesticides on the natural enemies can be found at www.koppert.com, www.biobest.be. Farmers are encouraged to use this information to make management decisions. Please check whether the active ingredient is still authorized.

TABLE 1 (cont'd)

Fungicides used in greenhouse production

Fungicide (active ingredient)	Targeted diseases	Crops	Comments
		Chemical products (cont'd)	
Propamocarb-hydroxychloride	Soil pathogens	Vegetables	Systemic fungicide with protective and curative action
Propineb	Late blight	Tomato	Contact fungicide with protective action
Tebuconazole	Powdery mildew	Cucumber	Systemic fungicide with protective and curative action
Tetraconazole	Powdery mildew	Tomato, cucumber	Systemic fungicide with protective and curative action
Thiophanate-methyl	Soil pathogens, grey/white/leaf mould, fusarium wilt	Vegetables	Systemic fungicide with protective and curative action
Thiram	Soil pathogens	Vegetables	Non-systemic fungicide with protective action
Triadimenol	Powdery mildew	Cucumber, tomato, lettuce, pepper	Systemic fungicide with protective, curative and eradicant action
Triadimenol	Powdery mildew	Cucumber	Systemic fungicide with protective, curative and eradicant action
Trifloxystrobin	Powdery mildew	Cucumber	Systemic fungicide with protective and curative action
		Bioproducts	
Bacillus pumilis (Sonata)	Powdery/downy mildew	Cucumber, lettuce	Contact biopesticide
Bacillus subtilis (Serenade)	Powdery/downy mildew, early blight	Vegetables	Contact preventive biopesticide
Fusarium oxysporum var. *lycopersici*	Soil pathogens	Vegetables	Preventive biopesticide
Streptomyces griseoviridis	Leaf spots and root rots	Vegetables	Contact biopesticide
Streptomyces lydicus	Downy/powdery mildew, grey mould, soil pathogens	Vegetables	Contact preventive biopesticide
Trichoderma harzianum	Soil pathogens	Vegetables	Preventive biopesticide
		Botanical pesticides	
Botanical oils	Powdery mildew	Cucumber	Contact botanical fungicide
HF-Pilzvorsorge	Powdery mildew, grey mould	Tomato, cucumber	Plant extracts and plant oils of fennel Contact botanical fungicide
Timorex 66 EC	Powdery mildew	Cucumber	Oil from *Malaleuca alternifolia*
Timorex Gold	Powdery mildew	Cucumber	Plant extract from *M. alternifolia*
Trilogy	Powdery mildew, early blight	Tomato, cucumber	Hydrophobic extract from Neem oil
		Other products	
Insecticidial soap	Powdery mildew	Cucumber	Contact products
Potassium bicarbonate	Powdery mildew and others	All vegetables	Contact fungicide
Sulphur	Powdery mildew	All vegetables	Contact fungicide

TABLE 2

Insecticides used to control pests in greenhouse production

Insecticide (active ingredient)	Targeted pests	Crops	Comments
		Insecticides	
Abamectin	Leafminer, two-spotted spider mite	Vegetables	Contact and stomach action
Acetamiprid	Aphids, greenhouse whitefly, tomato borer, thrips	Tomato, cucumber, pepper, eggplant	Systemic insecticide
Bifenazate	Two-spotted spider mite	Eggplant, cucumber, pepper, tomato	Contact action
Chlorantraniliprole	Tomato borer, silver Y-moth, cotton bollworm	Tomato, eggplant, lettuce	Contact and stomach action Ryanodine receptor modulators
Cypermethrin	Greenhouse whitefly, aphids, leafminer, thrips	Vegetables	Contact and repellent action
Deltamethrin	Cotton bollworm, greenhouse whitefly, aphids, thrips	Tomato, cucumber, pepper, eggplant, lettuce	Contact action, with knock-down effect
Dimethoate	Greenhouse whitefly, aphids, thrips, two-spotted spider mite	Tomato, pepper, cucumber	Systemic insecticide with contact and stomach action
Emamectin benzoate	Tomato borer, cotton bollworm	Tomato	Non-systemic avermectin insecticide with penetration action
Fenpiroximat	Two-spotted spider mite	Vegetables	Non-systemic acaricide with contact and stomach action
Gamma-cyhalothrin	Aphids	Vegetables	Contact action
Hexitiazox	Two-spotted spider mite	Cucumber	Local systemic acaricide with contact action
Imidacloprid	Aphids, tomato borer, leafminer, thrips	Cucumber, pepper	Systemic insecticide with contact and stomach action
Indoxacarb	Cotton bollworm; Tomato borer	Tomato, pepper, eggplant	Contact and stomach action
Metaflumizone	Tomato borer	Tomato	Rapid initial knock-down effect Contact and stomach action Sodium channel blocker
Oxamyl	Root-knot nematode	Tomato, cucumber, pepper, eggplant	Systemic product with contact and stomach poison
Pyridaben	Greenhouse whitefly, aphids, two-spotted spider mite	Tomato, cucumber	Contact action against insects and mites
Pyriproxyfen	Greenhouse whitefly	Tomato, cucumber	Contact and stomach poison Juvenile hormone
Thiacloprid	Aphids	Vegetables	Systemic insecticide with contact and stomach action
Thiamethoxam	Greenhouse whitefly, aphids	Cucumber, tomato, pepper	Contact and stomach action; Systemic

TABLE 2 (cont'd)
Insecticides used to control pests in greenhouse production

Insecticide (active ingredient)	Targeted pests	Crops	Comments
		Bioinsecticides	
Azadirachtin	Tomato borer, two-spotted spider mite	Vegetables	Systemic biopesticide with stomach and contact action
Pyrethrin	Greenhouse whitefly, aphids	Vegetables	Contact bioinsecticide, with knock-down effect
Spinosad	Tomato borer, leafminer, owlet moths, thrips	Tomato, cucumber, pepper, eggplant	Bioinsecticide with stomach and contact action
Bacillus thuringiensis	Caterpillars	Vegetables	Bioinsecticide with stomach action
Paecilomyces lilacinus	Root-knot nematodes	Vegetables	Bionematicide: soil fungus P. lilacinusis a pathogen that control all stages of root-knot nematodes

Note:
Effects of pesticides on natural enemies can be found at www.koppert.com or www.biobest.be. Farmers are encouraged to use this information to make management decisions. Please check whether the active ingredient is still authorized.

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6. Seedling production

A. Balliu,[a] N.K. Maršić[b] and N. Gruda[c]

[a] *Agricultural University of Tirana, Albania*
[b] *Biotechnical Faculty, University of Ljubljana, Slovenia*
[c] *University of Bonn, Germany*

ABSTRACT

The production of vegetable seedlings is an extremely important operation. If farmers do not use high-quality, healthy and vigorous seedlings, yield potential cannot be achieved. This chapter describes the facilities, materials and management practices used for seedling production. GAP recommendations aimed at smallholders are provided to assure high-quality vegetable transplants.

INTRODUCTION

The production of vegetable seedlings is an extremely important operation. If farmers do not use high-quality, healthy and vigorous seedlings, yield potential cannot be achieved. Although farmers continue to produce seedlings themselves, commercial transplant production in highly specialized nurseries is a worldwide trend. Production technologies have been gradually developed to reach the current stage of module propagation. In this system, each transplant grows in an individual cell: there is less competition among plants and more uniformity. Moreover, less labour is required for mixing and sterilizing soil, filling trays and growing seedlings.

The production of high-quality transplants is very important in greenhouse crop production. Although precise standards do not exist, transplants are generally defined as of **high quality** when they have the following characteristics:

- absence of disease and pest infections;
- ability to survive in unfavourable environments after transplanting;
- well-developed root system; and
- well-developed leaf area without visual defects of leaves such as chlorosis (yellowing tissues) or necrosis (dead tissues).

Key questions

- Why is it important to have good quality seedlings?
- What are the most important facilities and systems used in a nursery greenhouse?
- What are the most important materials used in seedling production? What requirements should they meet?
- How can you recognize a high-quality seedling?
- What are the most important issues in vegetable seedling management?
- What are the principal techniques for seedling growth control and hardening?
- What are the main issues regarding grafted seedlings and what is its purpose?
- Which are the main techniques of grafted seedlings?

There are wide discrepancies in nursery production among SEE countries. It ranges from almost 100% in Albania, Greece, Turkey and Croatia to little more than 0% in Moldova, the Republic of Macedonia, Montenegro and Serbia.[1]

SEEDLING PRODUCTION FACILITIES

Young seedlings are generally very sensitive to abiotic and biotic stresses. Therefore, the seedling nursery greenhouse must be equipped to ensure optimal growing conditions. The location and orientation are crucial for successful seedling production. Indeed, it is important to maximize the uniformity of sunlight and the nursery greenhouse should, therefore, be located at a sufficient distance from surrounding trees or buildings to prevent shadowing during the day. Furthermore, a good nursery greenhouse should be equipped with certain tools and systems, described below.

Germination chamber

The germination chamber is usually an insulated room with controlled temperature and relative humidity. The goal is to facilitate the germination process in a confined space while also avoiding the cost of heating a large greenhouse to germination temperature. Germination rooms are equipped with a heating/cooling system for temperature control and a misting/fogging system for humidification. Air circulation is important to ensure uniform temperature and humidity throughout the chamber, thus avoiding uneven germination and transplant development.

Tray supporting system

Module propagation is based on aerial root pruning. Trays are placed ≥ 5 cm above ground level, supported by benches, wooden blocks, wires or pots. When the seedling roots make contact with the air below the tray, the root tips die, thereby encouraging the formation of a ball of roots in the module: aerial root pruning.

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[1] See Part I, Chapter 2.

Irrigation system

Plate 1
Overhead boom irrigation system

An irrigation system must provide **uniform water distribution** – crucial for uniform growth of seedlings. Small producers can consider irrigating the seedlings using manual hose irrigation. However, large producers must install overhead spray lines. The most efficient watering systems use travelling overhead gantries, whereby a spray boom is drawn mechanically over the bed of modules. With any watering system, the outer cells in the outer trays of the block will dry out more quickly than those located in the centre. For this reason, some hand watering may be required.

Heating system

Any system that provides a uniform temperature without releasing toxic fumes to the plants is acceptable for heating a greenhouse. Suitable energy sources include natural gas, fuel oil, wood, residues from the olive oil industry and electricity. Incomplete combustion of petroleum products produces ethylene gas that can cause loss of plants; proper ventilation is, therefore, essential for all systems. The precise heating requirements depend on the amount of heat loss from the structure.

Cooling system

Greenhouses can be **ventilated** using side and ridge (roof) vents running the full length of the structure. Vents can be opened up as needed to reduce greenhouse temperatures. As the outdoor temperature rises, enhanced air movement may be needed to keep inside temperatures at the optimum level for plant growth; in this case, forced ventilation by electric fans can be used. If summer temperatures exceed acceptable levels and cannot be corrected by natural or forced ventilation, evaporative cooling is an alternative. The fan and pad system uses **evaporative cooling** to eliminate excessive heat and add humidity.[2] This results in decreased plant moisture loss and reduces the irrigation requirement.

Shading can also be adopted to cool down the nursery greenhouses. Different outdoor or indoor materials and systems may be used. The best, but most expensive, option is to employ internal movable aluminium screens which can also be used to reduce thermal losses during cold nights. Whatever type of shading system is adopted, the grower must be aware that reduced light intensity will cause seedling growth to be retarded. For this reason, shading should only be used temporarily, during the hottest hours of the day.

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[2] See Part II, Chapter 1.

MATERIALS FOR MODULE SEEDLING PRODUCTION

Seeds

A primary requirement of the module propagation system is **high-quality** seed. Not only is high percentage germination important, but seeds should also have high vigour. As a rule, seeds for module use should have a germination percentage of at least 90%. Additionally, they should be pest-free and uncontaminated by seed-borne diseases. It is therefore recommended to use seeds from a reliable source and to test the germination rate before planting.

As seed gets older, the germination rate declines depending on conditions and species. High temperatures and high humidity in the storage environment cause the decline to be very rapid.

Trays

Expanded polyethylene trays are the most widely used by commercial vegetable seedling producers in most countries, but rigid plastic trays are also used. Expanded polystyrene trays are less expensive, but they have disadvantages:

- They are easily damaged and broken.
- Seedlings can root into the tray resulting in poor plug extraction, even in new trays.
- They are difficult to clean.

Trays differ in number, size and shape of cells. Criteria for tray selection include: plant species, growing conditions, local availability and type of mechanical seeders used.

Tray hygiene is important. Soil-borne diseases can carry over from one round of plants to the next. Plastic trays should be sterilized by soaking in formalin solutions or 10% bleach (Kubota *et al.*, 2013). Polystyrene trays cannot be treated with formalin, but could be treated with a copper-based solution (3%). Containers must then be rinsed thoroughly to avoid chemical toxicity and dried prior to use. Polystyrene seedling trays must not be used more than 2–3 times.


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Plate 2
Pepper seedlings in polystyrene tray

Substrates

Given the small volume of growing media in seedling containers, the substrate must have specific physical properties. Various growing media may be used, but the most common material used for vegetable seedling production is peat, thanks to its excellent chemical, biological and physical properties. In soilless culture systems, rockwool cubes or containers filled with perlite, pumice, vermiculite and other inorganic substrates are used for transplant production. There is a growing trend towards using peat-free substrate. When choosing a growing medium, it is important to have a full understanding of its properties, as they affect plant response and production costs. According to Gruda *et al.* (2013), the preferred **properties for growing media** include:

- low volume–weight ratio;
- good aeration and reserves of easily available water;
- good rehydration properties after drying;
- stable structure;
- good pH-buffering capacity;
- absence of toxic compounds;
- low micro-organism activity;
- absence of weed seeds, pests and pathogens; and
- low level of fertilizers.

Industrial growing mixes are widely used in the vegetable seedling and transplant industry. They consist of growing media constituents and additives. Growing media constituents include combinations of peat and other organic or inorganic materials. Growing media additives include fertilizers, liming materials, and biocontrol or wetting agents. Commercial nurseries often mix peat with perlite or vermiculite to increase the water-holding capacity of growing substrate and avoid water content volume fluctuations of solely peat substrate.

Sometimes growers create self-produced mixtures using local resources. However, farm mixing of two or more constituents does not result in a direct mean value of these components and the mixture can sometimes represent a black box. Furthermore, seed-raising mix needs to be sterilized in order to be free of disease and weed seeds.

Adding water to growing media before placing them in the containers helps maintain a certain level of water and drastically improves substrate rehydration. This is very important for dry and non-standard materials. Compacting substrate in containers will not only modify the volume–weight ratio, but will in turn affect other physical characteristics, such as porosity and water and air volume. For frequently irrigated high-intensity greenhouse seedlings, it is recommended to use substrates with a low volume–weight ratio.

SEEDLING MANAGEMENT

The "ideal" technique for growing transplants is to raise the plant from start to finish by slow, steady, uninterrupted growth and with minimal stress. Since ideal growing conditions rarely exist, plant growth may need to be controlled through the manipulation of water, temperature and fertilizer. The main steps of this process are described below.

Tray filling and sowing

Trays can be filled with growing media either manually or using special machines. Hand **filling** is cost effective for small nurseries, but for large-scale operations specialized filling machines are a better option. In both cases, the substrate level should be a few millimeters below the edge of the module and slightly pressed to create a uniform medium for seeding.

Seeding may done manually, using small hand seeding tools, or with vacuum machines, depending on the quantity of seedlings being produced. Seeds must be laid horizontally over the substrate at the centre of each module. Avoid positioning the seeds vertically, as it would then be more difficult for the embryonal leaves to be released from the seed covers following seed emergence.

After sowing, the trays require **covering** with a free flowing and fine grade substrate. The most widely used covering materials are peat, vermiculite and perlite. Vermiculite is preferred because it is easy to apply evenly, allows good aeration, does not support algae growth and does not allow root growth between cells. Once the seed is covered, the trays are watered and send to the germination room.

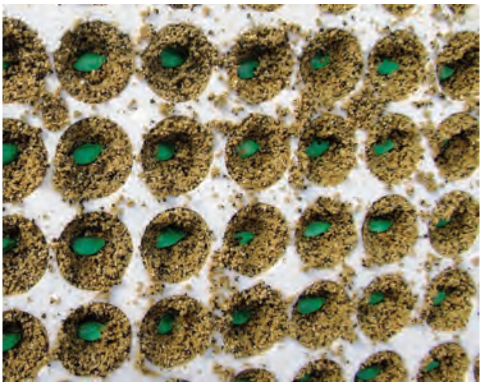
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Plate 3
Optimal sowing positioning of seeds in the tray

The sowing time should be scheduled backwards: it depends on the target delivery period, which in turn is determined by the final crop production schedule. The time required to reach the growth stage suitable for transplanting varies and depends on: crop species, climate conditions (e.g. solar radiation, day and night air temperature) and CO_2 concentration, as well as growing methods (e.g. substrate, fertilizer and tray type). Experience is required to accurately forecast the finishing time of transplants.

Inoculation of growth-promoting micro-organisms

Modern agricultural practices – in particular, tillage methods and application of mineral fertilizers – result in progressively reduced diversity and frequency of soil micro-organisms. In particular, phosphorus is known to have a negative effect on arbuscular mycorrhizal (AM) fungi (Nouri *et al.*, 2014). In intensive greenhouse production, the natural occurrence of AM fungi is therefore limited.

To minimize this risk, mycorrhiza is sometimes applied externally to growing plants. The inoculation of a mixture of AM fungi (*Glomus intradadices*, *G. etunicatum*, *G. mosseae*, *G. geosporum*, *G. clarum*) in the growing substrate of tomato and cucumber seedlings (10% of module volume) has significantly enhanced their stand establishment rate and yield under solar greenhouse conditions (Balliu *et al.*, 2015; Babaj *et al.*, 2014). Experiments have been conducted on the use of plant growth promoting rhizobacteria (PGPR), but no clear practical benefits are reported.

Germination

Trays are usually stacked on a pallet (100–150 trays/pallet) until germination begins. It is important to maintain optimal conditions for each species in order to improve uniformity, minimize time and reduce overall costs for transplant production. Environmental factors affecting germination include temperature, relative humidity and light.

Only few seeds (e.g. lettuce) require light for germination; most germinate best in the **dark**. It is important that the water content of the substrate remain constant until seed emergence. A state of almost saturated air **humidity** must, therefore, be maintained in the germination room by means of evaporative devices.

The **temperature** regime is very important for good and uniform germination. Therefore, temperature monitoring during germination is essential. For most crops, the temperature inside the germination room needs to be stable. Only a few species (e.g. eggplant and its rootstock *Solanum torvum*) require oscillating temperature (Kubota *et al.*, 2013).

The trays should be moved to the greenhouse once the seed-coat cracks and the shoot starts to emerge, in order to prevent excessive elongation (Plates 4 and 5). Optimum temperature and time for germination vary depending on the crop. Optimum germination temperatures for the major transplanted vegetables are listed in Table 1.

Plate 4
Proper time for removal of trays from the germination room

Plate 5
Stem elongation of seedlings due to the delay of tray removal from the germination room

Temperature regime

Once the trays have been transferred from the germination room, slightly lower temperatures should be applied in the growing environment. Optimum day and night growing temperatures for several crops are shown in Table 1. Warm season vegetable crops (tomato, pepper, eggplant and vine crops) are susceptible to chilling injury. Chilling occurs when transplants are exposed to temperatures above freezing but below 10 °C for an extended period. Chilling causes stunting of growth and chlorosis and can have a lasting effect on field establishment. For susceptible crops, a minimum greenhouse temperature of 10 °C is recommended.

Irrigation regime

Complete **water analysis** should be carried out every year since water quality can vary considerably over time. This is particularly the case when water is taken from shallow wells or high water table areas. The pH of the water used for watering plug transplants should be 5.5–6.5. At these levels, macro- and micronutrients are easily available to plants. Too high pH values may cause iron deficiency, often resulting in pale green newly emerged leaves; too low pH may cause micronutrient toxicity

TABLE 1
Optimum temperature ranges for germination of seeds and growth of various vegetable transplants

Crop	Germination period		After germination period	
	Germination temperature (°C)	Approx. no of days to emergence	Growing temperature – day (°C)	Growing temperature – night (°C)
Tomato	21–24	3–4	18–21	10–18
Pepper	26–28	4–6	18–21	12–18
Cole crops	18–24	2–3	12–18	8–5
Vine crops (cucurbits)	24–30	2–3	21–24	12–18
Onion	18–24	3–4	16–18	8–15

(e.g. boron). Water from ponds and wells is often alkaline (pH > 7.0) and should be treated with acid to lower the pH. When pH values are low and bicarbonates in the water are < 10 mg litre^{-1}, they need to be added in order to stabilize the pH. The use of potassium bicarbonate could under this circumstances help to increase bicarbonate concentration, as well as increase water pH.

The **frequency** of watering depends on weather conditions and on the stage of maturity of the crop. Watering should match water-holding capacity of the substrate in the seedling cell; drainage should be minimum, in order to prevent nutrients leaching from the growing medium. It is important to water thoroughly and moisten the entire plug so as to promote root growth to the bottom of the plug and ensure that root growth is not confined to the top of the plug. Plug transplants should be watered thoroughly in the morning, and not late in the afternoon to avoid plants remaining wet overnight, which can result in disease problems.

Uneven growth (knowing as pillowing) resulting from differences in air circulation and watering between cells within trays is a common problem. The outside cells are usually drier and growth is slower compared with the cells located in the centre of trays. This situation is compounded once the larger central plants begin to shade the growing media while the smaller external plants continue to let in more sun, allowing more evaporation. As a result, individual flats become dome-shaped or "pillowed". This problem tends to start when trays are not placed tightly against one another, allowing for greater airflow and a faster rate of drying.

Fertilization

Fertilizers are commonly applied through the irrigation system (fertigation). The frequency and concentration of fertilizers applied vary depending on the crop, stage of maturity and climate conditions (e.g. solar radiation and temperature). Some commercial substrates for transplant production contain a "starter charge" of fertilizers, in which case no fertilization is required for the first few days.

Nitrogen (N) is the most powerful nutrient element conditioning the growth of young plants. Vegetable crops vary in their response to fertilizer and the feeding programme must be modified accordingly – for example, tomatoes are very responsive to fertilizer and excess fertility reduces transplant quality. If feeding at every watering, use a fertilizer concentration of 50–100 mg litre^{-1} N, depending on the stage of plant development; but if feeding once every several days, use a concentration of 100–200 mg litre^{-1}. Peppers and eggplants require more fertilizer than tomatoes. If feeding at every watering, use approximately 100 mg litre^{-1}; increase the concentration if feeding less often. For cole crops, one application per week of 100–150 mg litre^{-1} should be sufficient under most conditions. Vine crops (cucumber, squash and melon) have a relatively short growing cycle compared with other crops. Two to four applications of fertilizer at weekly intervals at 100–150 mg litre^{-1} should be sufficient to produce good quality vine crop transplants.

For all crops, excessively high nitrogen doses may cause overgrowth or even toxicity to the plants. Seedlings grown on high rates of nitrogen fertilization are succulent, less resistant to dry weather and solar radiation; this leads to a low rate of plant survival after transplanting in the open field.

Phosphorus (P) and **potassium (K)** are also important to guarantee steady and balanced growth of vegetable seedlings. Therefore, combined nutrient solutions containing the three most used elements are commonly applied in nurseries. The solution should contain appropriate quantities of nutrients: N (50–200 mg litre^{-1}), P (10–40 mg litre^{-1}) and K (100–300 mg litre^{-1}). The use of combined fertilizers (0.5–1 g litre^{-1}) with a 2 : 1 : 3 ratio of the main nutrient elements (N : P_2O_5 : K_2O) and enriched with Mg and micronutrients is recommended for vegetable seedlings.

CO_2 enrichment

Normal concentration of carbon dioxide (CO_2) in the atmosphere is around 380 ppm. During seedling propagation in the winter, greenhouse CO_2 concentration can fall to suboptimal levels, with a consequent reduction in photosynthetic rate and slowing of seedling development. Under adequate light and temperature conditions, the artificial increase in CO_2 concentration (from 800 to 1 000 ppm) improves seedling growth. Supplementary CO_2 should be used during periods of sunny weather, but not in cloudy weather or at night. CO_2 can be extracted from burners using oils or natural gas. In such cases, care must be paid to avoid the presence in the greenhouse of toxic gases – whether for plants (SO_2, ethylene etc.) or humans (carbon monoxide). Alternatively, liquid CO_2 purchased from commercial suppliers may be used.

Module size

The cell size influences the field performance of the transplant. When larger cells are used the plant has more room to grow, so it is possible to produce an older, larger and more mature transplant without it becoming spindly with compressed roots. Transplants grown in larger cells have been reported to give higher early yields compared with those grown in smaller cells; however, there is little difference in overall yield. Moreover, larger cells take up more greenhouse space and are more expensive to grow.

A deep-celled tray has a larger cell volume and more water and fertilizer are available to the plant. Deep cells tend to promote faster growth and they do not need watering as frequently as shallow cells. With deep trays, it is important to water thoroughly and moisten the media to the bottom of the plug in order to promote root growth all the way down. Table 2 lists recommendations regarding cell volume for specific crops.

TABLE 2
Specifications of commonly used vegetable transplant trays (adopted from LeBoeuf, 2013)

Number of cells per tray	Plant density (cells m^{-2})	Cell volume (cm^3)	Recommended crops
24	140	171	Early tomatoes, vine crops
38	230	106	Early tomatoes, vine crops
50	310	66	Early tomatoes, vine crops
72	470	43	Early peppers, early cole crops, early vine crops
128	780	23	Main-season tomatoes, peppers, cole crops
200	1 220	11	Late-season peppers, cole crops
288	1 750	7	Processing tomato

LeBoeuf, 2013 (adapted).

Transplant age

The optimum age for vegetable transplants depends on both the crop and the cell size used. Generally, as the transplant becomes older, the leaf number, height, leaf area and dry shoot weight of the vegetable seedlings increase, regardless of transplant cell volume. Older transplants generally produce earlier yields, while younger transplants produce comparable yields, but take longer to do so.

While planting the largest seedlings possible might appear advantageous in terms of getting the crop off to a quick start, larger seedlings are also more prone to transplanting shock (Vavrina, 1998). Generally, relatively young vegetable transplants produce the best stand and fastest crop development. On the contrary, older plants have difficulties establishing their root system and commonly experience strong growth retardation after transplanting, followed by significant delays in crop development.

There is no single definition of the optimum seedling age or the most appropriate phenological stage of transplant. In general, northern countries are more suited to older and further developed seedlings. For example, the best transplanting age for tomato in Canada is considered to be when the first flowers are showing, while seedlings over 5 weeks old are less desirable in Mediterranean countries (Zeidan, 2005). Despite the fact that modern cultivars, improved production systems and technical expertise can all enable the production of high yields regardless of transplant age, the use of relatively young transplants is strongly favoured for commercial production under South East European conditions.

Growth control and hardening techniques

Hardening is a crucial step in transplant production. In general, transplants should have well-balanced shoot and root development. Young seedlings growing at high planting densities may have extended stems or their shoot mass may be too large in relation to the roots. Spindly tender plants are more vulnerable to mechanical damage during handling and transplanting.

The practice of hardening preconditions transplants to tolerate transplanting stress by exposing them to several hardening factors such as water stress. The practice is more commonly applied to transplants destined for open-field production or for cultivation under environmental conditions harsher than those they were exposed to during propagation. Nevertheless, excessive hardening should be avoided. Growth control and hardening practices are described below.

Day–night temperature difference (DIF)

The plant stem growth rate of some floricultural and vegetable species is positively correlated with the difference between day temperature (DT) and night temperature (NT), termed DIF (DIF = DT – NT). A greater DIF promotes stem elongation, while daily average temperature determines overall development rate (leaf emergence and flower initiation). A low DIF helps keep the seedlings compact in size without the use of growth regulators. Keeping transplants cooler during the day than at night (within a temperature range of 10–30 °C) reduces plant height (Wien, 1997). High temperatures in the first 3–4 hours after sunrise can cause considerable elongation in vegetable seedlings. This excessive elongation can be mitigated by keeping the greenhouse temperature 4–5 °C cooler than the night temperature for a few hours early in the morning.

Irrigation deficit / water stress

When plants are subjected to mild water stress, the rate of stem elongation and leaf area expansion decrease, and carbohydrates accumulate in the leaves. Water stress therefore induces changes in plant growth that are helpful in preparing the plant for transplanting. However, as the plant transpiration rate is largely affected by environmental conditions, it requires a lot of experience to determine irrigation timing without imposing too much water stress.

Nutrition deficit / oversupply

The growth rate of transplants can be regulated by controlling the concentration of nitrogen and other nutrients in the substrate. Reducing nutrient supply just before transplanting can slow down the growth rate during the hardening stage. As long as care is taken to not completely starve the transplants of the major nutrients, there should be little problem with the resumption of growth after transplanting (Wien, 1997). Transplants are sometimes treated with a concentrated nutrient solution: salt stress reduces the growth rate and favours earliness.

Shaking / brushing

Mechanical stress can enhance ethylene production, which affects seedling growth. Brushing the tops of transplants several times a day can have remarkable dwarfing effects (e.g. shortening of stem and petioles) and increase chlorophyll content. Brushing has proved successful in Solanaceous crops (tomato, pepper and eggplant); however, care should be taken with cucurbits, which are more fragile and prone to damage by brushing.

Pest and disease control

Early detection is critical to control biological problems and minimize damage. Propagation of vegetable seedlings is usually conducted in short cycles; nevertheless, pests and diseases spread very rapidly because of the high density. The following recommendations (Kubota *et al.*, 2013) aim to **minimize the risk**:

- Be familiar with the symptoms of commonly occurring pests and diseases, in order to help identify problems at an early stage and minimize the loss of plants.
- Minimize access to the affected area and notify workers of the outbreak as soon as any symptom is found.
- Apply appropriate control methods (chemical or biological) in consultation with the local extension agent or advisor.
- Do not apply foliar fungicides under high-temperature conditions as this may injure foliage.

Packing and transportation

Transplants are packed in trays inside cardboard boxes or on racks in trailers. The transport distance should be as short as possible, to minimize the costs as well as the damage associated with transportation. When scheduling transportation, time carefully to avoid the risk of exposing transplants to extreme heat or cold. In summer, heat stress can be avoided by selecting overnight or early morning transportation rather than midday transportation – especially when plants are transported in a non-refrigerated truck. On the other hand, when a freezing night is expected, midday transportation is more desirable.

Mechanical stress by vibration during transportation is known to negatively impact the transplants. It can cause physical damage and promote ethylene production. Ethylene accumulation induces adverse physiological impacts, such as flower abortion or leaf yellowing, especially during long distance transportation (Kubota *et al.*, 2013).

GRAFTED SEEDLINGS

Grafting of vegetable seedlings is a unique horticultural technology. It is used to overcome soil-borne diseases and pests and to add vigour to plants under various environmental stress conditions. An appropriate rootstock–scion combination can:

- increase soil-borne disease and pest resistance/tolerance;
- increase tolerance to abiotic stresses (e.g. soil temperature, drought or salt stress); and
- increase plant vigour and yields.

Grafting can also improve fruit quality (e.g. increasing firmness), although negative effects (e.g. altered flavour, reduced sugar content) are sometimes reported.

Rootstock selection

The selection of appropriate rootstock is a delicate process. It is necessary to take into account not only the specific problems to be solved by grafting, but also the compatibility between scion and rootstock. Therefore, it is essential to test the candidate rootstocks on a small scale before introducing the rootstock on a larger scale. Table 3 provides guidelines for rootstock selection.

Cucurbits (watermelon, muskmelon and cucumber) are grafted on interspecific hybrid squash (*Cucurbita maxima* × *C. moschata*), bottle gourd (*Lagenaria siceraria*), figleaf gourd (*C. ficifolia*) or other melon (*Cucumis melo*, or wild type etc.).

Some interspecific hybrid squash rootstocks have chilling tolerance in addition to disease resistance, but flowering can be delayed or sugar content reduced


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Plate 6
Cucurbit rootstock plant at the grafting stage


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Plate 7
Grafted cucumber seedlings

TABLE 3

Guidelines for selecting grafting rootstocks of tomatoes and cucurbits

Type	Resistance	Other traits
Tomato		
Interspecific hybrid (hybrid between different tomato species, e.g. 'Maxifort' [*Solanum lycopersicum* × *S. habrochaitaes*])	Different for different roostock varieties but generally include fusarium, verticillium wilt, root knot nematodes. Some include bacterial wilt and higher race (race 3) of fusarium.	They are generally vigorous. Some rootstocks have chilling tolerance. However, less uniformity in plant growth at the seedling stage (germination and emergency).
Intraspecific hybrid (hybrid within the same cultivated tomato species, e.g. 'Aloha' [*Solanum lycopersicum*])	Different for different roostock varieties but generally include fusarium, verticillium wilt, root knot nematodes. Some include bacterial wilt andhigher race (race 3) of fusarium.	Very uniform growth. Less vigorous.
Cucurbits		
Interspecific hybrid squash (hybrid between different squash species, e.g. 'Tetsukabuto' [*Cucurbita maxima* × *C. moschata*])	Fusarium. Some also have vine decline, verticillium wilt and anthracnose.	For all cucurbits. Traits varied among different rootstock varieties (vigour, chilling heat or drought tolerance etc.).
Bottle gourd (*Lagenaria siceraria*)	Fusarium. Some also have vine decline, verticillium wilt and anthracnose.	For watermelon. Chilling tolerance.
Fig leaf gourd (*Cucurbita ficifolia*)	Fusarium.	For cucumber. Chilling tolerance.

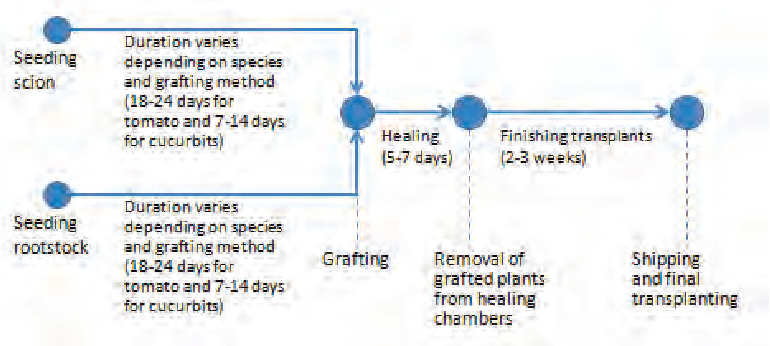
Kubota *et al.*, 2013 (adapted).

if fertilization is not managed properly. Bottle gourd rootstocks have chilling tolerance and are less vigorous than squash rootstocks; they have little effect on fruit quality and flowering. Cucumber rootstock is often selected for its influence on fruit quality, as certain rootstocks reduce the deposition of silicon over the fruit epidermis – or "bloom" – and therefore improve fruit quality. Some rootstocks are also more tolerant to chilling than others.

Rootstocks widely used for grafting tomato are simply tomato (*Solanum lycopersicum*) hybrids, or hybrids between tomato (*S. lycopersicum*) and a wild relative of tomato (e.g. *S. habrochaites*). The latter – also known as interspecific hybrid rootstocks – are generally more vigorous but sometimes lack uniformity of germination/seedling emergence.

Eggplant can be grafted on torvum (*Solanumtorvum*), eggplant (*S. melongena*) and scarlet eggplant (*S. aethiopicum*). For all crops, rootstock selection must take into account not only enhanced resistance to a common pest or environmental stress, but also the expected level of rootstock vigour in relation to the scion. If the rootstock is much more vigorous than the scion, there can be excessive vegetative growth, which can result in reduced yield (e.g. in tomato).

FIGURE 1
Example timetable for producing grafted tomato and cucurbit seedlings



Kubota *et al.* 2013.

Grafting time and methods

Grafting must take place at the optimal growth stage of the scion and rootstock seedlings; this depends in turn on the species and the grafting method adopted. If seedlings are overgrown or too young, the rate of success decreases. The timing of seed germination and the growing conditions are crucial for the production of optimal scion and rootstock seedlings for grafting. See Figure 1 for an example of a propagation timetable.

Healing grafted seedlings

Healing is critical in grafted seedling production; it requires appropriate facilities and a high level of expertise. There are generally two types of healing systems: growth room specifically designed for healing and greenhouse-based healing system.

Growth rooms create a uniform climate independent of the outside climate conditions; this system is suitable for grafts that are difficult to heal. The healing chamber has artificial lighting – typically fluorescent or LED lamps – installed in multi-layered shelving units. The chamber must also have good humidity control to create near-saturating humidity.

Greenhouse-based units (inside a greenhouse or high tunnel) are widely used. However, maintaining air temperature, light intensity and humidity at optimum levels presents a greater challenge. To achieve appropriate healing conditions inside a greenhouse, it is therefore essential to install: shade cloths to reduce light intensity, plastic covering to maintain the high humidity, a fogging or under-bench misting system, and a heating system.

GAP recommendations – Good quality vegetable transplants

Seed quality and germination

- Use seeds from a reliable source.
- Test seed germination rate prior to planting.
- Avoid using seeds stored beyond the expected storage life.
- Select germination conditions optimal for the crop species.
- Schedule transplant production backwards, starting from the target delivery period.

Materials

- Select types of tray/container suitable for the specific production.
- Limit re-use of seedling trays (or plug trays) to a maximum of 2–3 times.
- Select substrate carefully and understand its physical properties.

Seedling management

- Maintain the media pH and EC within the optimum range.
- Avoid over-irrigation to improve the fertilizer- and water-use efficiency.
- Avoid wetting foliage.
- Optimize fertilization based on the plant's needs and the climate conditions.
- Inspect for signs of diseases and pests and learn to identify them. If there is any sign of disease or virus infection, do not transport plants.
- Understand and practise hardening methods.
- Avoid delay in transplanting.
- Avoid long distance transportation and select the transportation route with the objective of minimizing mechanical stress.

When the grafted seedlings are set in position, the relative humidity must be ≥ 95%; it gradually decreases until the end of healing period. The optimum healing temperature is 28–29 °C. Under these conditions, cell division is fast; the callus develops quickly and bridges the cut surfaces of scion and rootstock. Grafted seedlings can be in the dark for the first 24–48 hours and light is then gradually increased; the target light intensity is 100 µmol m^{-2} s^{-1} PPF (or 5 400–7 400 lux, depending on the light source). The healing period for tomato and cucurbits is usually 4–6 days.

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7. Production systems: integrated and organic production, and soilless culture

G. Popsimonova,[a] B. Benko,[b] L. Karic[c] and N. Gruda[d]

[a] *University Ss Cyril and Methodius, Skopje, Republic of Macedonia*
[b] *University of Zagreb, Croatia*
[c] *University of Sarajevo, Bosnia and Herzegovina*
[d] *University of Bonn, Germany*

ABSTRACT

Vegetable production in South East European countries is generally carried out in the soil in plastic-covered greenhouses. This chapter presents greenhouse production systems – integrated production in the soil or in soilless culture systems and organic crop production – and compares them with conventional cultivation. Emphasis is placed on specific cultivation practices that can be easily and efficiently adopted by growers. Various options are described for growers, depending on the technology used and in accordance with the climatic and economic conditions. Investment costs and a template table for calculation of variable costs are included in order to provide farmers with a tool to make an economic assessment and quantify the various parameters requiring consideration.

INTRODUCTION

In South East Europe (SEE), out-of-season vegetable production is commonly carried out in the soil under plastic-covered greenhouses. Total protected cultivation area in the region amounts to about 101 888 ha (approximately 5.15% of the total vegetable cultivated area). The corresponding production is about 7 962 240 tonnes and accounts for approximately 19.09% of total vegetable production.[1]

Three main production systems are used in SEE countries: conventional, integrated crop production and organic production. This chapter describes specific cultivation practices that can be easily and efficiently adopted by the region's growers. For each system, options are presented to enable growers to evaluate practices based on the climatic and economic conditions and make the best choice.

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[1] See Part I, Chapter 2.

The concepts of integrated crop management and organic cultivation have been developed as a response to the intensive exploitation of the natural resources (soil, water and air). The EU member countries as well as the candidate countries have approximated the corresponding legislation that regulates agricultural practices, especially with regards to fertilization, irrigation and plant protection. Whereas in the EU countries, the term "conventional agriculture" (CON) implies application of integrated crop management, this is not the case with all SEE countries. Although the legislation might be in place, the actual implementation is just beginning or has not yet started. Moreover, there are still markets outside the EU that accept products with lower criteria on pesticide residue levels and fruit quality. For that reason, in the following comparison of production systems, a distinction is made between conventional cultivation and integrated crop management.

DEFINITIONS

In order to achieve efficient and durable production in line with the ecosystem and product quality demands, the concept of **integrated plant (or crop) production (INT)** – has been developed. It maximizes the powers of nature, but also incorporates modern production technologies that are adapted to the ecosystem, with respect for soil fertility, product quality and animal welfare, even if it entails forgoing maximum yields.

Principal characteristics of INT

- Selection of suitable location.
- Diversified crop rotation.
- Fertilization only when necessary and in accordance with soil and plant analyses.
- Weed control focused on sustainable yield stability rather than total weed elimination.
- Minimization of offensive pest and disease control applications and implementation of preventive measures, including:
  - grafting and cultivation of resistant crop species and varieties;
  - use of protective insect screens and safety access system (SAS);
  - promotion of crop resistance through fertilization, irrigation, biostimulants and other technological measures (e.g. climatic conditions regulation); and
  - promotion of beneficial insects and pest control, applying the damage threshold principle and in accordance with prognosis models.

Organic production (ORG) is an environmentally sustainable system that integrates the rational use of natural resources, biodiversity conservation and environmental protection.

Norms and regulations govern ORG, including the control and certification of production and products. Organic production methods are regulated at international level according to the standards of the International Federation of Organic Agriculture Movements (IFOAM), the international umbrella organization for organic agriculture. In the European Union, organic agriculture must conform to the provisions of the relevant EU regulation (834/2007).

Principal characteristics of ORG

- Good land management leading to good soil fertility, resulting in a high content of organic matter in the soil, high microbiological activity and good soil structure.
- Crop rotation with balanced fertility, weed control and reduction of pests and diseases.
- Preventive control by rejecting chemical approaches for the destruction of weeds, pests and diseases.
- Profitability, due to output of organic cash crops and/or livestock.

Little and Frost, 2008.

Integrated vegetable production in greenhouses may take place either in the soil or in soilless culture systems. The term **“soilless culture” (SC)** refers to the cultivation of plants in systems without soil in situ. It comprises systems without solid medium, i.e. liquid, as well as aggregate systems and is the most intensive and effective in today’s horticultural industry. The liquid system is also called “hydroponics”, whereas the periodic spraying of the plant roots with nutrient solution is called “aeroponics” (Gruda and Tanny, 2014). Adams (2002) divides soilless culture into two categories based on their structure and the way the nutrients are provided:

- Soilless culture on organic substrates (e.g. peat, coir, sawdust, pine bark and rice hulls), which are not inert and nutrients are supplied by solid fertilizers and liquid feeds.
- Hydroponics, which includes cultivation in either inert substrates (e.g. rockwool, perlite, gravel) or nutrient solution without the use of any aggregate (water culture systems, such as nutrient film technique [NFT], floating hydroponics, aeroponics, deep flow technique).

In all types of soilless culture, the supply of nutrients is based on the supply of a complete nutrient solution (Savvas *et al.*, 2013), because of the limited nutrient reserves that can be included in a substrate. Soilless cultivation systems offer significant advantages compared with direct cultivation in soil. For example, protected crops may be cultivated in areas with poor or adverse growing conditions (e.g. poor soil structure or high soil acidity/salinity). Whereas SC can be used in both CON and INT, for ORG it is still debatable whether the detachment from the natural soil generating layer can satisfy the concept of organically produced plants, and therefore the denomination “organic soilless culture” is not allowed in Europe. In most cases, soilless culture is applied as part of an integrated greenhouse production system to provide benefits arising from a more efficient control of the root environment.

Conventional agriculture refers to the current and traditional agricultural practices, without adherence to any specific crop production protocol. It is also considered the reference system (check) for comparison and improvement.

PREREQUISITES FOR STARTING PRODUCTION

Before starting the production and making the choice of a cultivation system, the grower has to take into consideration several important factors regarding the market, climate, water sources and environmental protection. Besides having access to sufficient solar irradiation, water, power, main roads for transport etc., there are technical specifications for each different greenhouse type.[2]

The capital costs vary depending on the climate conditions, support and covering material, and the applied technology: from €20 m^{-2} to as much as €200 m^{-2} for high-tech greenhouses. Variable costs include seedlings, heating, ventilation and transportation. Labour accounts for the largest portion of the variable costs. For conventional production there should be approximately 5 workers per hectare of production area. Organic cultivation requires a greater number of working days (i.e. workers per hectare of production area), since most of the operations are performed manually. For INT, the grower should foresee expenses for soil and tissue sampling and advisory services. At the end of this document, a template is provided for the calculation of the gross margin on variable costs.

Soilless culture should be suited to well-equipped high-tech greenhouses (Plate 1), where SC equipment represents only a small fraction of the total investment. However, low-tech greenhouses may sometimes be modernized and used for SC, depending on the economic and technical conditions, such as region, farm characteristics, type of greenhouse, soil situation, water resources, market requirements, establishment costs and, last but not least, restrictions on environmental pollution. Low-cost alternatives are suitable for growers with limited capital or in regions with a


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Plate 1
Soilless culture suited to well-equipped high-tech greenhouses

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[2] See Part II, Chapter 1.

fluctuating demand. In low-tech SC, a simple system can control the distribution of the nutrient solution or a drip irrigation system can be used.

For ORG, it is necessary to manage the greenhouse soil area according to the established norms for the 3 years preceding production. Only plots that have not been cultivated in the previous 2 years can immediately be adopted – provided they meet the other conditions. During the transition period, it is necessary to keep books for the fields and to record data for each greenhouse: orientation, size, soil analysis (on which to base fertilization), rotation crops planned and cultivation measures applied from planting to harvesting.

Greenhouse production makes it possible to extend the growing season for crop production and growing crops in regions where outdoor cropping is not normally possible. While this is not entirely consistent with Art. 3(a)(i) of Reg. 834/2007 ("respect nature's systems and cycles"), greenhouse production is considered acceptable in organic farming.

Greenhouse organic production is based on the following:

- Knowledge of plant biology.
- Cultivation closely based on ecological principles and in harmony with the technical potential of the greenhouse.
- Efficient use of energy and use of alternative energy sources.

The grower needs to ensure that the technical characteristics – dimensions and potential for climate control – of the greenhouse correspond to the existing norms for organic production.

SOIL AND SOILLESS CULTURE MANAGEMENT

Soil is fundamental in agricultural systems. A rich soil ecosystem contributes to crop and livestock performance. Good soil husbandry ensures long-term fertility, aids yield and profitability, reduces the risk of soil damage due to erosion and compaction and associated environmental concerns, and decreases crop susceptibility towards pests and diseases.

Quality of life below ground determines productivity above!

Soil organic matter has a vital role in the ecosystem, and is fundamental for the health of the soil and crops. It comprises a mixture of plant and animal residues in various stages of decomposition, their breakdown products, and the bodies of living and dead micro-organisms and their decomposing remains. Soil organic matter affects the soil structure, allowing aeration and biological activity, with a positive impact on both crop performance and plant defences. The crop yield depends, *inter alia*, on the level of plant nutrients released from organic matter during the mineralization process. The nutrient level depends mostly on the reserves of humus in the soil and its quality, as well as the climate. The reserves of humus and nutrients in the soil are constantly reduced as a result of organic matter mineralization, nutrient leaching and the permanent removal of nutrients during plant growth. If these losses are not compensated by the application of fertilizers, or by recurrent application of organic matter to the soil, the yield decreases. Organic or inorganic fertilizers containing nitrogen, phosphorus and potassium (NPK fertilizers), as well as other plant nutrients, have to be applied according to the results of soil analysis.

The quantity of organic matter, in particular soil humus, is determined by the proportion of carbon and nitrogen. A C : N ratio of 10 : 1 is preferable and considered optimal. Plant residues with a C : N ratio of 20 : 1 or lower (e.g. composted manure C : N = 15 : 1) ensure sufficient nitrogen for the micro-organisms required for decomposition, and release sufficient nitrogen to plants. However, for values above 20, there is competition for nitrogen among plants and bacteria, which can result in nitrogen deficiency for the plants. For example, if straw with low nitrogen content (C : N = 80 : 1) is incorporated in nitrogen-poor soil, bacteria will slowly increase, because the straw is poor "food" for micro-organisms. The process of decomposition can be accelerated by applying additional quantities of nitrogen fertilizers in order to meet the needs of micro-organisms and plants.

Selection of the SC system and growing media used has technical and financial implications and is not a simple process. Inorganic growing media include rockwool, perlite, tuff, volcanic porous rock, expanded clay granules, vermiculite, zeolite, sand and gravel; while organic growing media include peat, compost, bark, coir, wood fibres and other wood residuals. Growing media may be used in containers (organic substrates, perlite), in the form of prepared cubes (rockwool) for seedling and transplant production, in bags (peat-based substrates), as slabs (rockwool), on mats (polyurethane foam) and in troughs (rockwool).[3] Therefore, the decision to use a substrate as a growing medium in a greenhouse depends on availability, cost and the medium characteristics, i.e. its physical, chemical and biological properties.

In any substrate, the absence of pests and pathogens is very important. Biostability and biological inertia are other parameters to be taken into consideration, particularly when long cycles are carried out or the growing medium is reused in successive growing cycles. Depending on its physical, chemical and biological properties, each substrate is suited to its own growing technology and management approach (Gruda *et al*., 2013).

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[3] Growing media are described in detail in Gruda *et al*. (2013).

TABLE 1
Advantages and disadvantages of substrates used for vegetable production

Material	Advantages	Disadvantages
Sand	Relatively low cost Good drainage ability	Low nutrient- and water-holding capacity
Rockwool	Light weight and ease of handling Totally inert media Possibility to carefully control nutrition	Disposal problems Energy consumption during manufacture
Vermiculite	Light weight High nutrient-holding ability Good water-holding ability Good pH-buffering capacity Good aeration	Tendency to compact when too wet High cost High energy consumption
Perlite	Low density Sterility Neutral pH No decay Local product in some regions Excellent aeration	Low nutrient- and water-holding capacity High cost High energy consumption
Peat	Physical stability Good air- and water-holding capacity Low microbial activity Light weight Low pH, easy to adjust Generally low nutrient content depending on origin	Finite resource Environmental concerns and contribution to CO_2 release Increasing costs due to energy crises Possibly strong acidicity
Coconut coir	Physical stability Good air content and water-holding capacity Low pH, easy to adjust Low density	Potentially high salt levels Energy consumption during transport
Bark (well matured)	Good air content and water-holding capacity	Increasing costs – since used as an alternative to fuel and in landscaping
Green compost	Good source of potassium and micronutrients Suppression of diseases Good moisture-holding capacity	Variability in composition Potentially excessive content of salt or heavy metals High CEC Tendency to become easily waterlogged

Gruda *et al*., 2016.

There is a general trend towards the use of **natural resources** and **renewable raw materials**. For **sustainable production** of vegetables in SC, priority should be given to locally available and not very expensive or locally manufactured and standardized growing media.

PLANT NUTRITION AND IRRIGATION

It is important to know the soil and plant nutrient status to ensure that fertilizer application does not exceed the recommended requirement. Factors to be taken into account are crop demand, and any available nutrient supply from the soil and crop residues. A balanced approach is essential, adapting practices to local situations to reduce the risk of environmental pollution by fertilization.

In order to make an accurate fertilizer recommendation, representative soil samples must be collected with care. If the field is uniform, one sample for a 10-ha area can be analysed in the laboratory. An analysis sample comprises as many samples as possible taken from the whole area; these are mixed and a 1-kg composite sample is taken to the laboratory for analysis. It should be noted that of a 1-kg soil sample representing an area of ≤ 10 ha, only a few grams are used in the actual analysis.[4]


POPSIMONOVA

Plate 2
Soil sampling in a plastic tunnel

Soil analysis may be done with a simple tool or soil test kit for a quantitative analysis of soil pH, nitrogen, phosphorus and potassium; alternatively, a complete chemical analysis may be performed in soil laboratories. In both cases, the result helps farmers decide how best to prepare the land to provide for the nutrient requirements of the plants.

To supply a certain amount of plant nutrients, the amount of fertilizer to be applied per hectare depends on the composition of the fertilizer.

Nutrient solution

For the cultivation of leafy vegetables (e.g. lettuce, rocket, lamb's lettuce, spinach, chard, chicory, watercress and cress) and herbs (e.g. parsley, basil, oregano, marjoram, thyme, sage and dill), growing systems without solid medium are suitable. The most commonly used systems are: NFT, floating hydroponics and aeroponics.

With **nutrient film techniques (NFT)**, a thin layer (approx. 1 cm) of nutrient solution continuously flows over the roots of the plants in shallow inclined channels (0.3–2%), aided by gravity. Nutrient solution (root) aeration is achieved by turning up the edges of polyethylene pipes and positioning them around the sides of growing pots or cubes to form a gully through which a thin stream of nutrient solution flows. The nutrient solution is supplied from the tank to the channel by a pump. Any solution not taken up by the plants drains and is gathered in containers, analysed and recirculated into the system.

In **floating hydroponics**, plants are grown on polystyrene plates or in containers that float on nutrient solution. The plants have 24-hour access to water, macro- and micronutrients in the form of ions, and oxygen, which can be optimally used during all stages of growth. This produces faster growth and early harvest, resulting in a more productive cycle during the year and higher yields.

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[4] Note that if the area is not uniform, it is preferable to send several representative samples for analysis rather than mixing all soil samples.

TABLE 2
Content of fertilizers in different compositions

Material	Fertilizer		
	N	P_2O_5	K_2O
Anhydrous ammonia	82		
Ammonium sulphate	20		
Ammonium phosphate	16	20	
Ammonium chloride	25		
Urea	45		
Superphosphate		20	
Triple superphosphate		48	
Nitrate of potash			60
Sulphate of potash			50
Complete	14	14	14

Water forms the basis of a nutrient solution; quality water must be supplied in sufficient quantities. Prior to use, the water must be analysed to determine the basic level of minerals and ions, as well as the pH. Microbiological analysis might also be necessary in some cases. Water quality is directly related to **salinity**. Water with a low concentration of dissolved salt ions, especially NaCl, is of high quality and it is easier for producers to formulate an optimal nutrient solution. Salinity is a measure of all the salts present and is quantified as electrical conductivity (EC). The general recommendation for source water is that EC should be < 1.0 dS m^{-1}. A higher EC can sometimes be feasible, as long as the ions causing the high EC can be used as nutrients by the plants. However, the concentration of these ions should still not be excessive, with respect to the corresponding uptake concentrations (Sonneveld, 2000). When water with low concentrations of mineral elements (rainwater or desalinated water) is used, the drainage water can be completely reused in a closed loop. Natural groundwaters or surface waters commonly contain substantial concentrations of mineral elements (e.g. calcium, magnesium, sulphur), often in excess of the uptake concentrations, and tend to be less suitable for closed growing systems. This must be accounted for during the preparation of nutrient solutions and the necessary adjustments made (Sonneveld and Voogt, 2009).

The content of (bi)carbonate in the primary water is directly related to **alkalinity**, i.e. the sum of HCO_3^- ions in natural water, expressed in units of milliequivalents (meq) of carbonates. In soilless production, alkalinity up to 8 meq is not a problem (Lieth and Oki, 2008) because it can be controlled through the addition of nitric acid when adjusting the pH. Higher alkalinity levels can also be managed in soilless culture through the addition of nitric acid, but they are not desirable because they are associated with excessive Ca (and sometimes also Mg) levels in the nutrient solution, thereby leading to excessive EC levels. The pH should be adjusted accordingly by adding HNO_3; but H_3PO_4 or H_2SO_4 may also be used up to the target $H_2PO_4^-$ and SO_4^{2-} concentrations, respectively, in the nutrient solution (Savvas, 2001; Sonneveld and Voogt, 2009).

Plant **water** demands are mainly determined by microclimate conditions and leaf surface. In conditions of high humidity, low light and low temperature, water consumption can be very low. It is fundamental to estimate the maximum water requirement prior to construction and installation of the irrigation system. The plant's water consumption is determined by growth rate, solar radiation, relative humidity and air movement.

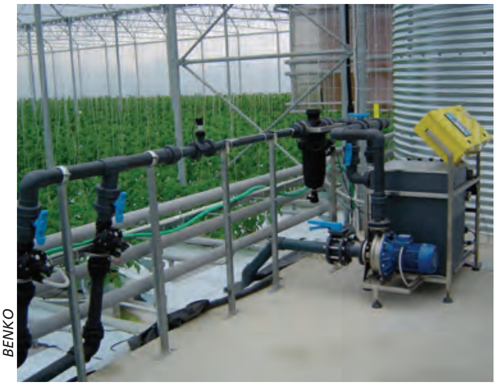

Plate 3
Fertigator for preparation and distribution of nutrient solution

In addition to water, **nutrient salts** or water-soluble fertilizers and acids are needed to prepare the nutrient solution. The advantage of nutrient salts is that they are chemical compounds comprising 2–3 elements, i.e. nutrients of high purity. Complex **water soluble fertilizers** usually contain nitrogen, phosphorus, potassium and magnesium, in addition to trace elements. Therefore, when the nutrient solution needs adjusting, it is not possible to alter the concentration of only one nutrient, but the levels of more than one nutrient in the fertilizer are changed. The **acids** serve to lower the pH of the water to the optimum level for hydroponics (5.5–6.5). The requirements (concentration and ratio) of specific ions depend on the crop. The EC should be 1.5–3 dS m^{-1}, depending on the crop.

Nutrient solution is prepared as 100 times concentrated solutions (stock solutions). At least two tanks are required for concentrated salt solutions and one for acid, because calcium salts should not be mixed with phosphates and sulphates. The nutrient solution is precisely prepared by fertigation heads, based on given parameters (pH and EC), climatic conditions (e.g. solar radiation, air temperature and humidity) and volume of leached nutrient solution. The fertigation head also distributes the solution following an irrigation schedule programmed by the user.[5]

In SC, the **fertigation system** may be either open or closed-loop. In an open system, excess nutrient solution is drained to waste and not recycled. It is the least expensive option. In a closed-loop system, drainage is captured, recovered and recycled (Gruda and Tanny, 2014). The volume of drainage for recycling should be 25–30% of the added nutrient solution. Closed-loop systems offer significant advantages: reduced environmental impact and greater savings. However, there are disadvantages: increased risk of spreading root diseases, buildup of high concentrations of unwanted ions and greater costs.

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[5] The composition and preparation of nutrient solutions in soilless culture are reported in detail by Savvas *et al.* (2013).

Plate 4
Filtration and UV sterilization unit

The drainage solution in a closed-loop system should be disinfected before reuse. There are various methods available for nutrient solution **disinfection**:

- **Pasteurization.** Nutrient solution is filtered then heated to pasteurization at 95 °C for 30 seconds. Pasteurized nutrient solution does not increase the temperature of the solution in the root zone because it is mixed with cooler fresh solution.
- **Chemical treatment.** In addition to typical fungicide disinfection, chemical treatment may also involve surfactants (non-ionizing, anionic, cationic), biogenic elements (Cu, Zn) and oxidizing agents (ozone, hydrogen peroxide, chlorine).
- **Ultraviolet (UV) radiation.** UV radiation at wavelengths of 200–280 nm (UV-C) has a strong impact on pathogens. For fungi, the dose is about 100 mJ cm^{-2}; for complete disinfection, including viruses, it is about 250 mJ cm^{-2}. UV-C wavelengths and doses are cited according to Wohanka (2002).
- **Filtration.** Membrane filtration, in particular slow sand filtration, has been successfully developed for the majority of pathogenic micro-organisms. Slow filtration is less effective against viruses and nematodes. Filtration is energy-efficient.
- **Microbial inoculation.** Although not universal, microbial inoculation of nutrient solution has a wide range of applications to specific pathogens. It is energy-efficient (Wohanka, 2002).

The nutrient requirements of vegetables do not depend only on the species and variety, but also on the means and timing of production in the greenhouse. Plants grown in the greenhouse are mostly produced from seedlings and they, therefore, develop a shallow and wide root system. It is important to have a good supply of easily available nutrients to avoid stress. Nutrition requirements are determined based on agrochemical analysis of the soil every year or every second year. Many producers also carry out chemical analysis of the plant tissues (commonly leaves), adjusting the plant nutrition based on the results.

Organic fertilizers

Mature organic fertilizers should be incorporated prior to soil tillage and planting, at a rate of 2–10 kg m^{-2}; the exact amount depends on the analysis results and the type of fertilizer. For species with adventitious roots (tomato, cucumber etc.), it is

TABLE 3

List of organic fertilizers and nutrients concentration used in greenhouse vegetable production

Fertilizer	N	P	K
Flour shellfish and crabs	9.2	1.5	0.5
Dry whey	5.3	2.5	0.9
Flour of feathers	13.6	0.3	0.2
Fish meal	10.1	4.5	0.5
Flour of animal origin	7.7	3.1	0.7
Cottonseed flour	6.5	1.1	1.6
Flour of fish scales	10.0	3.7	0.1
Distilled dry organic matter	4.3	0.9	1.1
Soy flour	7.5	0.7	2.4
Wheat bran	2.9	1.4	1.3
Alfalfas flour	2.5	0.3	1.9
Canola meal	6.0	1.1	1.3

Greer and Driver, 2000.

recommended to use organic compounds, compost or earthworms, levelling and filling around the stem. A variety of liquid organic fertilizers are available for the nutrient supply.[6]

CROP HEALTH AND PROTECTION

Crop protection refers to the control of pests, diseases and weeds.[7] An accurate understanding of crop health allows the farmer to assess resistance to biotic and abiotic factors. Crop protection practices should be rationalized, using integrated control to reduce risk. This could be achieved by:

- application of available biological methods;
- selection of tolerant cultivars; or
- balanced crop rotation.

Sanitary measures

Appropriate practices include soil solarization (sterilization) and steam pasteurization, in addition to integrated measures to combat nematodes (e.g. hygiene control, crop rotation). A wide range of biological resources have been developed, suited to crop protection in organic greenhouse production: biological insecticides (against thrips, whiteflies etc.) based on competition between useful and harmful insects; microbial toxins originating from fungi, bacteria and viruses

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[6] See Part II, Chapters 2 and 3 for more details about fertilizers and irrigation.

[7] See Part II, Chapter 5 for more details on IPM (integrated pest management).

(e.g. avermektins, Bactospeine, BioBit, Foray, Novodor); organic disinfectants (e.g. Jet 5); insecticides based on plant extracts (e.g. pyrethrum, Quassan, rotenone); and pheromone strips and plates (particularly suitable for greenhouses).

Biopesticides have advantages: in particular, their selective effect and low toxicity in the short term. Spinosad is used against many types of caterpillar and thrips. Capsaicin – an ingredient of essential oil of pepper – is effective in the fight against gossamer mites.

Agents based on *Trihoderma harzianumi*, *Gliocladium virens* can be used to combat *Pythium*, *Fusarium*, *Rhizoctonia* and *Sclerotinia* (Lazić *et al*., 2013). Soda is successfully used to suppress phomopsis, downy mildew, anthracnose, scab and botrytis. A mixture of 0.5% soda and 0.5% bio oil is an effective fungicide and can also be adopted for the disinfection of tools, shoes, clothes and tables, and as a disinfection barrier before entering the facility.

Biopesticides can be applied to protect against seedling lodging. Biopesticides based on *Bacillus subtilis*, copper products and preparations made with nettle, dandelion, wormwood, yarrow or garlic are effective. To achieve optimal results, biopesticides must be supported by preventive measures, for example, lowering the air humidity with regular ventilation and using nutrient preparations based on nettle, dandelion, yarrow or garlic. Growing seedlings grafted onto rootstocks resistant to specific soil-borne diseases and pests reduces the root damage caused by *Fusarium* and nematodes; this is particularly important for tomatoes.

Other **biological–natural means** are available for plant protection in greenhouse production to keep harmful organisms within the economic threshold level:

- Cultivation of “useful” plants that have allelopathic relations or are predators.
- Sowing of appropriate trap plants around the greenhouse (e.g. phacelia, plants of the Asteraceae family, calendula, marigold, buckwheat, nasturtium) to attract “useful” insects.
- Application of herbal preparations of species with known phytoncide effects (garlic and onions) or with an odour that repels or attracts pests (e.g. nasturtium attracts black aphids).
- Disinfection of seeds (using an infusion of chamomile, horseradish, garlic and nettle).
- Mulching to prevent the development of weeds (using organic or synthetic mulch).
- Mixed cropping.

Crop rotation

Organic vegetable production can be in pure or combined culture. A pure crop entails the cultivation of one species, while a combined crop is the cultivation of two or more cultures in the same area. In both cases, it is important to adhere to the principles of intensive crop rotation. Crop rotation helps reduce the accumulation of pathogens and pests (which, on the contrary, intensifies when one species is continuously grown), and also improves the structure and fertility of the soil when deep-rooted and shallow-rooted plants are rotated. According to regulation CL 12(b) in Reg. 834/2007, the rotation of legumes and green manure is recommended for proper plant nutrition. Adopting nitrogen from the air, legumes reduce the required amount of organic matter that is necessary to enter fertilization.

However, for economic reasons, it is not easy to follow this recommendation in greenhouse vegetable production. The vegetable species most commonly grown in protected cultivation belong to three plant families: Solanaceae (tomato, pepper, eggplant), Cucurbitaceae (cucumber, melon, squash) and Asteraceae (lettuce). In addition, green bean (*Phaseolus vulgaris* L.) is also grown in greenhouses.

It should be noted that the EU directive stipulates that, regardless of the species grown in crop rotation, short-term use of green manure and legumes is necessary for prevention against pests and weeds. (See Box for pre-crops recommended for association with certain vegetable crops.)

Good neighbours in the vegetable garden

Early carrot	Onion
Late carrot	Leek
Celery	Leek
Carrot	Lettuce
Tomato	Parsley
Tomato	Celery
Lettuce	Radish–kohlrabi
Brassicas	Bean
Cucumber	Dill

Kreuter, 1996.

Mixed cropping

Joint cultivation of two or more cultures – can be very beneficial. Positive effects are seen in the following joint crops: lettuce and onion; pepper and basil; tomato and cabbage. Moreover, mixed cropping can be adopted to repel or attract vegetable pests (Gilkeson and Grossman, 1991).

For example, growing tomato with cabbage reduces tansy and cabbage moth attacks on cabbage; or the cultivation of white clover with cabbage results in fewer attacks from aphids and cabbage moths. As a pre-crop, calendula, marigold, nasturtium or compost of some tropical plants (*Azadirachta indica*) are commonly used. Their chemical secretions reduce the number of nematodes.[8]

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[8] See Part II, Chapter 4 for more details on diversification.

Mulching

In organic production, it is advantageous to use organic green and dry mulch. However, in INT and CON greenhouse systems, it is easier to use plastic films of polyethylene, produced with permitted polymers and additives. Characteristics of different mulch foils include the following:

- **Black-foil:** increases temperature below the foil, decreases water consumption by approximately 50%, prevents weed growth, and improves phytosanitary conditions.
- **Silver–brown foil:** reduces heat conductivity, thanks to the brown colour beneath, reflects light, and reduces attacks by aphids, whiteflies and black spiders, thanks to the silver colour above.
- **Black–brown foil:** has a thermal effect that contributes to earlier harvesting (e.g. tomato ripening could be 10–15 days earlier) (Lazić *et al.*, 2013).
- **Black–white foil:** repels aphids and whiteflies, reflects light, and increases the quantity of photosynthesis active radiation, with a positive effect on off-season cultivation, especially tomatoes and peppers.
- **Red foil:** results in faster maturation, and improves fruit colouring.

METHODOLOGY FOR ECONOMIC ANALYSIS

The economic analysis is based on gross margin (GM) calculation of production systems. This provides a simple way to compare the profitability of enterprises that apply different management practices. The GM for any crop varies from year to year due to factors affecting actual yield (weather conditions, applied practices, prices and quantities of used inputs, labour skills) and market price (supply and demand).

Gross margin is defined as the enterprise's total income (marketed output value at market price) minus the variable costs: direct inputs, hired labour/machinery/services.

$$GM = \text{total income} - \text{variable costs}$$

Direct inputs include: planting material, crop nutrition and protection, packaging material, irrigation, heating fuel and energy for irrigation pumps.

Fixed costs are excluded from gross margin calculations. These costs remain constant in the short term, regardless of the level of output from the specific enterprise.[9]

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[9] Net margin is gross margin minus fixed costs.

For each production system, two separate gross margin budgets are calculated (GMEP for the existing practice; GMRP for the recommended practice).

The GM calculation is done at two levels, taking into account:

- GM1 – only direct inputs; and
- GM2 – also accounting for costs related to labour and machinery hire, as well as services provided by extension advisors, and laboratories for soil and water analysis.

The parameter is expressed in hectares of land. For maximum returns, the best production option is the enterprise with the highest GM per unit of limited resource (in this case, land).

The GM method enables calculation of the cost of production of the marketed output, in this case, the cost of producing 1 kg of tomatoes.

Cost of production = costs / marketed output

The cost of production is calculated at direct costs level (CP1) and at total variable costs level (CP2).

In Table 4, an indicative GM calculation is made for tomato production in soilless cultivation (rockwool slabs). The yield is 400 tonnes ha^{-1} and the output price is €1.5 kg^{-1}.

TABLE 4
Tomato production in soilless cultivation (1 ha)

Main product	Unit	Quantity	€/unit	Total
Tomato	kg	400 000	1.50	600 000.00
Total income	€			600 000.00
Variable costs				
I Direct inputs				
Transplants	Piece	30 000	1.00	30 000.00
Rockwool slabs	Piece	5 000	1.50	7 500.00
Nutrient salts	Lump sum	500	40.00	20 000.00
Plant protection products	Lump sum	1	1 000.00	1 000.00
Irrigation water supply	m^3	12 000	1.00	12 000.00
Polypropylene binder	kg	350	2.50	875.00
Hooks	Piece	240 000	0.01	2 400.00
Bumble bee hives	Piece	25	200.00	5 000.00
Heating, gas	m^3	130 000	0.60	78 000.00
Electricity	kWh	5 000	0.15	750.00
Packaging	Piece	40 000	0.60	24 000.00
Total direct inputs (I)				**181 525.00**
Gross margin (GM1) (total income, direct inputs, € ha^{-1})				**418 475.00**
Cost of production (CP1) (direct inputs, marketed output, € kg^{-1})				**0.45**
II Tractor services with labour costs included				
Transport	Treatment	3	1 000.00	3 000.00
				0.00
				0.00
				0.00
				0.00
III Engaged labour				
Planting	Working hour	600	0.98	588.00
Pruning	Working hour	2 000	0.98	1 960.00
Lowering	Working hour	2 000	0.98	1 960.00
Leaf removal	Working hour	2 500	0.98	2 450.00
Plant protection	Working hour	30	0.98	29.40
Harvesting (70 kg h^{-1})	Working hour	5 000	0.98	4 900.00
Grading and packaging	Working hour	4 000	0.98	3 920.00
IV Miscellaneous				
Nutrient solution analysis	Services	15	75.00	1 125.00
Extension service	Services	16	200.00	1 200.00
Total other variable costs (I+II+III)				**21 132.40**
TOTAL VARIABLE COSTS (I+II+III+IV)				**202 657.0**
GROSS MARGIN (GM2) (total income, total variable costs, € ha^{-1})				**397 342.60**
COST OF PRODUCTION (CP2) (total variable costs/marketed output, € kg^{-1})				**0.51**

GAP recommendations – Production systems

Integrated crop production

- Keep records of all inputs and operations. This will help with crop production planning and inspections.
- Conduct soil analyses and design a fertilization plan accordingly.
- Use drip irrigation in all kinds of greenhouse systems and especially in PE tunnels. When the irrigation system is also used for fertilization, monitor the water quality.
- Apply mulch to prevent weeds and limit evaporation from the soil.
- Monitor early symptoms of disease and pest appearance. Seek advice immediately on how to proceed with plant protection.

Soilless culture

- Determine the growing medium's physical and chemical properties and, if necessary, make adjustments to meet plant requirements.
- Consider container size and shape when selecting a substrate and an SC system.
- Adopt green technologies that reuse, reduce and recycle resources.
- Adapt the irrigation strategy to the physical properties of the growing media.
- Consider sustainability and environmental protection. If possible, use a closed system (more environmentally friendly than open systems).

Organic crop production

- Consider the exact location and size of the farm. Obtain the cadastral plan of the plot and take account of neighbouring, non-organic farms and other sources of pollution.
- Keep at least a three-year history of the plot.
- Use only certificated organic fertilizers and plant protection substances and keep all purchase records (invoices, receipts, delivery notes etc.).
- Record the use of certificated organic reproductive materials.
- Establish an insulating belt to avoid pesticide drift and crossover of grown varieties from surrounding conventional farms.
- Keep records of harvest, yields, storage, product labelling and packaging.

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8. Sustainability of vegetable production systems evaluated by ecological footprint

M. Bavec, M. Robačer, D. Stajnko, T. Vukmanić and F. Bavec

Faculty of Agriculture and Life Sciences, University of Maribor, Slovenia

ABSTRACT

Sustainability is a central issue in protected cultivation of vegetables, as greenhouse production considerably contributes to environmental pressures, such as greenhouse gas emission, nitrate pollution and biodiversity erosion. It is possible to reduce emissions by using renewable energy resources and sequestering carbon in soils or by adopting sustainable agricultural production systems, such as integrated vegetable production and organic farming. Sustainability can be evaluated through Life Cycle Analysis, which measures the environmental burden of a product and includes an eco-inventory, summarizing the mass and energy flows to and from the environment throughout the life cycle. In the case of protected vegetable production, it is necessary to take account of the energy consumed and the materials used to cover the building. An important evaluation tool is the environmental or ecological footprint, which estimates the biologically productive area needed to produce materials and energy. Ecological footprint calculations and the ecological efficiency index reveal the differences between production systems (e.g. organic, integrated and conventional, soil and soilless cultivation) in greenhouses, and take into account the distance from production to consumption.

INTRODUCTION

Greenhouse vegetable production is one of the most intensive agricultural productions with a high level of inputs. In addition, greenhouse vegetable production uses non-renewable materials and consumes large amounts of energy. On the other hand, greenhouse production is very productive with high yields. In a comparison of open-field and protected vegetable production in temperate climate areas, yields can be 2–3 times higher under plastic non-heated greenhouses, and up to 10 times higher in soilless crops in heated glasshouses.

Agriculture in the European Union (EU) must face serious **challenges** in the coming decades:

- competition for water and resources;
- rising costs;
- decline in agricultural productivity growth;
- competition for international markets;
- climate change; and
- uncertainties concerning the effectiveness of current European policy on adaptation strategies.

Greenhouse production provides an alternative approach for dealing with these challenges; it has the potential to change climatic conditions by implementing a range of technologies and practices for vegetable production (EGTOP, 2013).

The majority of today's consumers demand vegetables with high external and internal quality, free from pesticide residues and other agrochemicals (antibiotics, heavy metals, additives); moreover, there is increasing awareness of potential damage to the environment – whether in terms of soil, water, air or biodiversity. **Sustainability** is an important issue in agriculture and horticulture.

It is a global imperative to meet the growing demand for food in a manner that is socially equitable and ecologically sustainable in the long term. It is possible to design farming systems that are productive while **supporting the ecosystem** by contributing to (Kremen and Miles, 2012):

- greater biodiversity;
- improved soil quality (in particular, water-holding capacity);
- increased carbon sequestration; and, consequently,
- enhanced agro-ecosystem resilience and sustainability.

According to Vox *et al.* (2010), sustainable greenhouse systems should be resource-conserving, socially supportive, commercially competitive and environmentally sound; this applies to cultivation techniques, equipment management and construction materials. They should aim to reduce agrochemical use, energy and water consumption, and waste generation. Efficient management of climatic parameters (solar radiation, air temperature, relative humidity and carbon dioxide concentration) is essential, both to achieve suitable growing conditions and to save energy.

***Sustainable development** is development that satisfies the needs of current generations without compromising the needs of future generations.*

WCED, 1987.

Appropriate management strategies include:

- replacement of fossil fuels with renewable energy sources;
- use of innovative greenhouse covering materials with suitable physical properties and low generation of after-use waste;
- optimization of water and nutrient supply to reduce water and nutrient consumption, limit drainage into the groundwater and preserve the soil; and
- adoption of integrated management of pests and diseases aimed at the reduction of agrochemical use and, as a consequence, of pesticide residues in the product.

According to an EU directive of the European Parliament and of the Council establishing a framework for community action to achieve the sustainable use of pesticides from 1 January 2014, standard practice comprises: sustainable use of pesticides; promotion of low-pesticide-input management, including non-chemical methods; and – obligatory for all professional farmers – adoption of integrated pest management (IPM). Farmers must apply the general principles of IPM (Directive 129, 2009), but integrated crop management is more than just IPM. In some countries, the definition of integrated crop management is established by producers' organizations; in Slovenia it is considered a national quality scheme and an agri-environmental measure (Bavec *et al.*, 2009), and in 2013 it accounted for 70% of market vegetable production.

Organic agriculture refers to a farming system that enhances soil fertility by maximizing the efficient use of local resources, while foregoing the use of agrochemicals, genetically modified organisms and synthetic compounds used as food additives. Farming practices are based on ecological cycles and aim to minimize the environmental impact of the food industry, preserve the long-term sustainability of the soil and reduce the use of non-renewable resources (Goimero *et al.*, 2011); the result is organic food with added value. Current EU regulations on organic farming contain no rules for greenhouse cropping, with the exception of a ban on hydroponic production (EC 834, 2007). Consequently, practices vary considerably among EU Member States, in particular with regard to energy use and the use of substrates (EGTOP, 2013).

Taking the case of tomatoes in Slovenia, this chapter adopts a Life Cycle Analysis (LCA) approach to evaluate different production systems (conventional, integrated, organic). It examines both open-air and protected (plastic/glasshouse) cultivation, and it takes into consideration the distance from production to consumption (local, regional, cross-border, transcontinental).

METHODOLOGICAL APPROACH – ECOLOGICAL FOOTPRINT

The intensification of agriculture in Europe has at times involved economic activities with a major impact on the ecosystem, to the point that environmental stability and geographic political security may be endangered. A wide range of methods and tools have been designed to determine sustainable development at both individual and societal level. One such tool is the so-called **environmental** or **ecological footprint**, but there are also others (Foresi *et al*., 2016):

- Life Cycle Analysis (LCA) and Social Life Cycle Assessment (S-LCA)
- Social Impact Assessment (SIA)
- Social return on investment (SROI) methodology
- Sustainability Monitoring and Assessment RouTine (SMART)
- Public Goods (PG) tool
- Carbon footprint calculators

The concept of “footprint” conjures up the idea of a person walking ruthlessly in a meadow and leaving behind a trail: no grass will grow there for a long time. If more care were taken, the vegetation would regenerate quickly. In other words, the ecological footprint is a measure of the impact human activity has on nature. The greater the quantity of raw materials consumed and the more pollutants produced, the greater the pressure on the environment. The ecological footprint estimates the biologically productive area needed to produce the materials and energy utilized by the population of a given region. This estimate is then compared with the area actually available to a given population or individual – the biocapacity. **Biocapacity** is the productive land and/or water of a region. If the ecological footprint is greater than the biocapacity, human consumption is in excess of its natural capacity (Haberl *et al*., 2001).

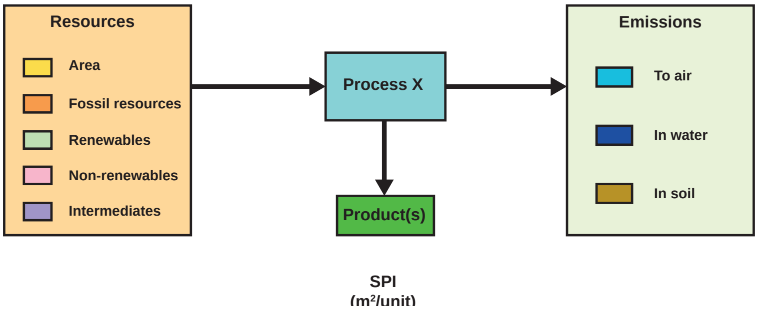
Statistical data are used to calculate the ecological footprint. Various tools exist for the evaluation of the individual production process, in particular, **Life Cycle Analysis (LCA)**, which considers the environmental burden caused by a specific product, production process or activity to provide services. LCA takes into account a wide range of impacts and considers the entire system; it is a tool for assessing the potential environmental impact of a production system, analysing the entire life cycle of the product from resource extraction to waste disposal. LCA has been standardized with ISO norms for Environmental Management – Life Cycle Analysis:

- ISO 14040:2006 Principles and Framework
- ISO 14044:2006 Requirements and guidelines
- ISO 14048 Life Cycle Assessment data documentation format

Ecological assessment allows us to analyse processes (material or energy flows) with the aim of determining a specific area in which a process can be sustainably embedded in the ecosphere (Narodoslawsky and Krotscheck, 1995). The results of ecological footprint calculations can be interpreted per unit of product (kg) or per equivalent area (ha). No ecological assessment method tells the "whole truth" because they depend on a value system and predictions of how the process can affect the environment. Nevertheless, they highlight important environmental aspects and provide useful support for the decision-making process. Depending on the scientific discipline, the definition of what is ecologically correct varies; there are different models to calculate the capacity of planet Earth; there are different approaches to different ecological dimensions.

One ecological footprint evaluation method is the **sustainable process index** (SPI), developed by Krotscheck and Narodoslawsky (1995). This method entails the creation of an entire life cycle in the form of process chains, which can be continually updated and improved. The SPI footprint calculates the actual surface needed for a specific process (Figure 1). It is based on the concept of "strong sustainability", assuming that a sustainable economy builds only on solar radiation as a natural input. Most natural processes are driven by this input and the Earth's surface is the key resource for the conversion of solar radiation into products and services. Global surface area is, however, a limited resource in a sustainable economy, and anthropogenic as well as natural processes compete for it. Therefore, the area required to embed a certain process sustainably into the ecosphere is a convenient measure for ecological sustainability: the more area a process needs to fulfil a service, the more it "costs" from an ecological sustainability point of view. This evaluation method has been adapted for agriculture (Kettl, 2013). Ecological footprint can be expressed per production area (ha or m^2) or per agricultural product (tonne or kg). In this case it is called the **ecological efficiency index (EEI)**.

FIGURE 1
Ecological footprint scheme based on SPI



Kettl, 2013.

Ecological footprint – units of measurement

- Global hectare per capita: **gha**
- Expressed as **SPI:**
  - per production area: **gha ha^{-1}** or **m^2 m^{-2}**
  - per product: **gha tonne^{-1}** or **m^2 kg^{-1}**
- Expressed as **GWP:**
  - **kg of CO_{2eq}** per kg product

Sustainability evaluation using the ecological footprint: Effect on biodiversity and product quality is NOT taken into account.

The ecological footprint expressed as **global warming potential (GWP)** is another important means for evaluating the impact of processes on the environment. The sum of CO_2 life cycle emissions and other GWP-relevant impacts gives the total GWP measured in kg of CO_2 equivalent (Cooper *et al.*, 2011).

Data for LCA including the calculation of the ecological footprint must be relevant for the comparison and evaluation of different production systems. Data may come from different **sources**:

- **Field or greenhouse experiments.** These data are of high quality and include a detailed inventory of inputs from experimental plots calculated per ha. To calculate the hours of machinery use, it is necessary to take into consideration data for bigger plots.
- **Interviews and farm inventories.** Data vary depending on the number of farms per production system and the quality of records at farm or production level.
- **Public statistical surveys.** These data are used for official calculations for payments for agri-environmental measures. The quality of the data as well as the reasons for collection may vary.

Based on research, field or greenhouse experiments provide the most appropriate data for the evaluation of different production systems. However, there are very few greenhouse production studies based on experimental data. In the case of Slovenia, studies are limited to open-field vegetable production (Bavec *et al.*, 2014). Data collected from farms are used most, for example, in Portugal to compare the production of one organic greenhouse with conventional greenhouse production (Baptista *et al.*, 2016), and in Slovenia (Stajnko, 2015).

EFFECT OF PRODUCTION SYSTEMS ON ECOLOGICAL FOOTPRINT AND ECOLOGICAL EFFICIENCY INDEX

The ecological footprint and the ecological efficiency index both depend on the production system adopted. The main features of conventional, integrated, organic and soilless culture systems, respectively, are presented in Table 1.

Based on experimental results, several calculations of ecological efficiency index (EEI) for different production systems are presented as ecological footprint. In the case of two open-field vegetables (cabbage and red beet) produced under three production methods – conventional (CON), integrated (INT) and organic (ORG) – and control, treatment in a 3-year field experiment in four replications in northeast Slovenia produced similar results (Bavec *et al*., 2014). The ecological footprint of integrated production and control was similar – the impact of a 1-ha production of white cabbage and red beet was around 70 gha surface area. For organic production, on the other hand, the impact was 3.5 times lower. Cereal production gave similar results (Bavec *et al*., 2012). Much of the impact is due to the use of synthetic fertilizers and chemical pesticides. In greenhouse production, if the same construction is used and the same heating system adopted, the relative

TABLE 1
Comparison between different production methods

	Conventional	Integrated[a]	Organic	Soilless culture
Seeds	No restrictions	No restrictions	Organic or not treated conventionally	No restrictions
Genetically modified seeds	Allowed	Not allowed	Not allowed	Allowed
Crop rotation	Not obligatory	Obligatory	Obligatory	Not obligatory
Soil health	No restrictions – registered chemicals	Chemicals not allowed	Steam, solarization, biofumigation and other natural methods	Soil not used as a substrate
Soilless	Allowed	Allowed, but only in closed system	Not allowed[b]	–
Fertilization	All fertilizers allowed	Based on N_{min} analysis,[c] all fertilizers allowed	Nitrogen from organic sources	Water-soluble nutrient salts
Plant protection	All registered pesticides	Preventive measures and treatments based on monitoring	Preventive measures and no chemical pesticides	Biological and chemical measures
Growth regulators	Allowed	Not allowed	Not allowed	Allowed
Irrigation	Allowed	Rational methods (drip irrigation ≤ 20 mm)	Allowed	Obligatory
Fertigation	Allowed	Allowed	Allowed only using organic fertilizers, i.e. vinasse, compost tea	Obligatory
Post-harvest treatments	No limits	Irradiation not allowed	Not allowed chemical nor irradiation treatments	No limits

[a] Based on Slovene integrated vegetable production (Official Gazette of the Republic of Slovenia, 2010, 2015).
[b] Not allowed in EU, but allowed in USA.
[c] Content of mineral nitrogen in soil.

differences in footprints between production systems remain the same. The highest yields for cabbage and red beet were achieved with the conventional method (68 475 kg ha^{-1} for cabbage and 27 879 kg ha^{-1} for red beet), while the lowest yield was in control plots where the lack of nutrients was evident (Table 2). The figures for yield and ecological efficiency are even more revealing. Integrated production produces the highest ecological efficiency index (EEI) for both cabbage and red beet, but it is not much higher than conventional production. Due to lower external inputs, the EEI of organic production is considerably lower than that of integrated and conventional production, but in the case of cabbage it is not much lower than the control. However, despite the low ecological footprint and almost no inputs in the control plots, production in the control is not ecologically efficient given the very low yield (only 27% of conventional for cabbage and 29% of conventional for red beet) (Bavec *et al*., 2014).

In greenhouse production, cumulative energy demand – direct energy (heating), indirect energy (manufacturing of greenhouse structure and covering materials), transport, waste management etc. – depends on the production system, but mainly with regard to fertilizer and pesticide production and use (Stanghellini *et al*., 2016).

With regard to energy used in the manufacture of the production factors, the greenhouse structure (including cover) is the single largest item, ranging from some 20 MJ m^{-2} for plastic-covered multi-tunnels to 40 MJ m^{-2} for a Venlo greenhouse (steel frame covered with glass). In all cases, reducing the amount of steel in the construction may weaken the structure and be in contradiction with local building requirements. Reduction of the structure-related energy use would require a major re-investment and is not the most practical approach to reducing energy use. On the other hand, the life span of the plastic could be increased, resulting in greater energy-use efficiency. At present, the plastic is usually renewed after 3 years and accounts for more than 50% of the cumulative energy demand of the multi-tunnel. Increasing productivity per surface area is a way to decrease energy use per unit of plastic-covered multi-tunnels. Glass has a long life (15 years), but requires a heavier structure; however, high-tech (glass) greenhouses are usually more productive than simple multi-tunnels (Stanghellini *et al*., 2016).

TABLE 2

Average yield and ecological efficiency index (EEI) depending on production method for white cabbage and red beet

	White cabbage		Red beet	
Production method	**Yield (kg ha^{-1})**	**EEI (m^2 kg^{-1})**	**Yield (kg ha^{-1})**	**EEI (m^2 kg^{-1})**
Conventional	68 475a	10.3 ± 6.1a	27 879a	26.3 ± 12.9a
Integrated	53 550b	12.9 ± 5.4a	26 547a	27.0 ± 17.4a
Organic	42 150c	5.0 ± 2.1b	17 955b	12.1 ± 6.2b
Control	18 825d	6.7 ± 3.5b	8 250c	19.3 ± 11.8c

The letters (a–d) in the columns are differences at P < 0.01 Duncan’s multiple range test.

EFFECT OF LOCATION AND TRANSPORT – THE CASE OF TOMATO IN SLOVENIA

Every year around 15 000 tonnes of tomatoes are imported to Slovenia, which has a population of 2 million. The local production of around 7 000 tonnes is simply not sufficient. Imports come from various countries over a range of distances (Figure 2).

FIGURE 2

Main production regions of imported tomatoes to Slovenia

Stajnko, 2015.

Calculations were based on data from interviews with tomato growers and retailers in Slovenia. To evaluate the impact of transportation on tomato production, the following scenarios were assumed:

- Local production and consumption (≤ 50 km)
- Regional production (50–250 km).
- Cross-border transportation from southern Italy (1 000 km)
- Transcontinental transportation from Almeria (1 000–2 500 km)

The type of transportation depends on the distance. In the analysis, the following truck types were assumed (Stajnko and Naradoslawsky, 2014):

- 16 tonnes (local)
- 28 tonnes (regional)
- 40 tonnes (cross-border and transcontinental)

Although transport does not depend directly on the production method, there is a clear relationship between distribution network and transport regime. Table 3 shows that the ecological footprint increases significantly as the transport distance increases. The ecological footprint depends on distance covered, truck capacity and quantity of tomatoes transported. Therefore, transporting 1 kg of tomatoes 2 500 km from Almeria (Spain) to Slovenia leaves the largest footprint:

Plate 1

Different sizes of trucks used in transport analysis: 16 tonnes (left); 28 tonnes (centre); 40 tonnes (right)

TABLE 3

Ecological footprint caused by transport of 1 kg of fresh tomato

Transport distance	Footprint (m^2a kg^{-1})	Index of footprint (L = 100%)
Transcontinental 2 500 km	177.7	3 625
Cross-border 1 000 km	125.6	957
Regional 250 km	17.8	326
Local 50 km	5.4	100

TABLE 4

CO_2 emissions caused by transport of 1 kg of fresh tomato

Transport distance	CO_2 (kg)	Index CO_2 (L = 100%)
Transcontinental 2 500 km	0.7500	3205
Cross-border 1 000 km	0.2146	933
Regional 250 km	0.0750	320
Local 50 km	0.0234	100

TABLE 5

GWP (kg) caused by transport of 1 kg of fresh tomato

Transport distance	GWP (kg CO_{2eq})	Index GWP (L = 100%)
Transcontinental 2 500 km	2.3418	2 968
Cross-border 1 000 km	0.6035	765
Regional 250 km	0.0234	297
Local 50 km	0.0789	100

177.7 m^2a (m^2 per year). This is followed by cross-border transportation (125.6 m^2a) and then regional, which has a significantly lower footprint (17.8 m^2a) – i.e. just 10% of transcontinental. By far the lowest footprint is left by local transportation (5.4 m^2a), with its shorter distances and smaller trucks. Local production is clearly preferable, but it is impossible to guarantee supply for all consumers in Slovenia, given the presence of urban areas and the specific growing requirements of tomato (i.e. daytime temperatures of 27–30 °C).

The transport distance has a direct and significant effect on CO_2 emissions (Table 4), which are dependent on the quantity carried and distance covered. The transportation of every 1 kg of tomato over 2 500 km from Almeria (Spain) to Slovenia results in 0.75 kg of CO_2 emissions, which is 10 times the CO_2 emissions for regional transport of the same quantity (0.075 kg). Most of the CO_2 released during transportation is due to the combustion of fossil-C.

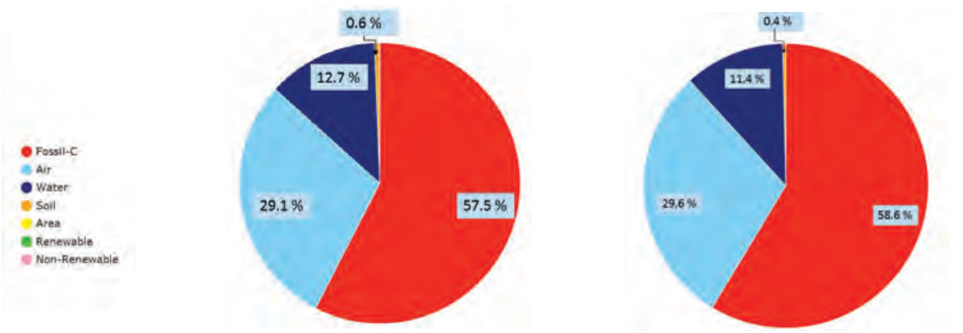
The additional global warming potential (GWP) follows a similar pattern (Table 5). Transcontinental transportation has the highest GWP (2.3418 kg), followed by cross-border (0.6035 kg). The GWP of regional and local transportation is significantly lower. However, when the relative increase in GWP is compared with the relative increase in CO_2 emissions, the difference is notably smaller. This is because GWP is based not only on CO_2 life cycle emissions, but also on other GWP-related impacts, such as CH_4, N_2O, chlorofluorcarbons (CFCs) and hydrofluorcarbons (HFCs).

The main reason for long-distance transport (from Spain or Italy) is the favourable regional climate in southern Europe, which permits open-field and polyethylene-tunnel production without additional heating from late spring to the end of autumn, compared with glasshouse production with minimal extra light oil (ELO) heating during the rest of the year. However, lower outdoor temperatures in Central Europe can be offset to some extent by the application of alternative renewable energy sources, which together with a reduction in transport distances, could significantly affect the ecological footprint, CO_2 emissions and GWP. Other energy-saving measures can also be implemented, such as the installation of thermal screens resulting in energy savings in low energy greenhouses and reduction of CO_2 levels.

Figure 3 shows the most important SPI impact categories for 2 500-km transcontinental and 50-km local transport systems. Fossil-C is the most prominent SPI category and its value was estimated at 57.5 and 58.6%, respectively. The second most important category is air (29.2 and 29.6%), and the third is water (12.7 and 11.4%). Transport also has a significant impact on the ratio of emissions to air and water. There is a general decrease in the emissions to water and an increase in the emissions to air. The greatest reduction in emissions to air was in cross-border transport (from 29.6 to 28.5%), while emissions to water rose (from 11.4 to 14.6%). This is mainly due to the combustion of diesel fuel used to transport 1 kg of tomatoes over 1 km. The figure becomes higher for 50-km transportation by 18-tonne truck, but lower for 1 000-km transportation by 40-tonne truck. In all other SPI categories, no significant changes were detected for any production system (Stajnko and Naradoslawsky, 2014). Similar studies have been conducted in other parts of the world and a comparison of results would be useful.

FIGURE 3

The most important SPI impact categories for 2 500 km and 50 km transcontinental transport



PRODUCTION SYSTEMS

A general trend in crop production, but more pronounced in greenhouses, **sustainable intensification** is characterized by high yields and extensive use of resources (e.g. nutrients, light, heating, CO_2 and external inputs: plastic mulches, containers, packaging materials). Excessive increases in production intensity threaten the sustainability of greenhouse production, including organic production. Compared with outdoor fields, the greenhouse environment is much easier to control: air temperature, light, air humidity, water supply and carbon dioxide in the air. In some modern greenhouses, even access of pests and pathogens can be restricted or prevented. Soilless production is possible in greenhouses, whether in substrates of organic or inorganic materials or as hydroponics – but it should be noted that inorganic growing media and hydroponics are not allowed in organic cropping (EGTOP, 2013). According to LCA principles, ecological footprint calculations also include: construction materials (glass, foil, steel, pipes, ground), equipment (heating, irrigation, ventilation) and inputs (fertilizers, growing media, substrates, pesticides, energy for heating, irrigation, fumigation, mulch foil).

A case study of tomato production in Portugal (based on data obtained directly from the growers) compared organic farming and conventional tomato greenhouse production. In an analysis of energy consumption and greenhouse gas emissions, the results revealed a lower input of energy per ha and per kg of organic tomato yield. Indeed, in organic tomato greenhouse production, a total energy consumption of 29.17 MJ m^{-2} (1.87 GJ $tonne^{-1}$) corresponds to an annual yield of 15.6 kg m^{-2} (with two crops per year). Structure materials accounted for > 50% of indirect energy consumption and indirect energy accounted for approximately 74% of the total energy consumption (Stanghellini *et al.*, 2016). In a comparative study, organic tomato greenhouse production also showed lower greenhouse gas emissions (Baptista *et al.*, 2016). In the case of tomato growers in Slovenia, analysis was carried out in different **production systems** and their variations (Table 6, Plate 2):

- Glasshouse – with additional heating, soilless
- Polyethylene (PE) tunnel – with additional heating
- Open-field production – according to the integrated production system
- PE tunnel – with additional heating, organic
- PE tunnel – no additional heating, organic

TABLE 6
Characteristics of production systems

Production system	Yield (kg ha^{-1})	Vegetation period (months)	Harvesting period (months)
Glass greenhouse – soilless	495 000	11	9
Foil greenhouse	275 000	8	6
Open-field	127 000	6	4
Organic under PE foil	57 000	6	4

Plate 2

Different production systems of tomato production in temperate climate (from left to right): soilless, integrated under foil, open-field and organic under foil

TABLE 7

Characteristics of production systems

Production system	Ecological footprint $(m^2a\ kg^{-1})$	CO_2 (kg)	GWP (kg)
Glass greenhouse – soilless, ELO	110.97	0.6435	0.9591
Foil greenhouse, black mulch foil – soilless, ELO	20.00	0.0831	0.4887
Foil greenhouse, black mulch foil – not heated	18.26	0.0681	0.4743
Open-field, black mulch foil – integrated	19.42	0.0673	0.5023
Organic under PE foil – not heated	13.46	0.0419	0.0645
Organic under PE foil – heated	16.75	0.0689	0.1006

In addition, different heating energy sources were taken into account (Stajnko, 2015):

- extra light oil (ELO) at 100 kW per 1 000 m^2 using fan-jet in plastic tunnel and pipes in glasshouse;
- wood chips in plastic house; and
- geothermal energy from a depth of 1 500 m in glasshouses.

There is growing concern about the trend for intensification of vegetable production under protected areas combined with increasingly long distances between production and consumption centres. Although the majority of consumers express a preference for vegetables with high external and internal values and which do not harm the environment, the reality is that the majority of vegetables that these same consumers purchase actually travel very long distances and are produced with very high inputs. For this reason, a **twofold strategy** is recommended:

- Adoption of local organic production under protected areas to achieve both improved quality and reduced ecological footprint due to transport. However,

TABLE 8

Ecological footprint, CO_2 emissions and global warming potential (GWP) per kg tomato as a function of different energy sources in glasshouses and plastic tunnels

Production system	Ecological footprint ($m^2a\ kg^{-1}$)	CO_2 (kg)	GWP (kg)
Glass greenhouse – soilless, ELO	110.97	0.6435	0.9591
Glass greenhouse – soilless, geothermal energy	31.98	0.1360	0.2942
Foil greenhouse – soilless, ELO	20.00	0.0831	0.4887
Foil greenhouse – soilless, wood chips	18.92	0.0706	0.3257

it is vital that the quantity produced is sufficient to match consumer demand and also that the production system is economically sustainable for growers.

- Replacement of expensive fossil fuels with renewable (low-cost) energy sources (geothermal energy, waste processing heat, wood chips and other biomass chips) to meet heating requirements (Table 8).

CONCLUSIONS

- Production method has a significant impact on ecological footprint. The footprint of organic farming is much lower than that of integrated and conventional methods, while the differences between integrated and conventional are negligible. Organic farming also reduces global warming potential (GWP) and CO_2 emissions.
- Transcontinental transport (≤ 2 500 km) of 1 kg of tomato has the greatest impact on fresh tomato production, accounting for 177.7 m^2a of the total footprint. This could be significantly decreased by reducing the transportation distance to 1 000 km (–71%). The reduction is even more considerable in regional (≤ 250 km, –90%) and local (≤ 50 km, –96%) production. A similar pattern is seen for CO_2 emissions and GWP.
- Organic production is the most ecologically efficient system, despite the difference in yield between organic and hydroponic tomato production (16.75 m^2 per kg and 110.97 m^2 per kg, respectively).
- Application of alternative renewable energy sources can offset to some extent the lower outdoor temperatures in Central Europe. If they are combined with a reduction in transport distances, there can be a significant effect on ecological footprint, CO_2 emissions and GWP.

GAP recommendations – Improving sustainability and ecological footprint

- Use new and alternative production methods and adopt innovative approaches to reduce water and energy consumption, increase efficiency, reduce use of chemicals and lower greenhouse gas emissions. The goal is **sustainability**, because greenhouse production is generally associated with high amounts of external inputs (construction materials, fertilizers, pesticides, water, energy for heating/dehumidification/cooling) and waste.
- Adopt Life Cycle Analysis (LCA) to evaluate sustainability. LCA is a standardized approach based on ISO norms for environmental management and it includes calculation of the ecological footprint to determine ecological efficiency expressed as global ha per ha of production or as m^2 per kg or tonne of product per year. **Ecological footprint** aims to improve sustainability in the long term and is a benchmarking tool for presenting sustainability to consumers.
- Introduce **organic farming** production methods in greenhouse vegetable production to reduce environmental impact and produce organic vegetables, which – given consumer demand for quality, nutritional value, taste and health – can be sold at high prices. The ecological efficiency index (ecological footprint per kg tomato) is 6.6 times greater for organic production under polyethylene tunnel with additional heating than for high-tech soilless production. However, in South East Europe, since small farms with seasonal vegetable production under foil tunnels or greenhouses are dominant, passive heating systems are more feasible.
- Consider various possibilities for **energy saving**, including passive means without the application of external energy (e.g. double walls or thermal curtains).
- Apply dark **mulches** to absorb light radiation and enhance soil warmth. Black mulch is a simple passive system for increasing solar heat storage in the soil and improving the air/soil thermal regime during the early stages of crop cycles starting in winter (especially in the south).
- Use **renewable energy sources** to save energy and achieve neutral production in heated greenhouses, including organic production. In soilless vegetable production, replace fossil energy sources with renewables (e.g. geothermal energy – 3.5 times better performance than extra light oil). Integrate photovoltaics in the greenhouse roof – in particular in South Europe and the Mediterranean. Photovoltaics have no significant effect on yield but can reduce the life cycle impact of the greenhouse by 5–10%.
- Optimize water use to maximize **water-use efficiency**. There is increasing concern about the quantity and quality of water available – indeed, this is reflected in the GLOBALG.A.P. standards and in the future it will be necessary to calculate the "water footprint" (litre of water used per kg of yield) to evaluate the sustainability of a product. Improved water management can lead to a reduction in both fertilizer use (with consequent savings in energy used in fertilizer production) and the electricity used for pumps.
- Promote **local and regional production**. Both the ecological footprint and the global warming potential are lower than in production requiring long distance (transcontinental) transportation.
- Increase the use efficiency of all external inputs. It is important that the public believes in the **sustainability** of greenhouse production, including organic production.

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9. Profitability, marketing, and vegetable loss and waste

S. Nicola and G. Pignata

Vegetable Crops and Medicinal and Aromatic Plants, Department of Agricultural, Forest and Food Sciences, University of Turin, Italy

ABSTRACT

Enhancing vegetable profitability implies cultivation of standardized high quality produce, implementation of advanced technologies for competitive production and optimization of resources. Small stakeholder farms require innovative strategies to enter new markets and extend the impact of local and niche productions, while achieving sustainability. Food wastage accounts for one-third of world food production; it occurs to varying degrees at all stages of the food supply chain. More than 60% of the total wastage of fruit, vegetables, roots, tubers and bulbs takes place during harvesting and consumption. To reduce food wastage in the food supply chain – by recycling and re-using plant residues, among other approaches – is both smart and sustainable. This chapter outlines production and marketing strategies that can be adopted by small stakeholder farmers in SEE countries to increase profitability. It illustrates in detail practices to minimize losses in protected cultivation systems and to reduce losses and waste during post-harvest and throughout the food supply chain. Recommendations are presented on produce handling in order to achieve sustainable added value.

Key questions

- What is the difference between food loss, food waste and food wastage?
- How do you increase profitability by reducing waste?
- What are important considerations for avoiding production losses?
- Why should promiscuity between horticultural and livestock farms be avoided?
- What are the recommended measures at harvest?
- How can the temperature of vegetables be rapidly reduced after harvest?
- What protection devices and services should the employer provide for employees?
- How often should you check the quality of the water along the food supply chain?

PROFITABILITY AND MARKETING

Agricultural and post-harvest innovations have led to a continuous increase in yield and productivity. Nevertheless, there is still not enough food for everyone. To meet the needs of the growing global population within sustainable limits, it is necessary to make the food supply chain more efficient, while protecting natural resources and effectively managing ecosystems. It is vital to:

- increase productivity;
- minimize production of wastage; and
- maximize re-use of wastage.

Small stakeholder farms in SEE countries can sustainably intensify production by adapting growing systems and improving the management of raw material. Protected cultivation is under continuous expansion: greenhouses are suited to soilless cultural systems and the farmer is able to control inputs. Moreover, soilless cultural systems – the most intensive production systems in today's horticulture industries – are ideal for standardizing production and enhancing yield, resulting in healthy and sustainable foods that satisfy market requirements (Nicola *et al*., 2007; Gruda, 2009).[1]

Thanks to innovation and new technologies in the horticultural sector, there are an increasing range of new products and fresh convenience foods. For example, leafy vegetables are not only available as whole-head and multi-leaf vegetables,[2] but also as **"baby" leaves**, which are increasingly used in salad mixes. Protected cultivation vegetable farmers in SEE countries could increase profitability by producing baby leaf vegetables: cost effective to grow, easy and fast to process (Martínez-Sánchez *et al*., 2012). Furthermore, baby leaf vegetables would allow farmers access to new markets, especially if supported by an efficient food supply chain. Indeed, despite the economic crisis in recent years, consumers have not necessarily reduced their consumption of vegetables, but they have changed how they consume them (Heaton and Jones, 2008).

Another rapidly expanding sector of interest to growers, processors, retailers and consumers is **fresh-cut vegetables**, characterized by convenience, freshness and health benefits. These vegetables represent an opportunity for small stakeholder farms in SEE countries, who could offer a wide range of species and varieties/cultivars, together with additional services, such as minimum processing (e.g. husking, cutting, packaging), particularly for vegetables sold independently by large-scale retailers.

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[1] See Part II, Chapter 7.

[2] See Part III, Chapter 5.

Profitability could be further enhanced by organizing the supply of raw materials based on the demands of customers and taking account of each smallholder's strengths. For example, one crop may be more suited to a large enterprise (e.g. tomato, pepper, strawberry), while another crop may be better suited to a smaller farm (e.g. leafy vegetables). The classification of raw material allows farmers to produce added value and sell vegetables at different prices, avoiding economic flattening.

Marketing the product offers many opportunities for increased profitability:

- identification of new markets and sales channels, including large-scale retail trade;
- organization in cooperatives to agglomerate and concentrate the vegetable production of a number of smallholdings;
- production of niche products, traditional or native varieties to create added value appreciated by consumers; and
- establishment of trademarks, certifications or labels to encourage consumption.

Certification systems distinguish vegetable products based on specific characteristics, qualities or reputations. A product may be differentiated by its geographical origin, history or distinctive character related to natural or human factors, such as soil, climate, local know-how and traditions. Certification (such as the IGP label in Italy, which guarantees the origin of food produced in specific areas, e.g. Pachino tomatoes cultivated in a specific area of Sicily) can increase profitability. It has additional advantages, allowing farmers to:

- contribute to rural development;
- preserve local resources;
- maintain traditions;
- increase food diversity and offer a wider choice to consumers; and
- prevent delocalization and rural exodus.

Labelling is an important commercial tool which could be exploited by small stakeholder farmers in SEE countries. Vegetable marketing and labelling in Europe is regulated by EU Regulation No. 543/2011, which includes detailed rules for the application of Council Regulation (EC) No. 1234/2007 with regard to fresh and processed fruit and vegetables. Farmers may also opt for voluntary private labelling – a potentially effective marketing strategy, as consumers are increasingly aware of the importance of vegetable quality and interested in a product's origins. Tailored stickers can be created with the name of the farm, logo, production area and any other information which personalizes the product and makes it easily recognizable. In order to reach new markets and take advantage of global tourism, information could also be made available in English.

Labelling not only guarantees fair trading and free movement of foodstuffs, and provides the consumer with accurate information about the product, but it can also be used as a marketing tool to promote the product and expand the market.

Other strategies may be adopted, depending on the local context, to attract consumers. For example, e-commerce combines accessibility with convenience, allowing the customer to choose products according to seasonal availability or on the basis of specific offers and promotions on the farm's Web site. The commercial side could be supported by a home delivery service (see "box schemes" below). Another strategy is to promote the hedonistic aspect, arousing human curiosity and encouraging contact with nature, for example, with direct sale at local markets, fairs and festivals or on the farm itself ("farmer markets"). Direct sale on the farm may also be combined with teaching or gastronomic tours to raise consumer awareness and give an insight into agricultural reality. Both e-commerce and direct sale could be further boosted by offering additional services, such as traditional recipes or tips for home storage, to create a satisfied and loyal customer base (e.g. the AMAP – Association for the Maintenance of Family Farming – system in France).

The direct involvement of consumers in the local community – through, for example, box schemes, solidarity purchase groups (GAS, in Italy) and community supported agriculture (CSA) systems – shortens the food supply chain.

- In **box schemes**, the customer signs up for a box of locally produced fruit and vegetables to be delivered directly to their home or to a collection point; alternatively, the scheme may be organized as a cooperative. Delivery is typically weekly or fortnightly.
- **Solidarity purchase groups** are promoted and organized by consumers, formally or informally, to share the purchase of goods, generally agricultural products. Such groups can benefit farmers and farmer associations, as well as the local community.
- **Community supported agriculture** allows individuals/consumers to support farm operations and activities through a "sharing economy". In CSA, individuals become "shareholders" of the farm, contributing in advance to the farm operation costs and farmer's salary and receiving a share of the revenue. CSA is a participatory economy, with growers and consumers providing mutual support and sharing the risks and benefits of food production. Consumers support the system that provides quality products at better prices, while growers gain financial security and are relieved of the burden of a marketing strategy.

The above schemes all shorten the food supply chain, which in turn results in competitive prices, allowing farmers to maintain the value chain. There is also a lower risk of unsold produce and a marked reduction in food wastage.

Definitions

FOOD LOSS

A decrease in the edible food mass or nutritional value of food resulting from shortcomings in the food supply chain at any stage: production, harvest, post-harvest, processing or distribution. Natural disasters can cause food loss, as can poor infrastructure and logistics, lack of technology, limited access to markets, and inadequate skills, knowledge and/or management capacity of food supply chain actors.

FOOD WASTE

The disposal of food that is still appropriate for consumption – usually at the end of the food supply chain (at the retail or consumption stage). Poor market management can result in overproduction or excess of supply, which in turn lead to food waste. Likewise, lack of organization by individual consumers (e.g. food kept beyond its expiry date or improper storage) can result in food waste.

FOOD WASTAGE

Any food lost through deterioration or waste. Food "wastage", therefore, encompasses both "loss" and "waste".

FOOD SUPPLY CHAIN WASTAGE

Food **loss**, **waste** and **wastage** refer to human edible material that is discarded, lost, degraded or consumed by pests at any point in the food supply chain. Food originally destined for human consumption but then redirected from the food supply chain to a non-food use – for example, as animal feed or in by-product industries – is also considered food loss, waste or wastage (Figure 1) (Parfitt *et al.*, 2010).

Food production and food wastage

According to FAO, vegetable production in Europe accounts for approximately 7% (0.07 billion tonnes) of world production.[3] Total food wastage accounts for around one-third of total food production for human consumption. Wastage occurs throughout the food supply chain to varying degrees, depending also on the location. It is as high in more industrialized countries as it is in less

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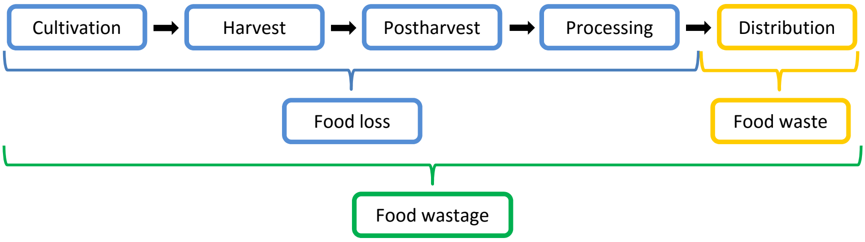
[3] See Part I, Chapter 2.

FIGURE 1
Food wastage line in the food supply chain



industrialized countries, but occurs at different stages of the supply chain. The more industrialized a country is, the higher the percentage of wastage after distribution (at retail and consumer level) – i.e. there is more waste than loss. In contrast, in less industrialized countries, the majority of wastage occurs during harvest and post-harvest – i.e. there is more loss than waste (FAO, 2011a).

Of the global production of fruit, vegetables, roots, tubers and bulbs, food wastage is 40–50%, depending on the product and season (FAO, 2011a, 2011b; Venkat, 2012). In Europe, food wastage in fruit and vegetable production is about 46% and occurs throughout the food supply chain (Plate 1). For root and tuber production in Europe, food wastage is even higher, accounting for over half the production (FAO, 2011a).

Added value and prevention of food wastage

Food wastage involves not only wastage of input and agricultural land area, but also missed opportunities. According to the European Commission, the global wastage market from collection to recycling is worth an estimated €400 billion every year; this represents significant potential in terms of the creation of jobs. A well-organized wastage industry, encompassing smart and sustainable activities, could permit countries to retain or create wealth and avoid disposal costs.[4]

Smallholder farms could implement a range of sustainable activities:

- Apply crop residues to the soil to improve the balance of the soil organic matter and for better weed control (some Brassicaceae species are particularly suited, given their high biomass).
- Recycle plant waste to exploit the extraction of bioactive compounds (tomato skin and seeds can provide polysaccharides and phytochemicals for use in the dietary supplement and cosmetic industries).

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[4] For extensive coverage of the waste market economy, see the chapter on "Waste" in the *Green Economy Report* of the United Nations Environment Programme (UNEP, 2011).

Plate 1
Food waste at the wholesale market

- Collect discarded unmarketable produce (whether whole or only the outer parts; damaged during production, transport or storage) for use as:
  - fertilizer, mulch or compost (Plate 2); or
  - feed for farmyard animals.
- Redirect material towards bioenergy (research is underway to valorize tomato crop residues for bioenergy production in the form of pellets).
- Exploit opportunities to use damaged or discharged raw material to obtain biodegradable containers or packaging material.

The above activities could be carried out on the farm or – when specific skills or equipment are required – by specialized companies. There are significant employment opportunities at food wastage collection and during transformation in the various industrial sectors.

A systemic approach to innovative wastage prevention and management has potential benefits both for society in general and in terms of farmers' profitability. There are many advantages, including:

- reduced impact of food loss and food waste (in terms of quantity and cost);
- increased income for smallholder farms;
- creation of sustainable value chains in the farming and processing sectors as a result of the efficient use of agricultural waste, co-products and by-products; and
- reduced impact on the environment, as a result of the adoption of sustainable extraction rates and optimal use of resources for soil improvement.

Plate 2
Crop residues to be wasted if not recovered

REDUCING WASTAGE AND INCREASING PROFITABILITY

To enhance the profitability of SEE vegetable small stakeholder farms, it is necessary to achieve standardized high-quality production while optimizing the resources. Vegetable quality and shelf-life are affected by pre-harvest, harvest and post-harvest conditions; consequently, to achieve profitability and competitiveness, action is required at the various stages of the food supply chain, including processing, storage, transport and distribution.

Vegetable production issues are global with variations at local, regional, national and international level. SEE vegetable farms – and farms worldwide – vary enormously, depending on, *inter alia*, the technological inputs available, infrastructure facilities, cultural systems, species grown, knowledge, business organization and management, and sales channels. There is no simple solution to reduce overall quality deterioration of fresh products. However, maintaining high hygienic standards reduces both microbial proliferation and physical pollution, resulting in reduced food loss and food waste and extended shelf-life.

Factors affecting vegetable quality and shelf-life

Pre-harvest

- Seed and cultivar choice
- Climate, environmental, soil/growing media and nutrient management and knowledge
- Water usage
- Standardization of cultural system
- Sowing and transplanting scheduling
- Agricultural practices and crop protection (e.g. soil amendments, fertilizers, pesticides, fumigants, growth regulators)

Harvest

- Timing
- Conditions and practices
- Standardization of raw material management

Post-harvest

- Best processing practices[5]
- Raw material manipulation (e.g. packaging)
- Storage conditions
- Transportation, distribution and sale

Vegetable quality and shelf-life are affected by pre-harvest, harvest and post-harvest conditions

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[5] Conditions after harvest can be modified with the objective of extending shelf-life and increasing the content of dietary phytochemicals, such as vitamin C, phenolic compounds and carotenoids, adopting techniques such as pulsed light or thermal shocks.

Tailored actions and solutions are necessary to increase efficiency, reducing food loss and food waste

The adoption of **international production practices and protocols** for the main commodities brings many benefits:

- Improved access to raw material with specific characteristics.
- Satisfaction of consumer demand.
- Creation of new demand.
- Respect for food safety limits, with the promotion of standardized vegetables with specific qualitative and commercial properties.
- Internationally recognized certification, meeting customer needs and expectations.

Nevertheless, to increase SEE small stakeholder farm productivity, improve competitiveness through standardization and enhance efficiency – and thus profitability – custom-made solutions are required. Good agricultural practices are not to be adopted blindly, rather carefully fitted, developed and adapted to enable small stakeholder farms to fit seamlessly into the production flow.[6]

Food loss

Actions to reduce food loss focus on preventing mismanagement at farm level. Poor management affects productivity (both directly and indirectly), as well as the post-harvest and processing stages.

Cultivation

To reduce food loss and input waste, it is necessary to plan and monitor every step of the growing cycle:

- **Variety/cultivar selection** should take account of characteristics (e.g. response to sowing or planting, disease, stress and pest resistance, edaphic and climatic adaptability, response to fertilizers and agrochemicals), and when possible combine with high yield potential in a short growing cycle (Plate 3). Produce should satisfy the needs of the food supply chain,


PIMPINI

Plate 3
Radicchio variety enhancement for reduced residue production: old variety with high percentage of non-edible head (top) and recent variety with reduced non-edible amount (bottom)

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[6] For more information on productions indications, practices, protocols and production disciplinaries, see "Useful links for vegetable quality" in the Bibliography on p. 263.

taking into consideration both the fresh market and the processing industry. Therefore, while storage resistance is an important characteristic, it is also important to seek processing opportunities to avoid unsold production.

- **Nursery management** is often neglected, particularly by smallholders, who do not adopt best practices. Nurseries should be located far from the production area to reduce the risk of pollution; seeds must be stored correctly. When external nurseries are used as contractors (a common practice), the transportation of transplants should be managed carefully.[7]
- **Scheduling** of agronomic activities can affect profitability and marketing and reduce post-harvest loss and waste. Sowing and transplanting should be timed separately for each commodity and speciality, taking into account the growing cycle, to avoid the maturation of all crops simultaneously. With planned scheduling, it is possible to:
  - avoid harvest overlaps resulting in huge amounts of raw material to be harvested and sold in few days;
  - optimize logistics and storage facilities;
  - control raw material quality;
  - facilitate traceability;
  - separate and store raw material in batches/lots;
  - optimize profitability, without having to propose special offers or discounts to sell in bulk;
  - avoid market saturation and consequent price reductions; and
  - reduce the possibility of being left with unsold raw material.

- **Cultural practices** have a major impact on profitability. When horticultural and livestock production overlap, there may be cross contamination. In protected cultivation using traditional soil cultural systems, knowledge of the site and of the history of the surrounding area is important to assess and manage risk adequately. For example, it is possible to avoid the cultivation of vegetables in soil previously used for animal production or chemical/biological waste disposal or once covered by polluted surface water. There is an increasing awareness of the potential harm caused by solid biological waste, water runoff and chemical usage. Correct manure management, the use of alternatives to chemicals (e.g. mulching) and the adoption of paved floors can all reduce the impact (Plate 4). The adoption of open or closed soilless cultural systems could avoid runoff and leaching of nutrients into the surface or the groundwater. During cultivation, bad practices, such as the improper disposal of pruning residues, can cause the spread of diseases resulting in food loss (Plate 5). Moreover, failure to achieve quality standard requirements can also cause food losses due to unsold production (Plate 6).

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[7] See Part II, Chapter 6.

Plate 4
Improper storage location for manure causing leaking: on roads between lots (left) and in fields and greenhouses (right)

Plate 5
Improper management of pruning residues

Plate 6
Food waste due to commercial requirements

GAP recommendations – Pre-harvest

- Conduct soil analysis.
- Use selected varieties/cultivars and grafted plants.
- Store seeds in a closed container in a dark refrigerated room.
- Promote practices that enhance soil productivity without compromising hygiene, depending on the cultural system used and the species cultivated (see Practical example a, p. 264).
- Apply recommended plant densities for each species and plan a balanced and constant supply of nutrients (see Practical example b, p. 264).
- Use registered materials for crop protection with short pre-harvest intervals, following label indications.
- Regulate the temperature, relative humidity and irrigation (dosage and timing) according to the growing systems and the species.

GAP recommendations – Harvest

- Remove damaged outer parts of the raw material to avoid fermentation or browning.
- Reduce rapidly the temperature of both the vegetables and the environment.
- Optimize timing in the field to coordinate with the shipping procedure to reduce raw material overheating and physical damage.

Harvest

Harvesting is a crucial stage in the food supply chain, with potentially high food losses due to improper preparation and handling. Most SEE small stakeholder farms are not equipped with rapid cooling systems to prevent an increase in temperature and respiration of harvested raw material. The only solution is to harvest early in the morning. While many farmers carry out the harvest using automated and mechanized systems, hand-picking has the advantages of reducing physical injury, preventing direct contact with the soil and selecting for quality.

Post-harvest

Raw material quality cannot increase after harvest; it can at best be maintained and preserved through the food supply chain.[8] It is important to avoid conditions that could cause physical damage, wilting and softening, and the subsequent increase in respiration, fermentation and browning. These negative effects are the result of:

- inappropriate handling;
- absence of rapid pre-cooling systems in the field and during transportation to the packing house;
- excessive delay in the field, coupled with poor coordination with the subsequent food supply chain steps; and
- transport on bumpy roads.

Transportation and storage are critical stages. To avoid food loss, it is important to separate the raw material, maintain a high level of cleanliness, and monitor carefully the temperature, controlled atmosphere, relative humidity and dark conditions according to the specific requirements of each commodity (Plate 7).

To reduce the risk of food wastage during processing, transportation and storage, it is also necessary to consider the respiration rate of the raw material and its sensitivity to temperature and to ethylene. Post-harvest temperature sensitivity varies depending on the commodity, and it can affect respiration intensity (Tables 1, 2). Chilling-sensitive commodities are bean, snap, cranberry, cucumber, eggplant, muskmelon, pepper, potato, pumpkin, squash, sweet potato, tomato, watermelon and yam. Horticultural products can synthetize ethylene and their sensitivity varies (Table 3). Producers should know the tolerance limit

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[8] However, it is possible to increase the content of ascorbate and other dietary phytochemicals.

Plate 7 *(From left to right and top to bottom)*
Truck with ice for transport from field to storage
Body icing in closed box storage for rapid raw material cooling
Closed and shaded truck for transport from harvesting area to storage
Hydrocooling system in transport truck on arrival at packing house
Top icing in closed insulated box storage for cold preservation of raw material before dispatching
Storage room at cold temperature on a small farm in Croatia

of each vegetable in order to properly schedule and manage the raw material. It is important to avoid mixtures and promiscuity, which might accelerate inner degradative physiological pathways. Failure to maintain optimal conditions or to properly manage raw material can cancel the positive effects of the previous steps in the supply chain, thus reducing the shelf-life.

GAP recommendations – Post-harvest

- Handle raw material in a refrigerated, clean and insulated room.
- Ship and store raw material in a clean environment under optimal conditions:
  - temperature 1–4 °C;
  - controlled atmosphere (relative humidity > 90%); and
  - darkness (or as close as possible).

- Check conditions routinely.

TABLE 1
Recommended transportation and storage temperature of vegetables

Temperature range °C	Commodities
0–5	Artichoke, broccoli, Brussels sprouts, cabbage, cauliflower, celeriac, celery, chervil, Chinese cabbage, chives, coriander, dill, leeks, lettuce, mushroom, onions, onions (bunching), parsley, radish, spinach, sorrel, watercress, witloof chicory
0–10	Sugar peas
1–5	Asparagus, cucumber (pickling)
2–7	Cantaloupe
5–10	Bean
5–12	Pepper bell, pepper chilli
8–12	Cucumber, okra
10–20	Tomato

Watkins and Nock, 2012 (adapted).

TABLE 2
Vegetable commodities classified in function of the respiration rate

Classification	mg CO_2/kg·h at 5 °C	Commodities
Very low	< 5	Dried vegetables
Low	5–10	Beet, celery, garlic, honeydew melon, onion, potato (mature), sweet potato, watermelon
Moderate	10–20	Cabbage, cantaloupe, carrot, celeriac, cucumber, lettuce (head), pepper, potato (immature), radish, summer squash, tomato
High	20–40	Carrot (with tops), cauliflower, leeks, lettuce (leaf), lima bean, radish (with tops)
Very high	40–60	Artichoke, bean sprouts, broccoli, Brussels sprouts, endive, green onions, kale, okra, snap bean, watercress
Extremely high	> 60	Asparagus, mushroom, parsley, peas, spinach

Watkins and Nock, 2012 (adapted).

TABLE 3
Vegetable commodities classified in function of the ethylene synthesis rate

Classification	µl C_2H_4/kg·h at 20 °C	Commodities
Very low	< 0.1	Artichoke, asparagus, cauliflower, leafy vegetables, root vegetables, potato
Low	0.1–1.0	Casaba melon, cucumber, eggplant, okra, pepper (sweet and chilli), pumpkin, watermelon
Moderate	1.0–10.0	Honeydew melon, tomato
High	10.0–100.0	Cantaloupe

Watkins and Nock, 2012 (adapted).

Processing

To avoid food loss during processing, it is important to apply rigorous standards of hygiene and ensure the water quality to avoid physical, chemical and microbiological contamination. Such standards apply to the physical structures, the workers and all equipment and instruments used.

Food waste

Food waste can occur both for niche speciality products with a limited scale of sale and for widespread commodities marketed over long distances. Small stakeholder farmers selling produce directly (farm shop, street and wholesale markets) or processing it individually may produce food waste for the reasons described above with regard to food loss. Farmers not marketing produce directly or processing vegetables individually must create a direct and quick communication channel with processors and/or distributors in order to preserve the vegetables (Plate 8). In both cases, storage for an excessively long period can lead to waste.

Plate 8 *(from left to right and top to bottom)*
Fresh produce on sale in improper, dirty and wet containers, located under the rain
Produce transported and left under the sun on a street market
Produce at wholesale market without any refrigeration system or insulation, stacked in large quantities possibly resulting in mass overheating
Improper handling on the wholesale market, fresh produce stored in non-insulated or refrigerated transport unit using newspaper and plastic bags with buildup of product temperature

Production environment

Water quality and management

It is essential to know the location of the water source and the history of the area in order to assess and manage risk adequately. There can be unforeseen variations in the chemical characteristics and level of contamination of the water used for irrigation and during post-harvest activities. The water supply needs to be monitored so that at each step in the food supply chain producers know the pH, conductivity and salinity, as well as the level of microbial, heavy metal and chemical contamination. Water is one of the main vehicles of contamination; if monitored accurately, it is possible to use sanitizers during cultivation (especially when using overhead irrigation systems) and during post-harvest washing procedures (Plate 9). It is imperative to protect and manage the water supply through:

- collaboration with neighbours to reduce sources of contamination using a vegetative buffer zone;
- protection of well openings;
- implementation of measures to avoid cross-contamination;
- selection of an appropriate water source;
- adoption of good water storage practices; and
- application of water dosage to avoid excess irrigation causing damage to the raw material (e.g. cracking, increased susceptibility to physical damage, delayed maturity and reduced soluble solids content).[9]


NICOLA

Plate 9
Rapid washing after harvest to remove foreign bodies and dirt, while preserving commercial quality

Physical, chemical and microbiological contamination

Contamination can occur at any stage in the food supply chain. Contamination places the hygienic and commercial value of the produce at risk, which in turn causes food loss and food waste. Small stakeholder farmers and post-harvest workers should identify potential sources of contamination, and implement practices to reduce or eliminate them. Possible **sources** of contamination include:

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[9] See Part II, Chapter 3.

- roads and the wheels of vehicles and machines (Plate 10, left);
- passageways and floors throughout the premises, as well as shoes (Plate 10, right);
- uncleaned stacked pallets and racks;
- containers and forklifts;
- ducts, fans and crevices;
- courtyard animals, pets, birds (and their fecal matter) – attracted by potential food sources and habitats – a situation exacerbated by the absence of a revolving door/double door/anteroom;
- mosquito nets/screens; and
- insect and rodent traps.


NICOLA
NICOLA

Plate 10
Pit with water and sanitizer to sanitize truck tyres when entering and exiting the premises (left)
Pad with sanitizer to sanitize workers' shoes at the entrance of the premises of a company in Croatia (right)


NICOLA
NICOLA
NICOLA

Plate 11
Double doors at the entrance and protected corridors between units (left)
Forced airflow at the entrance to prevent insect entrance (centre)
Door separating packing premises from cultivation area (right)

Inappropriate **practices** can also result in contamination, for example:

- absence of protection for light bulbs and glass;
- proximity between stored raw material and non-food substances; and
- poor cleaning practices (e.g. use of unsuitable cleanser prior to sanitization, incomplete removal of detergent from equipment, incorrect water temperature, wrong sanitizer concentration and re-use of rinsing water).

Workers, instruments, monitoring

Health and safety are often undervalued in the food supply chain. Employees at all levels should receive appropriate training to improve awareness of the potential risks derived from:

- poor personal hygiene;
- failure to recognize disease symptoms;
- lack of respect for regulations and safety signs;
- bad practices (e.g. eating, drinking or smoking in the working area);
- inappropriate dress (e.g. wearing jewellery); and
- misuse or non-use of personal protection devices (e.g. masks and gloves) (Plate 12).

Equipment, tools and conveyances do not always receive the necessary attention, particularly in small stakeholder farms. Cross-contamination and risk of pollution/proliferation may occur when plastic containers, wooden equipment, tools and conveyances are not properly repaired, visually inspected, cleaned, washed, sanitized, rinsed and stored. Similarly, poorly maintained crawlspaces and corridors for the passage of both employees and conveyances at the entrance and exit can result in food wastage.

Fast and simple **measurement instruments**, such as the chlorophyll meter, N tester, colorimeter, penetrometer and refractometer, are useful to control the

Plate 12
Sanitary units in place, strawberry tunnels, Croatia (left)
Safety precautions for visitors, tomato glasshouse, Croatia (centre)
Sanitation room for workers prior to entering post-harvest handling and processing premises (right)

maturation process and/or define the best harvesting time. These instruments can also be used to control and sort raw material according to quality prior to sale to wholesalers, enabling the delivery of products of high quality and with commercial added value.

Technical devices – sensors, diagnostic tools and data loggers – are necessary to check and measure growing and environmental conditions in the food supply chain. These devices can be used to obtain data on the temperature, relative humidity and atmosphere, and a timer and logic module can then be used to regulate/activate schedules and the water- and airflows.

Traceability is essential in order to track all the activities in the food supply chain. On small stakeholder farms, the harvested raw material should be divided and stored in batches/lots until the end of its shelf-life. It is important to record all cultivation and post-harvest activities and to keep the relative documentation for a set period (months or years) (Plate 13).


NICOLA

NICOLA

Plate 13
Samples of lots sorted for tracing purposes for fresh produce (left) and fresh-cut produce (right)

CONCLUSIONS

The measures implemented by each small stakeholder farmer in SEE countries depend on the size of the farm and the resources available. The suggested steps to increase profitability and reduce both food loss and food waste may be too complex and too expensive for consideration by some small stakeholder farmers. Priorities can vary, depending on the type of product and the cultural system. Consequently, a step-by-step approach is required, focusing on those factors that impact most on the protected cultivation system. It is imperative that farmers are open to new ideas, such as the development of a joint implementation strategy involving all beneficiaries. It is useful to establish a system to monitor and record performance, activities and achievement of objectives.

GAP recommendations – Along the supply chain

- Perform routine analysis on the water used for irrigation and during post-harvest (see Practical example c – in the box below).
- Implement actions to protect and properly manage the water source.
- Schedule periodic inspection of facilities to identify outbreaks and/or contamination.
- Avoid promiscuity and keep working tools and facilities clean.
- Separate equipment, tools and conveyances according to their function.
- Provide training to all employees on safety, technical knowledge and emergency action procedures.
- Provide employees with sufficient locker room space and with toilets or sanitary mobile units (located at an appropriate distance from the working area).
- Allocate a place for filing and checking all documentation required for traceability.
- As applicable, apply automated/mechanized practices and organize flows and communications in the food supply chain (see Practical example d – in the box below).
- Check for accuracy: calibrate measuring instruments prior to use and level all scales and balances.

Practical examples for small stakeholder farmers

a) Incorporate raw manure into the soil at least 2 weeks prior to planting, but avoid with commodities that are harvested within 120 days. Apply organic fertilizer in pre-planting or in the early stages of plant growth near the roots and cover with soil.

b) Apply nutrients with care. Selenium and sulphur uptake influence the concentration of organosulphur compounds in the *Allium* and *Brassica* genera. High calcium uptake reduces respiration rates, delays ripening, increases firmness, and reduces physiological disorders and decay affecting post-harvest shelf-life. High nitrogen content reduces post-harvest shelf-life due to increased susceptibility to mechanical damage, physiological disorders and decay. Avoid nitrate application in excess, especially for leafy vegetables (for the EU market, see Reg. EU No. 1258/2011 for maximum levels allowed).

c) Perform water analysis: for irrigation, at least every 2 years for well or groundwater or every year for surface water; for pre-cooling, every 6 months; for washing, every day.

d) Use coloured labels for rapid identification of containers, for example: green label for containers filled with vegetables without problems; red label for containers filled with vegetables with possible problems/which need more attention during processing.

Adapted from Lundqvist *et al.* (2008), Jones and Short (2010) and USDA (2014).

If growers implement the activities outlined in the GAP recommendations, they will be a step nearer to meeting GlobalGAP standards. The recommended agricultural practices serve to reduce vegetable loss and waste not only in terms of "volume" but also in terms of quality. Incorrect vegetable management can result in loss of nutrients, reduction of organoleptic properties and reduced colour, taste, firmness and turgour; the resulting negative impact on marketability leads to a reduction in consumer confidence and ultimately to decreased profitability of the farm.

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Watkins, C.B. & Nock, J.F. 2012. *Production guide for storage of organic fruits and vegetables*. NYS IPM Publication No. 10, 1–67.

Useful links for vegetable quality

http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2011:157:0001:0163:EN:PDF

http://mda.maryland.gov/foodfeedquality/Pages/good_ag_practices.aspx

https://international.jifsan.umd.edu/catalogue/course/good_agricultural_practices/#GAPs_manual_english

http://www.brcglobalstandards.com/

http://www.canadagap.ca/manuals/manual-downloads/

http://www.gaps.cornell.edu/index.html

http://www.globalgap.org/uk_en/

http://www.fao.org/prods/gap/

http://www.fda.gov/Food/GuidanceRegulation/GuidanceDocumentsRegulatoryInformation/ProducePlantProducts/ucm064458.htm

http://www.iso.org/iso/home/standards/certification.htm

http://www.kyagr.com/marketing/documents/GAP_selfaudit.pdf

http://www.kyagr.com/marketing/GAP-resources.html

http://www.wnc.edu/files/departments/ce/sci/value01.pdf

http://www4.ncsu.edu/~rmrejesu/Food_Safety_Risk/ag-709%20final%20printed.pdf

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PART III

Crop technologies

1. Tomato

Y. Tüzel and G.B. Öztekin

Ege University, Faculty of Agriculture, Department. of Horticulture, Izmir, Turkey

ABSTRACT

Tomato (*Solanum lycopersicum* L.) is one of the most economically important vegetable crops and accounts for 28.03% of total vegetable production including melons worldwide (FAOSTAT, 2013). Tomato is grown in open field, greenhouses and screenhouses. Open-field production may be for the fresh market or the processing industry, while greenhouse production is only for the fresh market. Tomato's popularity has increased in the last two decades, in particular due to its vitamin and lycopene content, as well as other health benefits.

Changes in consumer demand for a safe and healthy product, together with environmental considerations, have led to changes in production technologies. The emphasis is on sustainable production without excessive use of inputs with the aim of achieving improved quality and higher yield.

This chapter describes sustainable tomato production, including environmental requirements, cultivation schedule, variety selection, seedling growing and cultural practices (planting, training, pruning, fruit-setting, irrigation, fertilization and plant protection), according to the principles of "save and grow".

INTRODUCTION

Tomato (*Lycopersicon esculentum* Mill. syn *Lycopersicon lycopersicum* L. or *Solanum lycopersicum* L.) is a member of Solanaceae family originating in South America and Mexico. Tomato is one of the most economically important crops grown in greenhouses worldwide. In South East Europe, 3.63% of the total protected area is under tomato crop, and tomato production is < 13.7 million tonnes.[1]

Tomato is rich in vitamins A and C, in minerals and antioxidants, and it plays an important part in the human diet. Research supports the positive effects of lycopene and antioxidant activity on disease risk reduction (Burton-Freeman and Reimers, 2011).

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[1] See Part I, Chapter 2.

ENVIRONMENTAL REQUIREMENTS

- **Temperature.** A warm season crop, tomato is sensitive to frost. For optimum growth, it requires temperatures of 19–24 ºC during the day and 16–18 ºC at night. Air temperatures of ≤ 10 °C inhibit vegetative development, reduce fruit-set and impair fruit ripening. High air temperatures (> 35 °C) reduce fruit-set and inhibit development of normal fruit colour. The difference between night and day inside temperature should not exceed 6–7 °C.
- **Air speed.** Hot and dry winds cause excessive flower drop. Continuous moist, rainy conditions encourage the occurrence and spread of foliar diseases. An approximate air speed of 1 m s^{-1} is recommended to avoid moisture damage.
- **Light.** Light is important and affects flowering and fruit-set. Natural light decreases in winter. The required light intensity is 10 000 – 15 000 lux.
- **Humidity.** Relative humidity of 65–75% is preferred for good crop performance. Plants perceive humidity in terms of vapour pressure deficit (VPD); a lower VPD (higher humidity) leads to reduced yield and fruit quality.
- **CO_2-enrichment.** During winter, a CO_2 concentration of 800–1 000 ppm in greenhouse air is recommended during the day.

SOIL REQUIREMENTS

Tomato grow in well-managed sandy loams and in heavy clay loams free of hardpan, but the best results are obtained in deep, well-drained loams. The soil should be rich in organic matter and nutrients, with a pH of 6–7. Tomato has moderate resistance to soil salinity (2.5 dS m^{-1}). For root growth, the ideal soil temperature is 20 °C.

PRINCIPLES OF TOMATO PRODUCTION IN GREENHOUSES

Cultivation schedule

There are two principal cropping systems for greenhouse tomatoes: two crops per year (short cycle) and one crop per year (long cycle). The production season and length of crop cycle depend on the variety, local climatic conditions, availability of climate control in the greenhouse, market demand and marketing policy (Table 1).

Cultivar choice

There are thousands of tomato varieties available on the market in different sizes, shapes and colours, but only a few are acceptable for greenhouse production. The selection of a cultivar depends on growing period, market demand, size of fruit desired, yield, pest and disease resistance, potential physiological problems and growing conditions.[2] Refer to Hortivar, FAO's database listing horticultural cultivars and their performances, for easy retrieval and comparison of information.[3]

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[2] See Part II, Chapter 4.

[3] Available at www.fao.org/hortivar/.

TABLE 1
Cultivation schedule of tomato crop in different climatic regions of Europe

Region / Production type	Sowing date	Planting date	Start of harvest	End of harvest
North and Central Europe:				
Unheated	Mar.	Apr.–May	June	Oct.
Seasonal heated	Dec.	Mar.	May	Oct.
Long-cycle heated	Nov.	Jan.	Apr.	Nov.
Mediterranean:				
Long-cycle	July	Sept.	Nov.	July
Short-cycle spring	Dec.	Feb.	Apr.	July
Short-cycle autumn	July	Sept.	Nov.	Jan.

Koller *et al.*, 2016.

Seedling preparation

Seedlings are raised in seed beds and transplanted to the field. They are usually ready for transplant 3–4 weeks after sowing when they reach a height of 15–17 cm with 4–5 fully opened leaves; transplant them on moist soil in the greenhouse.[4] Seedling quality is key for successful fruit production as it affects, in particular, root development and the shoot–root ratio. Suitable transplants are stocky with healthy foliage and white, well-developed roots. Transplants must be free from nutrient deficiency and pest and disease problems (Kuboto *et al.*, 2013).

Soil preparation

The soil needs to be well prepared, loose and in good tilth, worked to a good depth to break any existing hardpans. Carry out pasteurization or partial sterilization of the soil at least once a year to destroy disease, nematodes and weeds and to avoid further deep tillage. Build up the organic matter content of the soil using compost, composted barnyard manure or other organic matter. Before production begins, carry out a soil analysis and use the results to draw up the fertilization programme.[5] For high yields and good quality of high-value greenhouse vegetables, good soil management is essential.

Soil management

- Increased content of organic matter to improve soil texture and related characteristics (e.g. chemical properties and cation exchange capacity).
- Control of salinity and/or alkalinity.
- Adequate and balanced supply of nutrients.
- Control of soil-borne pathogens.

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[4] See Part II, Chapter 5.

[5] See Part II, Chapter 6.

Planting

Plant density

Optimal plant density depends on the following: species; length of growing cycle; climate and seasonal changes in light; training and pruning; greenhouse design; and climate control (particularly ventilation). General **spacing** requirements are:

- access pathways 80–100 cm
- inter-row 40–50 cm (i.e. 100 × 50 cm)

Double-row planting:

- access pathways 100 cm
- inter-row 50 cm
- intra-row 50 cm (i.e. 100 × 50 × 50 cm)

Plant density is lower in long-cycle crops than in short-cycle crops. In long-cycle production with a single stem, tomato plant density is 2.5 plants m^{-2}. In short cycles, on the other hand, it is higher (3–3.5 plants m^{-2}) (Tüzel, 2013).

Effects of plant density

High plant density:

- Increased light interception
- Reduced ventilation rate
- Increased pesticide use (due to rise in pest and disease problems)
- Increased plant water use

Low plant density:

- Reduced pesticide use
- Reduced fertilizer application

Training (Trellising)

Tomatoes need to be trained, in order to control the number and the position of apical meristems per plant governing plant growth and development. Training systems depend on the crop species, length of growing cycle and greenhouse design. Support plants using strings made from plastic or polypropylene twine. Attach the string to a cable stretched above the plant row (Plate 1).

Plate 1

Plant training: trellising clockwise (left); string attachment (centre); upper part of layering training (right)

Wrap plants around the string or attach them with plastic clips (Plate 2). In long-term and layered tomato crops (Plate 3), various methods exist for attaching the strings and their plants to the cables, in particular, the slip knot (by hand), metal string bobbins or a notched spool with a hook (Hochmuth, 2011).


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Plate 2
Plastic clips and supports for trusses

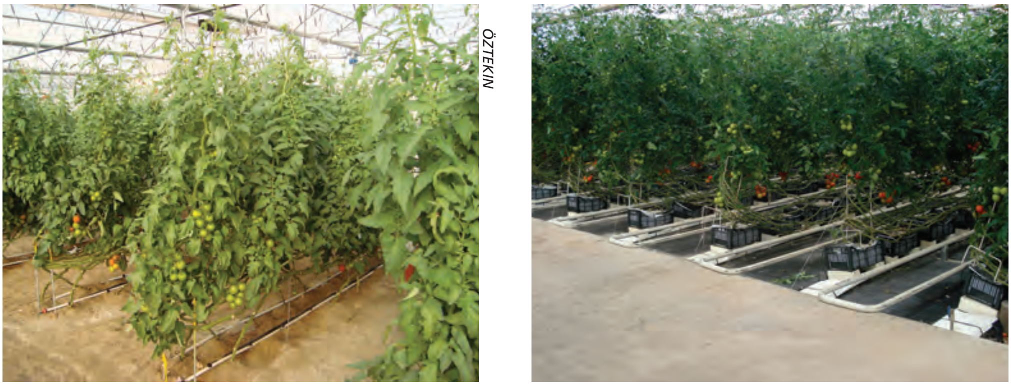
ÖZTEKIN
ÖZTEKIN

Plate 3
Layering system in soil culture (left) and soilless culture (right)

Pruning

Pruning influences the flowering and fruiting of the tomato plant. In greenhouse crops, it entails the complete removal of new side or lateral shoots, removal of shoot apices, removal of leaves and fruit thinning. Pruning provides an opportunity for close inspection to check for pests, disease or nutritional disorders. Prune plants properly and on time. Use disinfected tools and collect prunings to avoid infection (Plates 4 and 5).

Disinfect the equipment used for pruning!


GÜL

Plate 4
Disinfection of pruning equipment and collection of waste

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Prevent infection – leave NO WASTE in the greenhouse or nearby!

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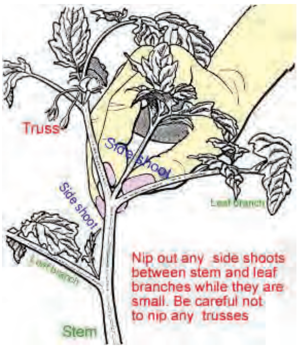
Plate 5
Plant waste left in and around the greenhouse – a source of infection

FIGURE 1
Side shoot removal



Nip out any side shoots between stem and leaf branches while they are small. Be careful not to nip any trusses

www.westcarlston.com/info_tomato_growing.htm

Plants are usually pruned to a single stem, removing all side shoots commonly referred to as "suckers". One side shoot forms at the point where the leaf originates from the main stem, just above the leaf petiole. Removing suckers once a week keeps them under control. In general, remove side shoots > 2–5 cm long. Late pruning of side shoots has a negative effect on crop performance, because developing side shoots compete with fruits and increase the risk of disease infection (Plate 6). Take into account the local growing season and climatic conditions (i.e. light, temperature) when defining the number of stems per plant. In some circumstances, money can be saved by allowing the development of two stems per plant: pinch off the apex of the main stem at an early growth stage and allow two lateral shoots to develop on opposite sides of the rows. Training into two stems is more frequent in grafted plants (which are more expensive) in order to reduce the cost of seedlings, since this practice reduces the number of plants per unit area by 50%. Tie each stem separately so it grows like a single plant (Plate 7).

The earlier they are removed, the less plant energy is wasted

ÖZTEKIN

Plate 6
Side shoot removal

Most of the assimilates supplied to the fruit of each truss (cluster) come from the 2–3 leaves beneath that truss. If these leaves are removed too early, the growth and final size of the fruit will be adversely affected. However, once the fruit is at the mature green stage, removal of the leaves beneath the fruit truss speeds up the ripening process, improves air circulation and reduces disease (e.g. botrytis) incidence. Remove all old leaves, even before they start yellowing.

Plate 7
Double-stem seedlings (left) and plants (right)

Truss (cluster) pruning serves to meet the market demand for fruits of uniform size and shape. Cluster pruning involves the removal of small fruits from some clusters, leaving the 5–6 best fruits. Remove misshaped or deformed fruits first, or remove the smallest – usually the last one formed on each cluster (Plate 8).

Topping plants

Mean cluster numbers are: 7–8 in double crop production in unheated greenhouses; 12 in small-scale unheated greenhouses; and 20–24 in single crop production in modern greenhouses. Leave 1 or 2 leaves above the highest cluster to shade the fruit and prevent sun scald.

Plate 8
Cluster pruning: not thinned (left) and thinned (right)


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Plate 9
Mechanical vibration

Fruit-setting

The yield of most fruit-bearing greenhouse vegetables depends on the success of fruit-set, linked in turn to pollination. In greenhouses, in contrast to open-field production, pollination requires assistance due to the limited air movement and high humidity. Two methods are available:

- **Mechanical vibration.** Vibrators are usually generally battery powered; they are held against the stem of each truss for a few seconds (Plate 9). At least three sessions a week are required between 10.00 and 15.00 hours, when humidity is low and pollen availability high (Hochmuth, 2011). This method is rather time-consuming.
- **Bumble bees.** Of the bee species used as pollinators (e.g. honey bees: *Osmia cornuta* and bumble bees: *Bombus terrestris*), bumble bees are the most efficient and are adopted as an excellent pollination agent in greenhouses worldwide. The advantages of bumble bees over honey bees are:
  - speed – 8–20 flowers per minute visited;
  - number of visits – ≤ 400 flowers in one trip;
  - improved contact – due to large size; and
  - incessant activity – due to absence of communication system.


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TÜZEL
TÜZEL

Plate 10
Brown marks on stamens – indication of bumble bee visits

Plate 11
Appropriate placement of hives

A standard bumble bee hive consists of 50–60 worker bees and a queen and remains active for about 6–8 weeks. Each hive has an approximate pollination range of 2 000 m^2 in tomato production. Introduce hives to the greenhouse when the flowers are open; position at a height of 0.5–1 m (Plate 11). They require protection against solar radiation and condensation of water; moreover, take care to avoid ants and/or any other insect entering the hives. Once the hive is in position, the bumble bees need to settle for ½–1 hour before the flight hole is opened. They are active during flowering of the crop. Tiny brown spots on the stamens show when they have visited the flowers.

The advantages of bumble bees over mechanical vibration and/or plant growth regulators are as follows:

- Increased yield and fruit quality.
- Low labour costs.
- Product safety.
- Reduced risk of fungal disease – associated with use of plant growth regulators.
- Low pesticide input and selection of low-toxicity pesticides – to avoid harming bumble bees.

Irrigation

Irrigation must supply sufficient water throughout the growth process, particularly at critical times (e.g. immediately after sowing/transplanting, on sunny days). The drip irrigation method is recommended: it allows the grower to not only meet water requirements but also to apply soluble fertilizers added to the water during the production period. Automatic irrigation is preferable, using timers or electronic irrigation controllers. The volume of water applied varies depending on the season and the plant size – the daily requirement of a plant at the seedling stage is approximately 50 ml, while for a mature plant it is 2.7–3 litres (Synder, 1997). Avoid excessive irrigation.

Fertilization

Establish a targeted yield level fertilization programme based on soil analysis results, and according to the quantity of major nutrients taken up by tomato (Table 2) and the length of the production period. The nutrition programme

TABLE 2

Amount of major nutrients taken up by tomato (kg tonne^{-1} produce)

N		P_2O_5		K_2O		Average ratio
Av.	**Range**	**Av.**	**Range**	**Av.**	**Range**	**N : P : K**
3.5	2.0–7.4	1.0	0.6–2.0	6.5	3.5–13.2	3.5 : 1 : 6.2

Gianquinto *et al.*, 2013 (adapted).

must be specifically for greenhouse tomatoes, using compost, plant meals, green manure, composted livestock manure, chicken manure, lime, rock phosphate and other rock minerals, and/or supplementary organic fertilizers. Moreover, the grower must be aware of the specific requirement for each fertilizer element and of the exact quantity applied. It is important to:

- monitor electrical conductivity (EC) and pH levels of applied fertilizers;
- avoid overuse and inadequate or imbalanced use of fertilizers;
- reduce nutrient losses in soil; and
- take periodic leaf samples (Plate 12) to monitor plant nutrient status (Table 3) and check that plants are receiving optimum nutrient levels (Synder, 1997).

TABLE 3

Optimum range of leaf nutrient elements

		Macronutrients (% in dry weight)		
N	P	K	Ca	Mg
3.0–5.0	0.2–0.6	3.5–6.0	2.0–4.0	0.35–0.80
		Micronutrients (mg kg^{-1} in dry weight)		
Fe	Mn	Zn	Cu	B
40–150	30–150	20–80	5–20	30–80

Note: Sampled plant part: most recent fully expanded leaf.
Gianquinto *et al.*, 2013 (adapted).

ÖZTEKIN

ÖZTEKIN

Plate 12

Leaf sampling method of tomato (between third and fifth youngest fully developed leaves on upper portion of plant)

SOILLESS CULTIVATION

Tomato is the most important vegetable grown in soilless cultivation systems in greenhouses. Many different types of substrate culture, such as rockwool slabs or locally available materials (e.g. tuff, perlite, pumice) are used. An open or closed (recycling) system can be used for soilless tomato cultivation. Recycling systems save on water and nutrients and reduce environmental impact. However, care must be taken to reddress any nutrient imbalance in the solution, disinfection is required and it is vital to carefully monitor the EC. In all systems, essential nutrient elements are supplied via the nutrient solution. The main **nutrition requirements** of tomato in soilless culture are as follows (Savvas *et al*., 2013):

- **Tap water.** Take into consideration the nutrient concentration.
- **N : K ratio in nutrient solution.** Note that the mean daily N : K uptake ratios were 2.40 and 2.25 on a molar basis, and that this ratio decreased to 1.12 (molar basis) when the fruit load increased (Table 4).
- **NH_4-N : total-N ratio of nutrient solution.** Maintain ammonium ratio at 10–15% of total nitrogen.
- **pH levels in root environment.** Note that plant nutrients are generally most available to plants in the pH range 5.5–6.5, while low pH causes the decrease of Ca uptake.
- **Macronutrients.** Note that K requirements increase with increasing fruit load, while Ca requirements decrease.

TABLE 4
N : P : K ratios recommended for summer and winter season in different climate regions

Climate	Season	N	P	K
Middle European	Summer	1	0.2–0.3	1.0–1.5
	Winter	1	0.3–0.5	2–4
Mediterranean	Summer	1	0.2	1
	Winter	1	0.3	1.5–2.0

Resh, 2013.

Formulations of specific nutrient solutions based on Knopp (1965) and Hoagland and Arnon (1950) are developed by different researchers (Savvas *et al.*, 2013) (Table 5).

TABLE 5

Recommended nutrient concentrations in nutrient solutions for soilless tomato grown under Mediterranean climatic conditions

	Hoagland and Synder,1933	Day, 1991	Schon, 1992	Sonneveld and Straver, 1994
Macronutrients (mg litre^{-1})				
Total N		210–240	200	
NH_4-N				20
NO_3-N	210			220
P	31	40	50	30
K	234	250–300	360	400
Ca[a]	200	150	185	200
Mg[a]	48	50	45	75
S	64			
Micronutrients (mg litre^{-1})				
B	0.1	0.40		0.3–0.4
Cu	0.014	0.10		0.3–0.4
Fe		2		10
Mn	0.1	0.75		0.8–1.0
Mo	0.016	0.05		0.1
Z	0.01	0.50		0.3–0.4

[a] Ca and Mg concentrations may vary depending on relative concentrations in tap water.

Resh, 2013 (Hoagland and Synder,1933); Day, 1991; Jones, 2014 (Schon, 1992); Adams, 2002 (Sonneveld and Straver, 1994).

Physiological disorders, pests and diseases

Many tomato problems are not caused by insects or diseases, but are "physiological disorders", i.e. environmental – depending on temperature, humidity, light, water etc. – and nutritional problems. Table 6 lists the most common disorders, nutrient deficiencies, pests and diseases affecting greenhouse tomato.

HARVESTING AND POST-HARVEST HANDLING

Fruits are harvested at the ripening stage. Depending on market demand and distance, harvest can be before the red ripening stage. Yield varies depending on climatic conditions, length of growing period, variety and heating requirements. The average yield is 10–25 tonnes ha^{-1}. Yield can be > 30 tonnes ha^{-1} in long-season crop production in heated greenhouses.

Fruits can be harvested when colour develops on the blossom end. High-grade fruits are packed in trays in wooden boxes or cartons, while lower-grade fruits are packed in jumble packs. Once at the ripening stage, fruits contain enough internal ethylene to continue the ripening process. Generally, tomatoes harvested at ripened (red) and breaker stage are stored at 7 and 10 °C, respectively, and 86–90% relative humidity for 20–25 days.

TABLE 6
Identification and control of the most common tomato disorders, deficiencies, pests and diseases

Symptoms	Reasons	Prevention and control measures
Disorders		
Circular patch at flower-end of fruit Greenish brown to black Black mould on surface of lesion	Blossom-end rot – calcium deficiency and drought	Use tolerant varieties Apply calcium fertilizers Irrigate during dry weather Apply mulch Avoid excessive N, irrigation deficit, high salinity soils
Scarring and malformation at blossom end of fruit	Catface – environment and variety interaction	Use tolerant varieties Apply adequate climate control
Circular, radial, concentric cracks around stem end of fruit	Cracking – environment and variety interaction	Use tolerant varieties
Flattened, blotchy, brownish grey and yellow areas Open, dark brown vascular tissue in fruit walls	Blotchy ripening – environmental factors in combination with fungi, bacteria and viruses	Use tolerant varieties
Nutritional deficiencies		
Older leaves chlorotic Dying leaves Plant stunted Light green foliage	N deficiency	Apply adequate fertilization Control soil pH
Stem, leaf veins and petioles reddish purple	P deficiency	Apply adequate fertilization Control soil pH
Older leaves chlorotic, veins green Burning of leaf margins Leaf roll	K deficiency	Apply adequate fertilization Control soil pH
Older leaves chlorotic between veins Leaves curled, brittle and dry	Mg deficiency	Apply adequate fertilization Control soil pH
Young leaves chlorotic, veins green	Fe deficiency	Apply adequate fertilization Reduce pH of soil or nutrient solution Spray minor elements on leaves
Young leaves mottled and chlorotic between veins	Mn deficiency	Apply adequate fertilization Spray minor elements on leaves
Pests		
Fine pale mottling on upper leaf surface Tiny yellowish green mites, white cast skins and egg shells on underside of leaves	Red spider mite (*Tetranychus urticae*, *T. cinnabarinus*)	Disinfect and remove severely infested plants Adopt biological control with predatory mites Spray with insecticide Use insect nets Avoid drought
Leaves yellow and curling Leaves shiny or blackened due to honeydew	Whitefly (*Trialeurodes vaporariorum, Bemisia tabaci*)	Use natural enemies and attractive plants Use insecticidal soap Apply yellow sticky traps Control weeds Maximize distance and time interval between host crops Apply pesticides Use insect nets and silver/aluminium-coloured mulches
Leaves misshapen, curling, stunted Leaves yellow Presence of honeydew	Aphids (*Macrosiphum euphorbiae, Myzus persicae*)	Use natural enemies Apply lady beetles Control weeds Use pesticides Use insect nets and silver/aluminium-coloured mulches

TABLE 6 (cont'd)

Identification and control of the most common tomato disorders, deficiencies, pests and diseases

Symptoms	Reasons	Prevention and control measures
Pests (cont'd)		
Blotch-shaped mines in leaves Wide galleries and burrows in fruit Malformation	*Tuta absoluta*	Use insect nets Use sex pheromone traps Adopt biogents for control Use microbial control with *Bacillus thuringiensis* var. *kurstaki* Rotate with non-solanaceous crops Practise ploughing Apply adequate fertilization and irrigation Destroy infested plants Spray with chemical or botanical pesticides
Diseases		
Older leaves yellow Bright yellow blotchy areas, Inside turning brown and leaf drying Powdery growth on upper leaf side and under leaf	Powdery mildew (*Oidium neolycopersici*, *Erysiphe orontii*, *Leveillula taurica*)	Use resistant cultivars Apply fungicides Apply sulphur dust or spray Apply humidity control Avoid excess fertilizer, high plant density, water on leaves
Yellow–white patches on upper surfaces of older leaves White–grey, cotton-like fungi on undersides	Downy mildew (*Phytophthora infestans*)	Use resistant varieties Remove weeds Improve air circulation Remove and destroy plants with infection Apply copper spray Use fungicides Avoid overhead irrigation
Grey, velvet coating of spores on fruit, stem and petioles	Grey mould (*Botrytis cinerea*)	Apply soil sterilization Maintain dry canopy Reduce humidity Increase temperature and air circulation Adopt adequate plant spacing Spray with fungicide
Yellowing of lower leaves accompanied by brown slightly sunken cankered area on stem at soil level Tissue shrinks Presence of black pycnidia	Didymella stem and fruit rot (*Didymella lycopersici*)	Use clean or chemically treated seeds/ seedlings and tools Apply soil sterilization Spray fungicides
Small pale green or yellowish spot with indefinite margins on upper leaf surface Spores released on lower surface Olive green–grey purple and velvety appearance on under side Leaves yellowish brown, curled and dry	Leaf mould (*Cladosporium fulvum*)	Adopt adequate plant spacing Reduce humidity Promote air circulation Remove and destroy (burning) of all plant debris after the harvest Use resistant cultivars Apply chemical control Avoid excessive N
Brown spots with concentric rings on leaves and yellow halos	Early blight (*Alternaria solani*)	Use resistant cultivars Apply sanitation measures Apply mulching Maintain air circulation Adopt crop rotation Apply copper spray Avoid water on leaves
Clearing of vines Chlorosis of lower leaves Wilting leaves and stems Marginal necrosis Defoliation	Fusarium wilt (*Fusarium oxysporum* sp. *lycopersici*)	Use resistant varieties Sterilize seeds Use soilless media Adopt good sanitation practices Avoid excessive warming

GAP recommendations – Tomato production

- Plan the production season based on market analysis.
- Select cultivars according to growing cycle, market demand, yield, and pest and disease resistance.
- Use high-quality seedlings – the key for successful vegetable production.
- Practise good soil management to attain high yields and quality of high-value greenhouse vegetables:
  - Maintain or restore soil organic content by manure or compost application.
  - Analyse the soil and organic manure (or compost) to prevent contamination and to ensure an adequate and balanced supply of nutrients at appropriate times and in appropriate doses.
  - Control salinity by irrigating with small volumes, by tillage and by mulching in order to prevent upward movement of saline water from the deeper layers; however under certain cases, increase irrigation to leach the salt into deeper soil levels.
  - Control soil-borne pathogens by avoiding application of chemical treatments for soil disinfection and adopting soil solarization (a non-chemical method widely used in integrated greenhouse vegetable production).

- Adopt correct plant spacing, avoiding high densities to prevent disease incidence, and using lower densities for long-cycle crops.
- Prune plants on time and properly, removing all waste material to prevent new infection and/or the spread of pests and diseases.
- Use bumble bees for pollination, positioning hives 0.5–1 m above ground, protecting from sun and water condensation and ensuring that ants and other insects do not enter the hives.
- Select and apply mulch according to the site, soil, crop and climatic conditions.
- Avoid excessive irrigation and fertilization; base fertilization on soil analysis.
- Handle harvested fruit with care to avoid damage, especially bruising.
- Respect the distinct quality standards with regard to size, colour, tolerances and other characteristics (well-developed or damaged, specific defects).
- Record usage and dates of chemical pesticides, fertilizer ppm (concentration) and water (daily dose).
- Record any changes in the cultural programme.
- Apply preventative measures to avoid pest and disease incidence.

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2. Cucumber

N. Gruda,[a] G. Sallaku[b] and A. Balliu[b]

[a] University of Bonn, Germany
[b] Agricultural University of Tirana, Albania

ABSTRACT

Cucumber is one of the most important cultivated greenhouse crops. Most varieties are female hybrid cultivars, but monoic cultivars are still in use in some South East European countries. Cucumber cultivation – as for other fast-growing vegetables – is characterized by technologies designed to increase intensive production. Cultural practices aim to provide an appropriate root medium, balanced root/leaf growth, balanced source/sink development, and a good harvesting rate of high-quality fruits. The most important growing practices are microclimate control, fertigation and training. Cucumber is very sensitive to both abiotic and biotic stresses, and serious problems can arise in the case of inappropriate crop management. Integrated pest management provides various approaches for smallholders.

INTRODUCTION

The cultivation area of cucumber in South East Europe (SEE) is almost 2 000 ha and it is the second greenhouse vegetable in the region after tomato. An additional area of > 700 ha is cultivated under tunnels.[1]

INFLUENCE OF ENVIRONMENTAL FACTORS

Cucumber is a typical subtropical plant and grows best under conditions of high temperature, humidity, light intensity and nutrient availability; it is highly sensitive to unfavourable environmental conditions.

Temperature

Air temperature influences vegetative growth, flower initiation, fruit growth and fruit quality. Cucumber growth rate depends on the average 24-hour temperature: the higher the average temperature (≤ 25 °C), the faster the growth. Optimum air temperature depends on the growing period. At germination, the optimum

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[1] See Part I, Chapter 2.

temperature is 25–35 °C and, with good moisture, it takes 2–3 days for seeds to germinate. In contrast, at 12 °C, seeds need 12–20 days to germinate and there are many losses. Shoot growth does not occur at air temperatures of < 13–15 °C, while the maximum temperature for vegetative growth is about 38–40 °C.

During the first week after planting, the ideal air temperature is 22–24 °C; thereafter, temperatures should be kept at 20–22 °C until the beginning of harvest. During warm weather, in late spring and early fall and at harvest, it is recommended to lower the air temperature settings by ≤ 2 °C to encourage vegetative growth, especially at night. At higher air temperatures, fruits grow rapidly and compete for assimilates. A longer harvest break may begin, particularly after harvesting cucumbers from the main stem. This can nullify the advantage of an earlier start to the harvest; in addition, plants get older earlier. For good fruit quality, temperatures should be 22–24 °C; at temperatures of < 18 °C, fruits tend to be shorter.

A day/night temperature difference is recommended for winter and early spring cultivation only. Growth performance depends on the 24-hour mean temperature during the long days and short nights of spring/summer. Lowering night temperatures in this period is of no physiological advantage for the plant; it could, however, be done to save energy.

Soil temperature is important, in particular at germination and the young-plant stage. If soil temperature remains < 14–16 °C for a long time, plants wilt and then die. For this reason, cucumber is said to need a “warm foot”. Soil heating enables cucumber plants to better endure low air temperature, but this practice is not adopted in SEE countries. Low soil temperatures stimulate soil-borne diseases and reduce the water and nutrient uptake ability of roots, particularly uptake of phosphorus. A minimum root temperature of 19 °C is required, but 22–23 °C is preferable.

Water temperature in irrigation must also be controlled and adjusted to avoid the appearance of cold shock symptoms (Plate 1). Heat injuries will appear under high transpiration and with inadequate water supply after 1–2 hours (Krug *et al.*, 2002).


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Plate 1
Cold shock of soilless cucumbers as a result of cold-water irrigation

Light

Temperature control must be considered in the context of light intensity. Radiation affects total plant leaf area, carbohydrate production and, consequently, productivity. During the winter, the carbohydrate supply is low and productivity is reduced, resulting in many aborted fruits. Light also has a direct influence on fruit quality. For example, fruits grown under low light conditions have less dry matter, are generally light green at harvest and easily turn yellow on the shelf. Young fruits are usually more sensitive to low light intensity than older fruits on the same plant.

Humidity

High humidity used to be generally recommended for greenhouse cucumber. However, high humidity is only appropriate if the water supply is periodically insufficient, because it is important to maintain continuous moisture. High relative humidity increases the risk of water condensation and the development of plant diseases, while low transpiration rate leads to inadequate absorption of nutrients (Krug *et al.*, 2002). 'Beit Alfa' cultivars have good tolerance against powdery mildew. A combination of high daytime and low night-time humidity is recommended for optimal cucumber fruit production and quality.

CO_2 enrichment

A decrease in CO_2 below the concentration in the outside air should be avoided. The recommended concentration is 600–800 µmol mol^{-1} to increase cucumber yield, although higher concentrations are found in the literature. The concentration of CO_2 applied depends not on the conditions, but on the incurred cost. If there are no industrial CO_2 sources in the vicinity, decomposition of manure or other organic products, such as straw bales, is an effective method. Indeed, the traditional straw bale cultural technique has long been adopted in cucumber cultivation, and it is one of the oldest and simplest methods of CO_2 enrichment in greenhouses.

Soil requirements

Cucumber requires a deep, well-drained, structurally stable, fertile soil with high pore volume. High porosity and stability are important for coping with high and frequent water supply, as well as with stress due to agricultural practices and harvesting. This can be achieved by incorporating large amounts of organic matter and adopting proper tillage measures. Compact, cold soils with a high level of groundwater are not suitable for cucumber. Sandy loam soils with a pH of 5.5–6.5 are more suitable.


BALLIU

Plate 2
Long-fruit cucumber cultivars


BALLIU

Plate 3
Short-fruit 'Beit Alfa' cultivars

PRINCIPLES OF CUCUMBER PRODUCTION IN GREENHOUSE

Cultivar choice

Traditional cucumber varieties have both male and female flowers and require pollination to produce healthy fruits with seeds and white spines. When cucumbers do not pollinate properly, the fruits are misshapen and poorly developed, especially at the blossom end (Vandre, 2013).

The most popular cucumber types currently grown in greenhouses are long, seedless hybrid cultivars, often referred to as "European" or "Dutch" cucumbers. These varieties are gynoecious and produce only female flowers. The fruits are parthenocarpic and there is no need for pollination. The fruit has thin, edible, smooth, green skin, sometimes with faint longitudinal ribs. They include the popular 'Beit Alpha' parthenocarpic cultivars, which are are adapted for trellising, have shorter internodes and set multiple fruits in a cluster (Plates 2 and 3).[2]

Soil preparation

Approximately 80% of cucumber roots develop and spread in the top 20-cm layer of soil; they possess poor tolerance to low temperature, drought and flooding. The soil for cucumber planting requires careful preparation and, as for other vegetable crops, it should not be too fine to enable appropriate aeration.

In greenhouse cucumber cultivation, the soil may be flat (Plate 4) or in raised beds. Raised beds are essential for early planting and when the water table is shallow. The bed width should be 60–100 cm, depending on the distance between rows, and the depth 25–30 cm. The topsoil should be finer than the soil layer below. Raised beds are often covered with plastic film or other mulching materials. The application of plastic films before planting brings many benefits: weed

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[2] For cultivar choice, refer to the FAO database, Hortivar, available at www.fao.org/hortivar/.

control, increased soil temperature, reduced water consumption and increased profitable early yield. It is, therefore, important to position plastic mulches as early as possible. Plastic films should be laid on moist soil, and a preliminary irrigation is recommended if the moisture level is not adequate. The ideal time to lay out the plastic is midday, so that it can be stretched tight (Egel, 2015).

Cucumber can also be cultivated in growing media. Cultivation in rockwool is common worldwide, but in some SEE countries, local growing media (e.g. perlite and pumice) are frequently adopted. Slabs or bags with a 15- or 30-cm width are used. As for other vegetables, nutrient solution is supplied, based either on the actual electrical conductivity (EC) and the desired pH value, or on average uptake rates. With good irrigation control, 5 litres of substrate per plant is sufficient. Since cucumber is sensitive to salinity, an EC of approximately 2 dS m^{-1} should be maintained during early plant growth and later adjusted to 2.5 dS m^{-1} as plant size increases (Savvas *et al*., 2013).

Cucumber is very sensitive to high salinity (Robinson and Decker-Walters, 1997). Plants grown under saline conditions are subject to serious problems resulting in unsatisfactory yield. High salinity causes retarded plant growth, short internodes and reduced leaf area. Leaves are often dark green and dull (Plate 5). In extreme conditions, necrotic tissues may be present in older leaves. Salinity can be due to a high level of salts in the groundwater, irrigation water, soil or growth medium, or to excessive application of fertilizers.

Planting

Greenhouse cucumbers usually start from transplants. However, direct seeding in beds can sometimes be adopted for late summer or early autumn plantings, when temperatures are sufficiently high for seed germination and the timing of the start of harvest is of less consequence.

GRUDA

Plate 4
Greenhouse cucumber plants cultivated directly in soil using drip irrigation system

BALLIU

Plate 5
Growth retardation of cucumber plants as a result of high soil salinity

Plate 6
Grafted cucumber transplants

Cucumber transplants may be grown on their own rootstock or grafted (Plate 6). Successful cucumber establishment from transplants requires special care and attention. The root system of very young seedlings is easily damaged and is slow to resume growth under low soil temperature. On the other hand, overgrown transplants develop thick tap layers over the roots, resulting in poor stand establishment.[3]

Seedlings should be placed deep in the ground and irrigated immediately with sufficient water to guarantee quick stand establishment. It is imperative to maintain optimum temperatures and avoid major fluctuations between day and night temperatures in the days immediately after transplanting.

Plant density

The plant density in greenhouses depends on the expected light conditions during growth and the pruning method. To avoid overlapping leaves and shading by adjacent plants, a plant typically requires about 0.5 m^2 with good sunlight, but nearly twice as much space may be needed in northern countries where light intensity is low.

In general, under good light conditions in southern Europe, a plant density of 2.2–2.5 m^{-2} is adequate. In northern locations 1.3–1.5 plants m^{-2} are recommended to ensure good air circulation and sufficient light for fruit production. Spacing between rows and between plants within the row varies according to grower preference. Rows are often 1.2–1.5 m apart, with plants 0.40–0.45 m apart in the row. In general, planting density is higher for short-fruit cultivars of the 'Beit Alpha' group.

Trellising and pruning

Cucumbers are trellised using a string or wire system. Growers, according to their experience and preference, adopt various methods. The main objective is to achieve uniform sunlight throughout the greenhouse.

For optimal cucumber production, it is important to achieve a balance between vegetative growth and fruit load throughout the plant growth cycle. Continuous pruning of shoots, foliage, fruits and flowers is necessary. If there are too many fruits, a large proportion may be aborted, malformed or poorly coloured, because

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[3] See Part II, Chapter 6.

the plant may not have sufficient assimilates (Plate 7). The situation deteriorates further under poor light conditions.

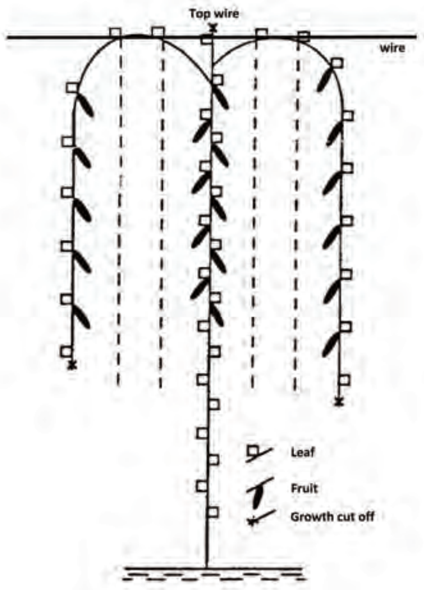

GRUDA

Plate 7
Heavy, not balanced cucumber fruit load with aborted and malformed fruits

Generally for long-fruit cultivars, only one fruit per leaf axial should be allowed to develop, although with vigorous cultivars more than one fruit may sometimes mature at a node. Short, midi types can support several fruits per node and give good yields, with a minimum of three to four fruits harvested at each node.

Most growers in SEE countries prune their plants using an umbrella system (Figure 1). Plants need to establish a strong root system and vegetative stem prior to fruit-set. It is, therefore, important to remove all lateral branches, flowers and tendrils for 8–10 leaf nodes. The first fruit may be allowed to develop earlier at 5–6 leaf nodes in the case of short-fruit cultivars, or under favourable growing conditions (e.g. optimum temperature and high light intensity). The main stem fruits above that point are allowed to develop at the base of each leaf. All lateral branches are removed, and plants are trained to a single stem. The bottom leaves should also be gradually removed as new leaves form on the upper part of the stem.

FIGURE 1
Umbrella pruning system



Vandre, 2013.

Once the plant reaches the support wire, it is allowed to grow about 20 cm along the support wire, or two leaf nodes above the height of the wire. A lateral shoot is then allowed to grow at each of the two top leaf nodes hanging down from the wire.

Irrigation

Proper irrigation is key to both yield and product quality. Cucumber has relatively high water requirements; irrigation frequency is therefore generally high. It is important to maintain a proper water–air ratio in the root zone to ensure an adequate supply of oxygen to the roots.

Daily water consumption depends on climatic conditions, such as light intensity, temperature and relative humidity, as well as plant density and phenological stage. The soil type does not affect the total amount of water needed, but it does influence the frequency of water application. In light sandy soils, the water drains off quickly, and high frequency with less water per application is required. When mulching is applied, significantly less water is needed through irrigation because of reduced evaporation.

Drip irrigation is the most common and convenient irrigation method for cucumbers. Furrow irrigation can cause plant lodging due to an overdose of water. Sprinkler irrigation can encourage fungal diseases. The EC of the water must be taken into account when choosing the water source: water with $EC < 1$ dS m^{-1} and a slightly acidic pH is recommended. The pH can be lowered by using inorganic acids. On the other hand, when soil is saline, the irrigation amounts should be increased to allow salt leaching.

Fertilization

Nutrient demand of cucumber is highest at fruit-set. It remains high throughout production and decreases at the senescence stage. While cucumber has a high nutrient requirement, it is very sensitive to excesses or sudden variations in the nutrient supply, as well as to significant fluctuations in nutrient concentrations in the soil. In order to prevent over- or underfertilization, it is vital to carry out frequent analysis of the nutrient content of the soil and water used. The fertilization programme should be based on the analysis results.

Nitrogen (N) is crucial for cucumber growth. Plant growth and fruit harvesting rates largely depend on N availability. The N requirement is lower at the beginning of the growth cycle. The N absorption rate increases rapidly from day 36 after emergence. This corresponds to the start of fruit harvesting and continues throughout the harvesting period. Other nutrients follow a similar pattern. Therefore, while the daily rates of N and K application gradually increase with time, the rate of P fertilizer application remains almost unchanged during the growing period (Table 1).

As with other fruit vegetables, the most absorbed nutrient is **potassium (K)**. Approximately 90% of K is absorbed during the last 36 days of the crop cycle (SQM, 2015). Although it does not have a major effect on the total harvested yield, K enhances plant resistance to several abiotic stresses and plays an important role in improving fruit quality.

Fertigation, or the application of fertilizers through the irrigation system, is the most popular and efficient method of fertilizing greenhouse vegetables. Recommendations regarding the nutrient content of fertigation solutions are based mainly on the physiological responses of the specific crop to each element. There are two methods:

- **Quantitative:** Fertilizers are dissolved in a large holding tank and the solution is pumped straight to the crop (Table 1).
- **Proportional:** Fertilizers are mixed in concentrated stock solutions and incorporated into the irrigation water through fertilizer injectors (Table 2). The total amount of nutrients delivered to the plant depends on the amount of irrigation water (Haifa, 2011).

Side-dressing fertilizers should not be applied when drip irrigation is used, as it is assumed that fertigation can easily satisfy the precise daily demands of the crop. However, organic fertilizers and lime may be needed before planting, in order to improve soil structure and adjust soil pH.[4]

TABLE 1

Recommended nutrient amounts as active ingredients for quantitative fertilization method of soil-grown, greenhouse cucumbers

Growth stage	Nutrient demand (kg ha^{-1})			
	N	P_2O_5	K_2O	MgO
Establishment	40	10	60	10
Vegetative growth	70	20	140	40
Flowering – fruit-set	80	20	200	30
Harvesting	50	20	100	20
Total	240	70	500	100

Haifa, 2011.

TABLE 2

Recommended nutrient amounts as active ingredients for proportional fertilization method of soil-grown, greenhouse cucumbers

Growth stage	Assumption		Nutrient demand (kg m^{-3})			
	No. days per stage	Irrigation rate (m^3 ha^{-1} day^{-1})	N[a]	P_2O_5	K_2O	MgO
Establishment	25	25	0.06	0.02	0.10	0.02
Vegetative growth	30	40	0.06	0.02	0.12	0.03
Flowering – fruit-set	30	55	0.05	0.01	0.12	0.02
Harvesting	25	60	0.03	0.01	0.07	0.02

[a] 80–90% as NO_3^-, 10–20% as NH_4^+.
Haifa, 2011.

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[4] See Part II, Chapter 2.

Main disorders, pests and diseases

Cucumber grows fast and develops an abundant leaf area. The leaves are soft, tender and highly susceptible to pests and diseases. The most frequent and devastating pests and diseases are listed in Table 3.[5]

Harvesting and post-harvest handling

Cucumber harvest in a protected environment starts approximately 30–45 days after transplanting with variations according to cultivar, climatic conditions and technology used. Cucumbers are harvested as immature fruit when full length has been reached. Over-mature cucumbers left on the vine inhibit new fruit-set, and production decreases if fruits are left on the plant for a long time. Harvest should take place at the coolest time of day, in order to avoid excess heating of the product. To minimize damage and disease spread, it is important to use a sharp clean tool to cut the fruit from the plant.

For cucumber and other vegetables, European marketing and quality standards are adopted. Explanatory brochures are published by the United Nations Economic Commission for Europe (UNECE)[6] and the Organization for Economic Co-operation and Development (OECD).[7]

Cucumbers lose moisture rapidly and tend to soften during storage. Harvested fruit should, therefore, be placed in clean harvesting containers, kept in the shade and taken to the packing house as soon as possible after harvest. Careful handling is vital to avoid damage to the thin skin. The optimum storage temperature for cucumbers is 10–12.5 °C at a relative humidity of 95%. Storage or transit temperatures below this range may result in chilling injury after 2–3 days.

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[5] See Part II, Chapter 5.

[6] Available at http://www.unece.org/trade/agr/standard/fresh/FFV-StandardsE.html.

[7] Available at http://www.oecd.org/tad/code/oecdfruitandvegetablesstandardsbrochures.htm.

TABLE 3

Identification and control of the most common cucumber disorders, pests and diseases

Symptoms	Reasons	Prevention and control measures
Pale green to yellow leaves, especially in older leaves New leaves green but small	N deficiency	Apply adequate fertilization
Chlorosis at leaf margins in interveinal area, especially in older leaves	K deficiency High root pressure	Apply adequate fertilization and irrigation
Youngest leaves cup downwards, edges scorched Death of growing points	Ca deficiency High salinity	Control climate and growing conditions Apply adequate Ca fertilization Avoid overfertilization Use good water quality
Flower and fruit abortion Malformed fruits	Fruit overload, delayed harvesting Low light intensity Temperature and humidity variation Thrips	Control climate conditions Harvest frequently Control thrips
Pale green to yellow chlorosis with green veins of newest leaves	Fe deficiency	Lower pH of soil or nutrient solution Use Fe formulation available in higher pH (e.g. iron chelates) Improve soil drainage and aeration
Trails and tunnels in leaves	Leafminer	Adopt hygiene measures Destroy infected leaves Spray with insecticide
Yellow leaves, sticky or covered with sooty mould	Whitefly	Use whitefly parasitoids (e.g. *Encarsia formosa*)
Stippled, distorted and light-coloured leaves	Mite	Apply *Phytoseiulus persimilis* Use insecticides
Stunted plant growth	Nematodes (*Meloidogyne* spp.)	Adopt crop rotation Adopt integrated approach for plant growth Apply soil solarization Adopt grafting and use resistant cultivars Use soilless culture
Wilting of plants	*Fusarium oxysporum* f. sp. *radicis-cucumerinum*	Adopt crop rotation Adopt grafting and use resistant cultivars Use soilless culture Remove and destroy infected plants
Yellow spots on the upper leaf side, undersides with fluffy purplish mildew, especially in older leaves	Downy mildew caused by *Pseudoperonospora cubensis* Humid conditions at night Temperatures of 15–20 °C	Adopt drip (not overhead) irrigation Improve air circulation Reduce air humidity Use resistant cultivars
White superficial spots on leaves (and stem)	Powdery mildew caused by *Sphaerotheca fuliginea* or *Erysiphe cichoracearum*	Use resistant cultivars Avoid high plant densities Apply fungicides
Mosaic colouring of leaves	Cucumber mosaic virus spread by aphids	Use healthy, certified seed Use insect-proof nets and mulch Monitor and control aphid vectors Control weed Use yellow sticky traps

GAP recommendations – Cucumber production

- Pay maximum attention to soil and irrigation water temperature and soil management, in order to obtain high yields and high-quality greenhouse cucumbers:
    - Maintain a “warm foot” for optimal growth.
    - Control the temperature of the irrigation water to avoid shock caused by cold water at the beginning of cultivation. If cold water from wells is used, keep it for a while in a small reservoir to allow it to reach the ambient temperature.
    - Analyse soil, water and nutrients, in order to apply adequate and balanced nutrients or fertigation at appropriate times and in appropriate doses.
    - Avoid using saline water and do not overfertilize.
    - Irrigate frequently and in small doses.
    - Apply tillage and mulching to prevent upwards movement of saline water from deeper layers.
    - Control soil-borne pathogens, avoiding chemical treatments for soil disinfection.

- Use the correct plant density:
    - Increase plant space under low radiation.
    - Consider the cultivar used – short-fruit plants can generally be planted at a higher density than long-fruit plants.

- Do not allow plants to become overburdened with fruits.
- Carry out timely pruning of plants to balance leaf/fruit development.
- Apply mulch to control weeds, increase soil temperature, reduce water consumption and increase profitable early yield.
- Handle harvested fruit carefully without damaging the thin skin.
- Keep harvested fruit in the shade and take to the packing house as soon as possible after harvest.
- Maintain appropriate storage temperatures (not too low) to avoid chilling injuries.

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3. Pepper and eggplant

E.M. Drăghici,[a] P.M. Brezeanu[b], P. Muñoz[c] and C. Brezeanu[b]

[a] Universiy of Agricultural Sciences and Veterinary Medicine, Faculty of Horticulture, Bucharest, Romania
[b] Vegetable Research and Development Station, Bacau, Romania
[c] Institute of Research and Technology Food and Agriculture, Barcelona, Spain

ABSTRACT

Peppers and eggplants belong to the Solanaceae family and have relatively similar growing requirements. They are grown on all the continents. They have high yields and are rich in vitamin C, sugars, vitamin A and minerals, and therefore have high antioxidant potential, good nutritional energy value and a wide range of potential uses. In South East Europe (SEE), the protected cultivation area under peppers and eggplants has expanded in recent years and greater diversification of varieties is required. Variety selection is key, as it is important to meet the growing and often changing requirements of production, driven by consumer needs. Consumers have high demands in terms of colour, shape, size, taste and nutrition; producers must meet these requirements. Other important characteristics for both growers and consumers include productivity, precocity and resistance to pathogens. Producers must use up-to-date knowledge and apply it according to the genotype requirements with the aim of achieving optimal cultivation conditions and ensuring sustainable vegetable production in SEE countries. Specific indeterminate hybrids with high resistance to diseases and pests are cultivated. This chapter describes the biological characteristics and requirements of pepper and eggplants under certain environmental conditions; it presents relevant specific technologies, including year-round cultivation, plant density, plant growth conditions, crop fertilization, integrated pest control, harvesting and calibration of fruits for marketing.

PEPPER

Introduction

Pepper (*Capsicum annuum* L.) is a member of the Solanaceae family. A popular vegetable, it is one of the most important crops grown in greenhouses all over the world. It is native to Central and South America, where it is perennial, but in European and Asian climates it grows annually.

In South East Europe (SEE), the largest total production of pepper is in Turkey, where the major production region is Antalya. Bell pepper production in this area is about 31 400 tonnes, of which 18 460 tonnes in glasshouses, 12 180 tonnes in plastic and 800 tonnes in high tunnels. In Turkey, sweet pepper protected production is 256 343 tonnes, of which 38 033 tonnes in greenhouse, 194 236 tonnes in plastic, 19 652 tonnes in high tunnels and 4 422 tonnes in low tunnels. In Greece, sweet pepper production in protected areas accounts for a mere 5% of the vegetables cultivated in greenhouses.[1,2]

Environmental requirements

All pepper cultivars are sensitive to **temperature**. Greenhouse air temperature should be 15–30 °C; temperatures of > 30 °C prevent fruit-set and cause leaf wilting and fruit browning. For optimal vegetative growth, daytime air temperature must be 20–25 °C and night temperature 16–18 °C. During fruiting, an air temperature of 26–28 °C during the day and 18–20 °C during the night should be maintained. The temperature of the substrate must be higher than that of the air. Temperatures of < 15 °C in the substrate affect the growth of the root system, as well as vegetative development and flowering of buds.

For optimal production, the air relative humidity must be about 75%. Pepper is very sensitive to light deficiency; for this reason, in protected spaces during winter, it is necessary to provide supplementary light. The light intensity during the day must be sufficient for growth and development, i.e. around 5 500 lux for 18 hours a day. Below this level, growth and development are impaired. Carbon dioxide enrichment (800–1 000 ppm) improves growth and development. Pepper plants perform best in light soils, with a good supply of nutrients and a pH of 5.5–6.5. Peppers do not tolerate air currents.

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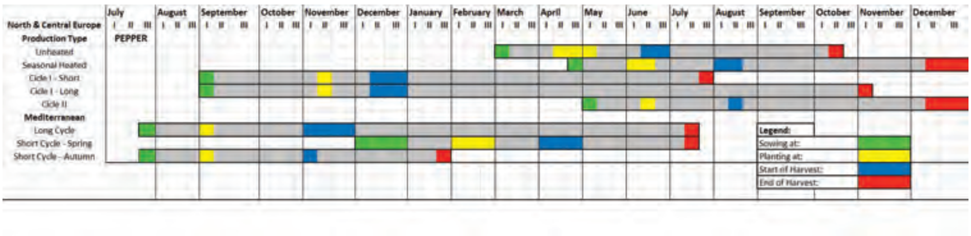
[1] Data from http://www.povrce.com/index.

[2] See Part I, Chapter 2.

FIGURE 1
Pepper growing in protected areas



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Growing cycles

Given the year-round demand for bell pepper, farmers can choose one of the options shown in Figure 1.

Cultivar choice

The following species of pepper are suitable for protected cultivation:

- Bell pepper: *Capsicum annuum* sp. *macrocarpum* – convar. *grossum* (L.) var. *grossum*
- Sweet pepper: *Capsicum annuum* L. convar. *longum* (DC.) Terpo (hybrids with long fruit)
- Hot pepper: *Capsicum* spp. *microcarpum*

There is a high level of diversity with a wide range of fruit shapes (conical, elongated), fruit weight (50–200 g) and colours (green, yellow, orange, red). Taking into consideration precocity and the culture system adopted, it is important to select cultivars according to market requirements. Indeterminate hybrids with high productivity and resistance to diseases and pests are recommended in protected areas.

Producers should consult the Plant Varieties Database, listing varieties of pepper recommended for the specific conditions prevailing in EU country areas.[3] Another reference for searching the characteristics and performances of horticulture cultivars is the FAO database, Hortivar,[4] which is free of charge for consultation.

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[3] Available at http://ec.europa.eu/food/plant/plant_propagation_material/plant_variety_catalogues_databases/search/public/index.cfm?event=SearchForm&ctl_type=H.

[4] Available at www.fao.org/hortivar.

Seedlings

Pepper seedlings are produced in specialized nurseries or directly on the farm. For crops in protected areas, seedlings should be 60–100 days old, 20–25 cm high and with a floral bud (Plate 1). At planting, it is vital to remove the first flower. Failure to do so can lead to development of small, deformed fruits, which are difficult to harvest; the fruiting branches may even break with a consequent reduction of the potential fructification (Plate 2).

Plate 1
Pepper seedlings

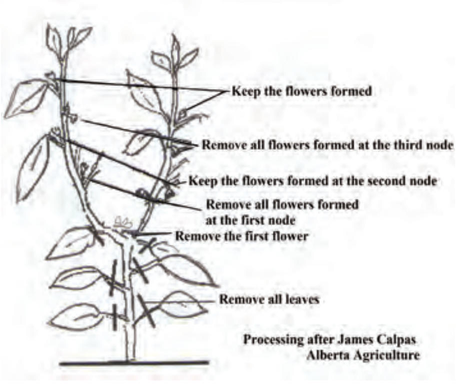
Planting

The optimum plant density is 3.0–4.5 plants m^{-2} in low tunnels, depending on the variety, crop cycle and technology adopted. Higher densities can impede plant management, hinder the control of fructification and inhibit air circulation. Poor circulation leads to high humidity and excessive shading, creating favourable conditions for disease development and mass abortion of the flowers. The plant density for a long growing cycle can be 2.2–2.5 plants m^{-2}, and for the shorter spring cycle it can be 2.5–3.5 plants m^{-2}.

There needs to be an isolation distance between sweet and hot pepper cultivars to avoid cross-pollination and transfer of the hot taste.

Plate 2
Seedling before planting – remove the first flower

FIGURE 2
Pruning pepper plants



www.dj-products.com

Pruning

Pepper plants grow and fructify continuously. In greenhouse conditions, to ensure good growth and fructification, plants are cultivated with one, two or three branches. Fewer ramifications on the plant result in improved air circulation, increased lighting and reduced pests. Perform pruning at 10–14-day intervals as new shoots appear. Remove the base leaves, shoots and some flowers to stimulate plant growth and development. Shorten the lateral shoots, leaving 2–3 fruits on secondary shoots. There should be a maximum of 2–4 branches: the lowest at 15–20 cm from the ground or mat, the next at 20–25 cm. Prune secondary shoots or branches to leave only the ramifications of the main stem. When using plants pruned to 3–4 branches in an unconventional system (mattress or culture bags), plant vigour is reduced and plant height should be limited.

Training

The main stem grows to a height of 3.5–4.0 m and must be trained to remain vertical. Use threads or plastic or metal rings to trellis each fructification stem of the pepper so it can bear the weight of the fruits. Trellising is necessary only for the main branches, not for secondary ramifications.

Plate 3
Training pepper plants in Dutch system

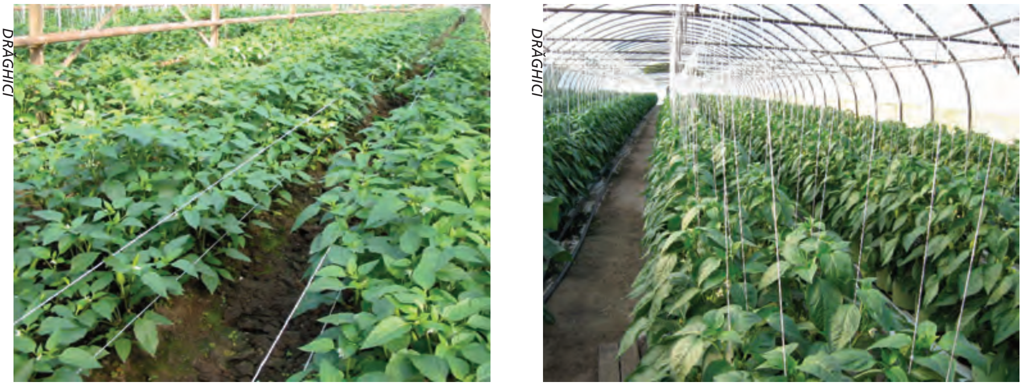

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Plate 4
Training pepper plants in Spanish system

Defoliation

To ensure good ventilation and lighting conditions for plant development, remove the ageing basal leaves, from the bottom to the top, as the plants grow.

Fruit-setting

For flower pollination, it is recommended to introduce bumble bees into the greenhouse. Bees (*Bombus impatiens*) are excellent buzz-pollinators and a single hive of bumble bees can pollinate 3 000 m^2 of greenhouse cultivated with sweet peppers. Temperature drop, especially at night, can result in aborted flowers (especially in the first week).

Irrigation

Bell pepper has a superficial root system and is very susceptible to water stress. Large amounts of water are required because the root system does not penetrate deep into the soil; for this reason, it is recommended to irrigate frequently with small amounts of water. Water scarcity causes abortion of flowers results in fruits of poor quality.

The requirement of both water and nutrients is higher during flowering and fructification than during the remaining vegetation period. Indeed, insufficient nutrient supply in this phenophase can lead to a high percentage of flower abortion, and if fruits do form, they grow slowly or fall, are deformed and lack turgidity. The temperature of the irrigation water is vital and should be 22–24 °C (Drăghici, 2014).

Fertilization

Avoid overuse and inadequate or imbalanced use of fertilizers. Before planting, apply manure at a rate of 2.0–3.0 tonnes 1 000 m^{-2}, taking care not to exceed 170 kg N ha^{-1}. Table 1 shows the quantity of major nutrients taken up by peppers for different yields and greenhouse systems.

TABLE 1
The amount of minerals extracted from the soil

Culture in protected crops	Yield kg m^{-2}	Total consumption (g m^{-2})				Specific consumption (g kg^{-1} fruit)			
		N	P	K	Mg	N	P	K	Mg
Long-cycle	6–8	26.6	7.3	54.5	6.9	3.80	0.46	6.46	0.59
Short-cycle spring	4–6	19.7	6.0	32.6	3.3	4.38	0.58	6.02	0.45
Short-cycle autumn[a,b]	7.2[a]	38.5	12.0	52.2	12.1	5.14	0.7	6.81	0.97

[a] Drăghici, 2014.
[b] Lăcătuş, 2004.

Physiological disorders

Conditions of high relative humidity (e.g. 85%) in a greenhouse can lead to disorders, such as poor or incomplete pollination, sunburn, fruit cracking and red fruit.

Pests and diseases

Common pests and diseases include: leafminers (*Liriomyza* spp.), damping-off (*Pythium* spp.), *Rhizoctonia solani*, pepper weevil (*Anthonomus aenotinctus*), nematodes (*Meloidogyne incognita*), bacterial spot (*Xanthomonas campestris*), cucumber mosaic (*Cucumovirus*), powdery mildew (*Leveillula taurica*), tobacco mosaic virus (*Tobamovirus*), tomato spotted wilt virus, verticillium wilt (*Verticillium dahliae*), bacterial canker (*Clavibacter michiganensis*) and bacterial spot (*Xanthomonas campestris*). Table 2 lists some of the most important pests and diseases.[5]

Harvest

Harvesting takes place when fruits reach the characteristic hybrid size, at technological or physiological maturity. Carefully cut or break the fruits at the insertion point. Yield is 7.0–7.5 kg per plant, depending on plant density, conduction of plants and culture cycle. In the greenhouse, California type cultivars in the production of bell pepper can reach yields of 10–11 kg per plant.

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[5] See Part II, Chapter 5.

EGGPLANT

Introduction

Eggplant (*Solanum melongena* L., Solanaceae family) is native to India and is grown in different regions of the world under different culture systems. The young fruits of eggplant are used for fresh consumption and for industry.

Thanks to its favourable climatic conditions, Turkey is the world leader in eggplant production, with a total annual production of 180 000 tonnes, of which 47 000 tonnes are produced in glasshouses, 74 000 tonnes in plastic houses, 39 000 tonnes in high tunnels and 20 000 tonnes in low tunnels.[6]

Environmental requirements

Eggplants require warmer conditions than other members of the Solanaceae family (e.g. tomatoes or peppers). The seeds germinate at a temperature of 24–32 °C. The optimum temperature for growth is 21–30 °C, but plants can withstand temperatures of ≤ 35 °C. At temperatures of < 10 °C and > 40 °C, growth stagnates and flowers abort and fall.

Sunny areas are necessary for proper development of eggplant culture. Planting at high density creating excessive shade should be avoided, because flowers may abort and fruits remain small. In greenhouses, during periods of low light, fruit-set will not occur and the flowers will drop. Minimum light intensity is 8 000 lux for flowering, but for appropriate fructification it needs to be 20 000–40 000 lux.

Growing cycles

In greenhouses, eggplant cultivation may take place in two stages: from winter to summer and from summer to winter. The former is the most common: from January/February to June/July. In winter, when light conditions are poor, supplementary artificial lighting is required.

Greenhouse production is based on the use of simple low-cost structures with very limited climate control. During the winter–summer cycle, low light intensity results in reduced yield and quality. Heating systems allow for an increase in both yield and quality, but they entail high fuel consumption, are not energy-efficient and their adoption must be considered carefully in the context of the local climate conditions. A minimum night temperature of 12 °C resulted in highest yield and lowest fuel consumption, due to the fact that higher night temperatures modify the distribution of assimilates, stimulating vegetative growth (López *et al*., 2014). Various culture systems can be applied to the cultivation of eggplant, including soil, substrate and nutrient film technique (NFT) systems.

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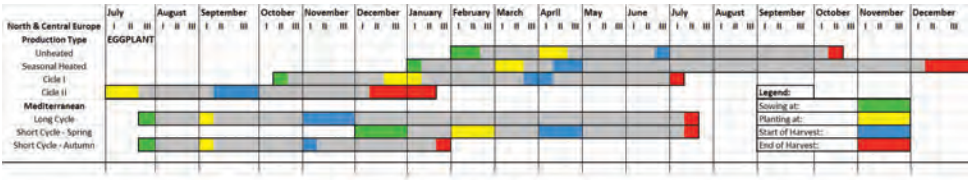
[6] 2010 figures.

FIGURE 3

Eggplant growing cycles in protected areas



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Eggplant can be cultivated year-round and farmers can choose from the options shown in Figure 3.

Cultivar selection

For protected cultivation, eggplant assortment is adapted to market requirements. For EU countries, it is possible to consult the Plant Varieties Database, listing the eggplant varieties registered in the EU plant list.[7] Another reference for searching the characteristics and performances of horticulture cultivars is the FAO database, Hortivar,[8] which is free of charge for consultation.

Hybrids are characterized by precocity (number of days from planting seedlings to harvesting the first fruit), fruit characteristics (uniformity, colour, shape and weight), tolerance or resistance to pests and diseases, and productivity.

Plate 5
Eggplant varieties grown in protected areas

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[7] Available at http://ec.europa.eu/food/plant/plant_propagation_material/plant_variety_catalogues_databases/search/public/index.cfm.

[8] Available at www.fao.org/hortivar.

Plate 6
Transplants of eggplant

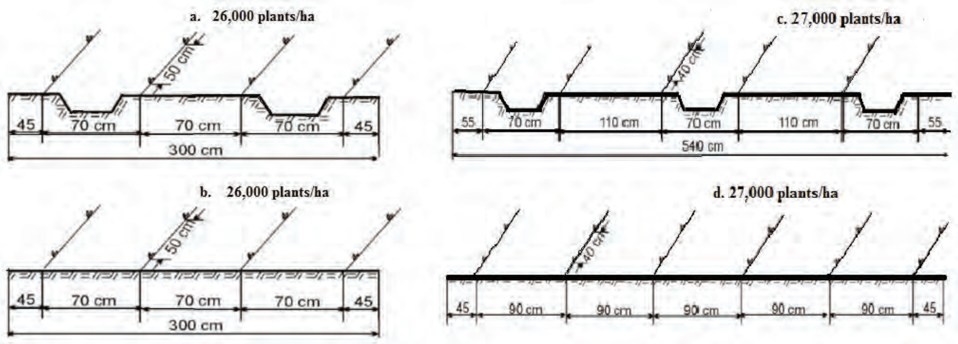
Seedlings

Grafted or non-grafted seedlings (Plate 6) may be used for planting. Grafted plants are more vigorous, yielding 34.1–43.3% more fruits than non-grafted seedlings in greenhouse production (Khah, 2011). Grafted seedlings are permitted in organic (biological) cultivation, where they help prevent attack by *Verticillium* and *Meloidogyne*. Suitable rootstocks for grafting are resistant tomatoes (KNVF and Kyndia F1) or wild relatives of eggplant (*Solanum torvum* and *S. integrifolia*) (Chaux and Foury, 1994). Seedlings are transplanted when 50–60 days old, 20–25 cm high and with 6–7 leaves. In all cases, it is essential to know the biological details of the plant and its specific requirements in terms of light, temperature, humidity and nutrition.

Planting

Plant density depends on hybrid vigour, structure type (greenhouse, tunnel), length of crop cycle and technology applied (soil culture, shaped/unshaped field, crop nutrient substrates, NFT). For example, in soil culture for the first cycle in greenhouses, the optimum density is 2.1 plants m^{-2}, while in low tunnels it is 2.66–2.77 plants m^{-2} (Figure 4). In soilless culture systems, the density can be 1.6–2.5 plants m^{-2} (Iapichino *et al.*, 2007). Higher densities can cause problems, especially during intense fructification – inducing inadequate ventilation, poor lighting and increased humidity, resulting in development of diseases or attacks by pests.

FIGURE 4
Planting density



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Pruning

Pruning intensity significantly affects the quantity and earliness of eggplant under protected cultivation. The highest early fruit yield was achieved with plants having 1, 2 and 3 shoots. Intense plant pruning – with 1 guiding shoot – resulted in a reduction in the number of marketable fruits. The highest marketable fruit yield was obtained from plants pruned to have 2 (3.82 kg m^{-2}), 3 (3.98 kg m^{-2}) and 4 (3.87 kg m^{-2}) guiding shoots. A single topping cut performed after the first fruit harvest did not affect marketable yield and fruit number (Buczkowska, 2010). The largest fruits – in both early and total yield – were produced by 2-shoot plants with the second shoot leading out from the sixth node (Ambroszczyk, 2008).

The **plant management** approach depends on the growing system and on the precise objectives of the culture:

- **Low tunnels or unheated greenhouses:** Attach the branch, leave one flower, eliminate all shoots up to the first flower; prune branches after 2–3 flowers; remove all diseased and ageing leaves from the stem.
- **Prolonged cycle greenhouse crops:** About 2 months after planting (March), keep fruit load at the minimum necessary to allow better development of fruit-bearing branches. In subsequent periods (April–June), aim to achieve maximum number of fruits per well-developed branches. In the first 5 months (until early May), keep 3–4 fruiting branches and remove all shoots from the stalk. After May, leave the fruit and 3–4 secondary branches. Eliminate flowers at the base of the leaf, leaving only the most developed ones. About 40 days before the end of culture, prune plants to stop the main arms growing and to prevent the emergence of new flowers. Eliminate ageing leaves, any new flowers and shoots on a weekly basis. During cloudy periods, remove leaves to enable proper lighting and ventilation.

Training

The stem is straight, 70–100 cm high. The leaves are well developed with large surfaces and there are sometimes thorns on the leaf vine. Eggplant hybrids – specifically in protected systems – have indeterminate growth; therefore, support is required for each branch. Fasten the stems using strings or polypropylene, plastic or aluminum clips (Plate 7).

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Plate 7
Training

Fruit-setting

At the base of the leaf, one flower or a group of 2–3 flowers appears 55–70 days after seed germination. Eggplant flowers are self-pollinating, but a major problem in greenhouses is insufficient pollination. **Artificial pollination** is recommended:

- brush each flower with pollen collected in advance;
- apply mechanical pollination using air jets; or
- use bumble bees.

Placing hives with bumble bees in the greenhouse is the most economical method. A bumble bee hive provides pollination for 8–10 weeks.

Bumble bee (*Bombus terrestris*, *Bombus impatiens*) activity increases between 9.00 and 11.00 and peaks between 10.00 and 11.00. It then decreases gradually and stops between 13.00 and 14.00. Bees start foraging again in the afternoon from 15.00 to 18.00. In a comparison of bumble bee and vibration pollination, bumble bees gave higher yields (25%), bigger fruit size (14% weight, 7% length) and more seeds per fruit (4 times) (Abak *et al.*, 2000).

Plate 8
Eggplant flowers

Irrigation

Irrigation needs to be sufficient to facilitate a strong root system, but not so high as to encourage lush plant development. The temperature of the irrigation water should be ≤ 20–22 °C; higher temperatures encourage the *Verticillium albo-atrum* pathogen. Open air vents daily, intensifying ventilation as the plants grow. However, take care, as eggplant does not tolerate cold air drafts.

The ideal soil is permeable, rich in organic matter, with a neutral pH of 6.0–7. For good results, maintain almost constant soil moisture (70–77%) throughout the growing season and especially during fructification; however, avoid irrigation when the soil temperature is < 14 °C. Water scarcity has negative impacts: mass fall of flower buttons, flowers or fruits; underdeveloped, small, old fruits; or pale fruits lacking lustre.

Fertilization

The quantity of nutrients required depends on the yield potential of the cultivar, the level of available nutrients in the soil, and the growing conditions. The N, P and K requirements are highest from about 10 days after flowering to just before fruit ripening. Prior to planting, apply manure at a rate of 8–10 tonnes ha^{-1}, and compost or chicken manure at 2–3 tonnes ha^{-1}. Gianquinto *et al*. (2013) and Savvas *et al*. (2013) provide data on the supply of nutrients and nutrient solution to be used in the cultivation of eggplant.

Physiological disorders

Eggplant produced in greenhouses may present disorders, including sunken fruits and water-soaked spots on the blossom end of fruit. The spots can turn black, mould may develop and patches sometimes have a leathery appearance. Disorders may arise from nutrient imbalances. Calcium in the soil may inhibit the uptake of water; add limestone to the soil if the pH is < 6.0. Likewise, soil rich in nitrogen and poor in phosphorus can produce plants with lush foliage and little fruit.

Pests and diseases

Pests include: *Tetranychus urticae*, *Polyphagotarsonemus latus*, *Trialeurodes vaporariorum* and *Tuta absoluta*. Pathogens encountered in protected eggplant culture include: *Cercospora* leaf spot, *Cercospora melongenae*, *Colletotrichum* fruit rot, *Colletotrichum melongenae*, *Phomopsis* fruit rot, *Phomopsis vexans*, *Phytophthora* blight, *Phytophthora capsici*, powdery mildew, *Leveillula taurica*, verticillium wilt, *Verticillium dahliae*, *Fusarium oxysporum* and *Botrytis cinerea*. Table 2 presents some of the most important pests and diseases.

Harvest

At maturity, fruits are smooth and glossy. Their colour depends on the variety, and may be black–purple, white, white striped, purple or green, light green or green with purple stripes. Fruits are harvested manually by cutting. Yields can reach 3.5–4.5 kg m^{-2} for short cycle and 11.5–13.0 kg m^{-2} for long cycle in greenhouse cultivation.

TABLE 2

Identification and control of the most common pepper and eggplant disorders, pests and diseases

Symptoms	Species	Reasons	Prevention and control measures
Plants smaller, overall light green colour, especially in lower leaves Fruits small with thin walls	Pepper/ eggplant	N deficiency	Apply adequate fertilization
Leaf and fruit burning (especially with application of ammonium formulation)	Eggplant	Excess nitrogen High ammonium	Apply adequate fertilization
Bronzing and/or burning of leaf margins Chlorotic leaves Small plants Reduced fruit production	Eggplant	K deficiency	Apply adequate fertilization
Interveinal chlorosis and leaf margin necrosis at growing points of leaves and fruits Leaves distorted Fruit developing blossom-end rot	Pepper/ eggplant	Ca deficiency	Apply adequate fertilization
White spots below the surface of fruit Open-pollinated fruits developing stip	Pepper	Excess Ca	Apply adequate fertilization
Water-soaked area near blossom scar of fruit, developing into tan–brown, leathery lesion Grey–black, velvety lesions colonized by *Saprophytic* fungi	Pepper/ eggplant	Blossom-end rot	Control climate and growing conditions Apply adequate Ca fertilization Avoid excessive application of fertilizers Use good quality water
Slight yellowing of foliage Wilting of upper leaves	Pepper/ eggplant	Fusarium wilt	Adopt crop rotation Use grafting Plant resistant cultivars Adopt soilless culture Remove and destroy infected plants
V-shaped lesion on older leaf tips, expanding to cover leaf in eggplant Peppers stunted Lower leaves slightly chlorotic Stunting and chlorosis severe with diurnal wilting (as disease progresses) Fruit small and deformed with internal discoloration	Pepper/ eggplant	Verticillium wilt	Apply soil fumigation and solarization Adopt crop rotation with non-hosts Graft onto resistant rootstocks
Yellow leaves, sticky or covered with sooty mould	Pepper/ eggplant	Whitefly	Use whitefly parasitoids (e.g. *Encarsia Formosa*)
Stippled, distorted and light-coloured leaves	Pepper/ eggplant	Mite	Apply *Phytoseiulus persimilis* Use insecticides
Plants lacking vigour Symptoms of nutrient deficiency Diurnal wilting Bead-like galls in roots	Pepper/ eggplant	Root-knot nematode	Adopt crop rotation Adopt integrated approach for better plant growth Use grafting Plant root-knot nematode-resistant varieties Fumigate infested soil
Vein banding, blistering, with bright yellow mosaic pattern Leaves distorted, developing epinasty Plants stunted Fruit with mosaic pattern and distorted	Pepper	Pepper yellow mosaic virus spread by aphids	Plant PepYMV-resistant varieties Use reflective mulches Apply weed control

GAP recommendations – Pepper and eggplant production

- Design production schemes for the benefit of both farmers and consumers, taking into account variety, growth conditions, hygiene and handling of the product.
- Use resistant varieties to control pests.
- Use eggplant grafted on tomato to obtain strong plants producing high yields and good quality.
- Avoid too high planting density to prevent disease incidence.
- Avoid cold air currents, which eggplants do not tolerate.
- Use mulching to provide uniform moisture, conserve water and reduce weeds.
- Adopt a 2–3 year crop rotation schedule.
- Harvest when the fruits reach one-third of their full growth and the skins turn glossy.
- Adopt timely and correct pruning techniques and remove all waste material to prevent new infection or the spread of pests and diseases.
- Use sharp tools (scissors or knife) to harvest the fruits.
- Use beneficial insects (e.g. ichneumon wasps and predatory mites) for natural protection against diseases and pests.
- Use **soil solarization** to combat soil-borne pathogens:
  - Apply in the summer months (June–Aug.).
  - Irrigate before and during solarization if soil becomes dry.
  - Place transparent polyethylene (25–30 µm) over the soil surface and bury the edges without gaps.
  - Leave in place for 4–6 weeks – under the foil film, temperatures can reach 50–60 °C at a depth of 2–3 cm and 30–40 °C at a depth of 30 cm.
  - Plant – once the foil has been removed – once the soil or the substrate has warmed to an average temperature of 18 °C.

- Use **bumble bees** for pollination – an efficient and environmental friendly form of natural pollination:
  - Protect hives against sun and condensation of water.
  - Prevent mice, ants or other insects from entering hives.

- Implement **irrigation** according to the following guidelines:
  - Avoid excessive irrigation and fertilization (base fertilization on water and soil analysis).
  - Avoid overwatering: eggplant is susceptible to root rot; pepper is susceptible to *Phytophthora capsici*.
  - Increase watering when blooms appear.
  - Increase irrigation (for pepper cultivation) when evaporation is high and when the plants are flowering and setting fruits.
  - Adopt furrow or drip irrigation.
  - Avoid sprinkler irrigation – wet leaves and fruits promote disease development, especially at night.
  - Avoid evening irrigation if overhead irrigation must be used.

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4. Lettuce and other leafy vegetables

N.K. Maršić

Department of Agronomy, Biotechnical Faculty, University of Ljubljana, Slovenia

ABSTRACT

This chapter presents the production of the main leafy vegetables, typical of South East Europe. The production seasons, climatic and soil requirements, varieties and planting techniques are described for lettuce, endive, chicory, lamb's lettuce (corn salad), spinach and Swiss chard. Recommendations are provided concerning planting dates, seeding and transplanting; agrotechnologies linked to irrigation, fertilization, mulching, harvesting and handling are presented. Finally, GAP recommendations for the cultivation of selected species are given.

INTRODUCTION

The group known as "leafy vegetables" comprises a wide variety of crop plants grown for their edible leaves. Inexpensive and high yielding, they are often easily available and already a part of the local diet. They supply roughage, and dieticians recommend a daily consumption of ≥ 116 g of leafy vegetables for a balanced diet. Most leafy vegetables can be grown in protected areas during cool growing seasons; they are, therefore, available for fresh harvest earlier than most other crops, and with proper planning, they can be harvested year round. In South East European (SEE) countries, leafy vegetables are produced in various kinds of glasshouses and plastic greenhouses, on a total harvested area of 2 608 ha (Gruda, 2014).[1]

Leafy vegetables adapted to cool spring and autumn growing conditions include lettuce, endive, chicory, corn salad, spinach and Swiss chard. Many new cultivars of these cool-season crops have improved heat tolerance and are productive until early summer. Seeds of most leafy vegetables can be sown directly in the greenhouse soil (e.g. lamb's lettuce, spinach, chard).

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[1] See Part I, Chapter 2.

LETTUCE (*LACTUCA SATIVA*)

Introduction

Lettuce is one of the most consumed vegetables worldwide, with a global production of about 24 million tonnes in 2012 (FAOSTAT, 2013). Mean daily consumption of lettuce in Europe is 22.5 g per capita, accounting for about 6.5% of the total dietary intake of vegetables (WHO, 2003). Lettuce contains several macronutrients (e.g. K, Na, Ca and Mg) and trace elements (e.g. Fe, Mn, Cu, Zn and Se), essential for human nutrition. It is also a good source of photosynthetic pigments (chlorophylls and carotenoids) and other phytochemicals with nutritional advantages and a significant role in the prevention of oxidative stress-related diseases (Krug, 2003).

Environmental requirements

Lettuce is a cool-season crop with distinct temperature requirements. The optimum growing temperatures are 23 °C during the day and 7 °C at night. The optimum relative humidity range is 75–85% (70–75% of field capacity). Light requirements are 12–14 mol m^{-2} d^{-1}. High temperatures may cause bolting (Plate 1), bitterness, poor head formation and tipburn (Plate 2). At near freezing temperatures, the outer leaves of mature lettuce can be damaged, leading to decay during handling and storage (Krug, 2003).

Soil requirements

In regions with temperate climatic conditions, lettuce can be grown on heavy clay soils as long as there is a good soil structure and adequate drainage. Lettuce has a moderately low degree of salt tolerance; excess salinity results in poor seed germination and reduced growth.

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Plate 1
Bolting of lettuce plants

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Plate 2
Tipburn (marginal leaf necrosis)

Principles of lettuce production in greenhouses

Cultivar selection

Lettuce is grouped into four classes:

- **Crisphead** (head lettuce) has a firm head and crisp, curly leaves. The outer leaves are dark green, the inner leaves pale and lacking chlorophyll. Many cultivars originate from the old 'Great Lakes' cultivar and are cold tolerant.
- **Butterhead** is well adapted to greenhouse conditions.
- **Loose-leaf** does not form heads and has soft leaves. Cultivars include 'Grand Rapids'. It grows well under protection and can be shipped long distances.
- **Cos** (romaine lettuce) has a loose head with narrow, soft leaves. The outer leaves are dark green, coarse and have heavy ribs; the inner leaves are pale green. It is relatively resistant to cold and is usually grown in open fields.

Producers should consult the plant varieties database which lists all varieties of lettuce to recommended for the particular conditions of each area in EU countries.[2] Cultivar selection decisions should be based on the growing period, market demand, size of lettuce heads, yield values, pest and disease resistance, lack of physiological problems and growing conditions.[3] Hortivar – FAO's database on the performances of horticultural cultivars – can be used for easy retrieval and comparison of information.[4]

Planting

In recent years, common practice has been to grow lettuce from seedlings transplanted from nursery beds. Seedlings require hardening before transplanting – withholding water for 6–8 days. Transplant seedlings in flat beds at a spacing of 25 × 25 cm (butterhead) and 30 × 30 cm (crisphead and loose-leaf).

Irrigation

A range of different irrigation systems are used in lettuce production, including furrow, surface, trickle and sprinkler. After planting, irrigate crops at 2–3-day intervals, applying most water in the 30 days before harvest. With early season lettuce, avoid oversaturating the beds, because excess moisture favours the development of bottom rot. Sprinkle-irrigate seeded and transplanted lettuce every 2–3 days until seedlings are established.

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[2] Available at http://ec.europa.eu/food/plant/plant_propagation_material/plant_variety_catalogues_databases/search//public/index.cfm?event=SearchForm&ctl_type.

[3] See Part II, Chapter 4.

[4] Available at www.fao.org/hortivar/.

Depending on the soil type and terrain, hand-move, linear-move and permanently buried **sprinklers** may all be used through to maturity. In late summer or autumn, corky root disease is a potential problem and sprinkler irrigation is often adopted because the plant's root system becomes degraded. As the crop approaches maturity, excess water and fertilizer cause heads to become large and puffy, reducing their value.

Surface-placed **drip systems** are widely adopted in temperate regions. Drip systems are usually installed after the first cultivation and side dressing; they allow growers to irrigate frequently during the phase of rapid vegetative growth. One drip line is installed between 2 plant rows on 1-m beds; or 3 drip lines are installed between 5–6 plant rows on 2-m beds. The drip lines are retrieved before harvesting and re-used for subsequent crops. Drip irrigation provides more even distribution than furrow or sprinklers and maintains uniform soil moisture levels across the field, contributing to uniform growth in fields with variable soil textures (Pavlou *et al*., 2007). Drip irrigation systems save water and increase water-use efficiency.

Fertilization

The amount of nutrients added to the soil varies according to the expected yield. During the cold growing period (Nov.–Mar.), lettuce yield is around 2.5 kg m^{-2}, while during the production period with more favourable growing conditions, yield may increase to 4 kg m^{-2}. Table 1 presents the amounts of nitrogen (N), phosphorus (P) and potassium (K) removed by harvested portions of lettuce crop (Krug *et al*., 2003).

Fertilization depends on the availability of essential nutrients in the topsoil: carry out soil analysis before deciding on the fertilization programme. Apply **phosphorus** when it is < 60 ppm. **Potassium** fertilization presents no environmental risk and many growers routinely apply potassium, even in fields with high levels of exchangeable soil potassium.

Autumn application of **nitrogen** is not recommended, because winter rains increase the risk of nitrate–nitrogen leaching beyond the root zone. Therefore, apply only small quantities of nitrogen (22 kg ha^{-1}) at pre-planting or planting. One or more side dressings of nitrogen are common, several weeks apart. Estimate the nitrogen requirements for side dressing by soil nitrate testing. Nitrate levels of > 20 ppm in the top 30 cm of soil are adequate for crop growth. Repeat the test later in the season to ensure continuous nitrogen sufficiency. A

TABLE 1
Nutrient removal rate per unit of yield by lettuce crop

Marketable yield	Mass of whole plant	N	P	K
kg m^{-2}		g m^{-2}		
2.0	2.2	7.5	0.75	7.5
2.5	2.8	9.0	1.0	9.0
3.0	3.4	10.5	1.25	10.5
3.5	4.0	8.5	1.5	12.0
4.0	4.6	10.0	1.75	13.5

small quantity of nitrogen (10–17 kg ha^{-1}) may be applied 7–10 days prior to harvest to ensure that crop colour and growth rate are acceptable. In drip-irrigated fields, apply nitrogen through the drip system. Drip systems are an efficient method both for managing water and for delivering nitrogen fertilizer. For this reason, fertilizer application rates in drip systems are often 20–30% lower than in conventionally irrigated fields (Pavlou *et al.*, 2007).

Harvesting and post-harvest handling

Harvesting begins as soon as plants reach an acceptable size and firmness; it should be completed before the leaves become tough and bitter and before stalks start to bolt. Harvest maturity depends on the variety of lettuce and the purpose for which it is grown. Head lettuce for market is allowed to grow to full size and to develop a solid head, but for home use is often harvested before the head is well formed. Leaf lettuce plants may be thinned repeatedly, removing the largest leaves for use and leaving smaller ones to develop. Lettuce is usually cut with a long-handled sharp knife; it is packed into cartons, vacuum-cooled and stored in a cold room. Vacuum cooling for 32 minutes reduces the temperature: lettuce leaves to 0.3–1.1 °C and butts to 1.6–2.3 °C. The recommended final temperature for unwrapped lettuce is also 1.6–2.3 °C.

Disorders, pests and diseases

Table 2 lists the most common lettuce disorders, pests and diseases.[5]

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[5] See Part II, Chapter 5.

TABLE 2

Identification and control of the most common lettuce (*Lactuca sativa* L.) disorders, pests and diseases

Symptoms	Reasons	Prevention and control measures
Tipburn – necrosis of portions of inner leaf margins of lettuce	Ca deficiency High temperature High relative air humidity	Control climate conditions Foliar application of Ca
Russet spotting – reddish, tan, olive or brown elongated pit-like spots on midribs of leaves	Kept at 3–10 °C Ethylene concentration ≥ 0.5 ppm	Keep lettuce at 0–2.5 °C and far from ethylene
Rib discoloration – yellow–black lesions discolouring mostly cap leaf and first few inner leaves	Maturation during hot weather	Adopt good refrigeration practices
Blistering and subsequent drying and darkening of epidermis of outer leaves	Freezing injuries (in the field or during storage)	Avoid too low temperatures during growth and storage
Brown stain developing within a week due to temperatures encountered during marketing of crisphead lettuce	CO_2 injury when greenhouse CO_2 concentration reaches 1–2%	Control greenhouse air CO_2 concentration
Small red–brown spots on lower leaves usually on underside of midrib, sometimes expanding rapidly causing leaves to rot	Bottom rot – *Rhizoctonia solani* Kuchn	Plough soil before planting Adopt crop rotation Avoid irrigation close to harvest Plant varieties with erect growth habit to reduce leaf contact with soil
Light green or chlorotic angular lesions on topside of leaves, turning yellow Fluffy white growth on underside of leaves	Downy mildew – *Bremia lactucae*	Plant resistant varieties Adopt crop rotation
Soft watery lesions on leaves Collapse of leaves to lie on soil surface Black fungal structures on infected leaf tissue and soil surface	Leaf drop – *Sclerotinia sclerotiorum*	Plough soil deeply Rotate crops with non-hosts
White, powdery fungal growth on top and underside of older leaves Leaves turning yellow or brown	Powdery mildew – *Erysiphe cichoracearum*	Apply sulphur at first sign of symptoms (if temperatures high enough)
Veins enlarged and clear Puckered or ruffled leaves Upright outer leaves	Big vein – Mirafiori lettuce big-vein virus (MiLBVV)	Plant resistant varieties
Irregular holes in leaves and stems Shredding of leaves if infestation severe Slime trails present on rocks, walkways, soil and plant foliage	Slugs and snails	Practise good garden sanitation: - Remove garden trash and weeds - Reduce moist habitat to discourage slugs and snails - Hand-pick slugs at night to decrease population - Spread wood ashes or eggshells around plants
Presence of yellow virus disease	Greenhouse whiteflies – *Trialeurodes vaporariorum*	Integrate chemical control with biological control (e.g. parasitism, predation and genetic resistance)

ESCAROLE AND ENDIVE (*CICHORIUM ENDIVIA*)

Introduction

Endive is a popular salad vegetable mostly produced in northern and western Europe, and also in some colder regions in SEE. Escarole and endive belong to the Chicoriaceae family and are annual chicories of the same species – *Cichorium endivia* – differing only in leaf shape. Endive leaves (*C. endivia* var. *crispum*) are deeply cut (Plate 3), escarole leaves (*C. endivia* var. *latifolium*) are broad (Plate 4). Both produce a loose head of leaves, which are usually serrated or ruffled. The outside leaves are green and bitter, but the inner leaves are light green to whitish. Both can be used raw (in salad) or cooked (sautéed or in soups). They are an important component in the increasingly popular cut-and-washed salad mixes (Krug, 2003).

Environmental requirements

Both types of endive are cultivated mostly as a stubble crop with a planting date from mid-July to mid-September. In cold weather conditions during the autumn–winter period, endive should be grown in an unheated greenhouse. The optimum temperature for growth is 15–18 °C, while relative humidity should be around 70% (60–80% of field capacity). Flowering is stimulated by temperatures of 20–25 °C and > 14 hours of sunlight.

Soil requirements

Cichorium endivia grows well in soils with residual nitrogen from previous cropping seasons. The appropriate soil is loose, well drained and fertile (higher than average, especially nitrogen content).


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Plate 3
*Escarole (*Cichorium endivia *var.* latifolium*)*


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Plate 4
*Endive (*Cichorium endivia *var.* crispum*)*

Principles of escarole and endive production in greenhouses

Cultivar selection

- Curled-leaf endive: 'Green Curled Pancalier' and 'White Curled Endive'
- Broad-leaved endive or escarole: 'Broad-leaved Batavian' and 'Full-Heart Batavian'

Cultivar selection should be based on the growing period, market demand, yield values, pest and disease resistance, lack of physiological problems and growing conditions.[6] For relevant information, refer to the FAO database, Hortivar.[7]

Seedling preparation and planting

Escarole and endive can be produced by direct seeding or transplants. Sow seeds in styrofoam trays; after 4–6 weeks, transplant the seedlings in the flat beds. Transplanting in a triangular pattern (rather than in rows) gives a uniform, fuller stand and more plants per area. Relatively close spacing (25 × 25 cm) is used with all endive and escarole varieties to force upright growth and some self-blanching.

Irrigation and fertilization

The irrigation and fertilization requirements and techniques for escarole and endive are very similar to those for lettuce. To prevent tipburn, apply calcium foliar nutrition (Krug, 2003).

Harvesting and post-harvest handling

Escarole takes at least 8 weeks from transplanting to maturity, endive about 6 weeks. Endive and escarole can be harvested at any stage, but for a blanched effect, full heads are needed. Blanching is a simple technique, and produces a bright, yellow–white, tender heart that makes the plant less bitter as well as visually attractive. Some varieties are self-blanching and as the outer leaves grow, the inner leaves are naturally protected from sunlight. For other special salad greens, **blanching** may be done manually. At 5 days before harvest, when the head is almost fully grown, but still growing vigorously, pull the leaves together and place wide rubber bands around the plant to blanch the hearts. Any new growth is then white, because sunlight never reaches it. The slower the growth of the plant (e.g. in cold weather), the longer the plant remains tied up. Alternatively, place a 1.5-litre plant container over the whole plant about 5 days before harvest.

Endive and escarole are leafy salad greens not adapted to long storage. Even at 0 °C they will not remain in satisfactory condition for more than 2–3 weeks. Vacuum-cooling or hydrocooling can help maintain their fresh appearance. Relative humidity in storage rooms should be > 95% to prevent wilting (Krug, 2003).

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[6] See Part II, Chapter 4.

[7] Available at www.fao.org/hortivar/.

CHICORY (*CICHORIUM INTYBUS*)

Introduction

Chicory (*Cichorium intybus*) is perennial, but usually grown as an annual. It can be divided into five groups:

- Radicchio (round heads with dark red leaves, a popular Italian variety)
- Sugarloaf (a popular heading variety)
- Large-leafed chicory
- Cutting or leaf chicory (Catalogna or asparagus chicory)
- Belgian endive or witloof chicory (white or blanched varieties originating in France and Belgium)

Environmental and soil requirements

Chicory is a cool season crop and radicchio varieties require cool temperatures (optimum 15–18 °C, minimum 6–8 °C) to produce heads. Plants grow best in a sunny position in fertile, well-drained soils with a pH of 6.5–7.2.

Principles of chicory production in greenhouses

Cultivar selection

Radicchio is the Italian word for all members of the chicory clan, whether with green, cream, red, striped or marbled leaves. The leaves are often ruby-coloured (ranging from purple to red) with ivory veins. There is also a green variety. All radicchios begin as green leafy clusters. Some gradually turn red and change shape (Plates 5 and 6). Radicchio heads are usually harvested with a small root stub attached to help the leaves or heads hold their shape. Depending on the type, radicchio may form small heads or open-leaf rosettes. 'Palla Rosa' and 'Castelfranco' are two especially popular varieties.


JAKŠE

Plate 5
Radicchio 'Di Chioggia'


JAKŠE

Plate 6
Radicchio 'Palla Rosa'

Witloof chicory is grown in two stages:

1. Grow the roots during the summer, lift from the soil, sever and discard the tops. Subject the roots to cold treatment (vernalization) – either in the field or in cold storage – then replant.
2. Force the roots during the winter in darkened beds covered with sand peat under conditions of constant temperature and humidity. Three weeks after root planting, exhume and clean the chicons, then ship to market (Plate 7).

Producers should consult the plant varieties database, which lists all varieties of chicory recommended for the particular conditions of each area in EU countries.[8]

Seedling preparation and planting

Chicory may be either directly seeded or started indoors for transplanting. If started indoors, sow seeds in a sterile seed starting mix, planted to a depth of 0.6 cm. Thin the seedlings when they have 3–4 sets of true leaves; they are ready for transplanting when they are 5–6 weeks old with 5 or 6 mature leaves.

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Plate 7
Forcing witloof chicory

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Plate 8
Different systems of forcing plants from the Cichoriaceae family

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[8] Available at http://ec.europa.eu/food/plant/plant_propagation_material/plant_variety_catalogues_databases/search//public/index.cfm?event=SearchForm&ctl_type.

Plate 9
Field production of chicory plants for forcing

Harden seedlings prior to transplanting by gradually increasing their exposure to outdoor conditions (day/night temperature 22–25 °C / 16–18 °C). Transplant seedlings 20–23 cm apart, 20 cm between rows. Thin directly seeded plants to this spacing.

Production of roots for forcing

Witloof chicory requires sufficient phosphorus, potassium and magnesium to produce quality roots. In general, avoid applying nitrogen fertilizer to prevent excessive top growth in the field and to discourage unfurling of the outer leaves of the chicon during forcing. Nitrogen supplied by decaying organic matter in the soil is usually sufficient for field growth.

Plant seeds by hand in the first week of July. This ensures that the roots will mature in late fall, allowing for sufficient cool treatment (vernalization) of the roots for direct forcing without placing them in cold storage. If seeds are planted too early in the spring, the seeds vernalize in the cool soil and the plant bolts in the field. Once a plant has bolted, its root cannot be forced. Place rows 90 cm apart to allow cultivation by rototiller. In the case of manual cultivation, reduce row spacing to 60 cm. Thin plants to 10 cm apart within the rows. Do not allow the soil to dry out during germination (Plate 9).

Harvesting and post-harvest handling

Roots are usually harvested from mid-October to mid-November. Small quantities can be harvested with a digging fork. For mechanical harvest, root crop or modified potato harvesting equipment is used. Cut the leaves about 2.5 cm above the root crown and trim the roots to 20 cm. Discard roots with a diameter of < 2.5 cm. Trim roots that branch into two or three forks to one dominant branch.

For **forcing**, the optimum temperature is 18 °C, the planting media is 15–25 cm of unfertilized 1 : 1 sand : peat mixture. Plant roots to their crowns using a dibble to make the holes. Spacing is close, with a density of about 80 roots m^{-2}. Drape the forcing bed with black plastic to exclude light and leave for about 3 weeks until harvest. Chicons from roots replanted directly from the field can be harvested in 18–21 days. Chicons from roots stored for 3–7 weeks can be harvested after 28–30 days. Stored roots partially wither if humidity is < 95%. Once the roots are replanted in the forcing bed, turgour is regained after a few days and the chicons begin to grow.

TABLE 3

Identification and control of the most common endive (*Cichorium endivia* L.) and chicory (*Cichorium intybus*) disorders, pests and diseases

Symptoms	Reasons	Prevention and control measures
Poor seedling germination Dark lesions on and collapse of stems Brown rotting roots	Damping off – *Pythium* spp., *Rhizoctonia solani*	Plant pathogen-free seed or transplants Shallow-sow seeds or delay planting until soil warms
Abundant white mycelium on any part of plant Wilting of outside leaves spreading inwards and affecting whole plant Soft watery lesions on leaves	White mould – *Sclerotinia sclerotiorum*	Rotate crop to non-hosts for ≥ 3 years Control weeds Avoid dense growth by planting in adequately spaced rows Plough soil deeply
Water-soaked lesions expanding to form large rotted mass of cream-coloured tissue which is liquid underneath	Bacterial soft rot – *Erwinia* spp.	Adopt appropriate cultural practices Rotate crops Harvest heads when dry Avoid damaging heads during harvest
Small circular or irregular dry spots on leaves Lesions coalescing to form large necrotic patches causing leaves to turn yellow and wilt Lesions splitting or cracking in dry centres	Anthracnose – *Microdochium panttonianum*	Treat seeds with hot water prior to seeding Rotate crops Plant in area with good soil drainage Remove all cruciferous weeds (potential reservoir for the fungus)
Small red–brown spots on lower leaves Tan or brown mycelial growth in infected tissue	Bottom rot – *Rhizoctonia solani*	Plough soil before planting Rotate crops regularly Avoid irrigation close to harvest Use plant varieties with erect growth habit to reduce leaf contact with soil
Young leaves drying and dropping off Old leaves developing papery texture White fuzzy mould on underside of leaves	Downy mildew – *Bremialactucae*	Plant resistant varieties

In the traditional method, exhume the whole plant and cut the chicons from the roots. Trim chicons to remove unfurled leaves and outer leaves soiled with sand and peat. Protect the heads from light even after harvest to keep them white. Refrigerate the unwashed heads in loosely closed plastic bags. Roots kept in the bed may produce new growth around the crown. These small "chiclets" are also edible, in particular in salads (Limamii *et al*., 1993).

Disorders, pests and diseases

Table 3 lists the most common endive and chicory disorders, pests and diseases.[9]

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[9] See Part II, Chapter 5.

TABLE 3 (cont'd)

Identification and control of the most common endive (*Cichorium endivia* L.) and chicory (*Cichorium intybus*) disorders, pests and diseases

Symptoms	**Reasons**	**Prevention and control measures**
Small, irregular chlorotic spots on oldest plant leaves Leaf spots with chlorotic halos Lesions coalescing forming large necrotic patches Wilting leaves and plant death in worst cases	Septoria blight – *Septoria lactucae*	Plant pathogen-free seed Select planting sites in regions with low rainfall Treat seeds with hot water prior to seeding to reduce disease incidence
Small soft-bodied insects on underside of leaves and/or stems of plant, usually green or yellow Secretion sticky, sugary substance (honeydew) encouraging growth of sooty mould on plants	Aphids: - Green peach aphid – *Myzus persicae* - Lettuce aphid – *Nasonovia ribis nigri* - Plum aphid – *Brachycaudus helichrysi*	Prune out infested shoots Check transplants for aphids before planting Use tolerant varieties Use reflective mulches to deter aphids from feeding Spray sturdy plants with a strong jet of water to knock aphids from leaves Apply biological control with *Aphidoletes aphidimyza* or *Chrysoperla carnea*.
Thin, white, winding trails on leaves White blotches on leaves Leaves dropping from plant prematurely in serious cases	Leafminers – *Liriomyza* spp.	Check transplants for signs of leafminer damage prior to planting Remove plants from soil immediately after harvest Apply biocontrol with *Steinernematid* nematodes)
Leaves distorted (when population high) Leaves covered in coarse stippling and silvery Leaves speckled with black faeces	Thrips: - Western flower thrips – *Frankliniella occidentalis* - Onion thrips – *Thrips tabaci*	Avoid planting next to onions, garlic or cereals where very large numbers of thrips can build up Use reflective mulches early in the growing season to deter thrips Apply biological control with *Neoseiulus cucumeris*
Irregular holes in leaves and stems Slime trails present on rocks, walkways, soil and plant foliage	Slugs and snails: - Grey garden slug - Spotted garden slug - Brown garden snail - European garden snail	Practise good garden sanitation: - Remove garden waste, weeds and plant residues to promote good air circulation - Reduce moist habitat for slugs and snails - Hand-pick slugs at night - Spread wood ash or egg shells around plants

CORN SALAD (LAMB'S LETTUCE) (*VALERIANELLA LOCUSTA*)

Introduction

Corn salad, also known as lamb's lettuce or mâche is an unusual salad crop because it is very cold hardy and grows best during the autumn and winter, outdoors or in unheated greenhouses. Its nutritional value is very high: it contains many nutrients, including three times as much vitamin C as lettuce, beta-carotene, B6, B9, vitamin E and omega-3 fatty acids. It is also a significant source of iron containing 30% more than spinach. Plants usually have long, oval, glossy green leaves forming a heavy bunch. They have a tender, delicate nutty, minty flavour. Corn salad is an excellent winter gap filler, both in the vegetable garden and at the dining table (Krug, 2003).

Environmental and soil requirements

Corn salad is a cool-season crop with distinct temperature requirements. The optimum growing temperatures are 14 °C during the day and 4–7 °C at night. Optimum relative humidity is 75–85% (70–75% of field capacity). Corn salad grows in nearly all soils, but the most suitable is rich, moist soil. It is winter hardy; however, mulch lightly during very severe cold weather. If the flavour turns slightly bitter, blanche the leaves before the next picking by covering the plants with a box or pot for a few days before harvesting. Do not grow corn salad during summer, since high temperatures invariably cause it to run to seed very quickly (Krug, 2003).

Principles of corn salad production in greenhouses

Sowing and cultivation measures

Sowing takes place from late summer to late autumn. The most common sowing method is to broadcast the seed on a plot of well-prepared ground; alternatively, sow closely in rows 13 mm deep and 15 cm apart. Cover seeds with 3 mm of fine soil. Cultivation in rows produces large, bushy salad greens of the most succulent texture. When 5 cm tall, thin the plants to 15–20 cm apart within the rows. Sowing in late summer allows young plants to become sufficiently well established to survive the rigours of winter. Young plants require irrigation during dry spells to ensure that weeds do not swamp the plant (Krug, 2003).

MARŠIĆ

Plate 10
Production of corn salad in trays

Harvesting and post-harvest handling

Plants are harvested 30–60 days after sowing. Robust growth in suitable conditions provides the first serving of corn salad by late October. Corn salad is ready for harvest when 3–4 leaves have developed. The outer leaves are used in salads or cooked like spinach. Grasp the plant and cut with a small sharp knife: near the base for a whole rosette, 2.5 cm higher for individual leaves. If only some leaves are cut, the corn salad continues to grow and produce more leaves for harvest.

SPINACH (*SPINACIA OLERACEA*)

Introduction

Spinach (*Spinacia oleracea* L.) is a popular vegetable crop and production is increasing gradually. The rise in consumption is due to its excellent nutritional value. This leafy vegetable is an important source of nutrients, including vitamins C and A, carotenoids, flavonoids, folic acid, calcium and magnesium (Krug, 2003).

Environmental and soil requirements

Spinach is a quick-maturing, cool-season hardy vegetable crop. Seeds germinate at 2–30 °C, but the optimum temperature range is 7–24 °C. Spinach will grow at 5–24 °C, but growth is most rapid at 15–18 °C. Spinach can withstand temperatures as low as –9 or –6 °C without great injury. Freezing weather is most harmful to small seedlings and plants approaching maturity; at other growth stages, the crop can tolerate subfreezing temperatures for weeks.

A variety of soils are used for spinach production, but in most regions sandy loam soils are preferred (Krug, 2003).

Principles of spinach production in greenhouses

Cultivar selection

Spinach (*Spinacia oleracea*) belongs to the family Chenopodiaceae and is classified according to leaf type: savoy (wrinkled) (Plate 11), semi-savoy and smooth (flat) (Plate 12). Savoy types are grown mainly for fresh market purposes, while smooth types are preferred for processing. Semi-savoy types are grown for either market. Spinach can also be classified according to seed type: prickly or smooth. Most commercial varieties are now smooth-seeded, which are much easier to handle and plant. Decisions for cultivar selection should be made in consideration of market demand, yield values, pest and disease resistance, lack of physiological problems and growing conditions.[10] Refer to the FAO database, Hortivar.[11]

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[10] See Part II, Chapter 4.

[11] Available at www.fao.org/hortivar/.

Plate 11
Savoy spinach

Plate 12
Smooth spinach

Sowing

Spinach is typically grown in 2 or 4 rows on beds 95–100 cm wide. All spinach is direct-seeded; seeding rates are 10–28 kg ha^{-1}, depending on row configuration and market destination.

Irrigation

Spinach fields are usually sprinkler-irrigated through to germination. The first irrigation germinates the seed, and several short sprinkler applications may then be necessary to prevent soil crusting. Once a uniform stand is established, most growers switch to furrow irrigation. However, some grow the entire crop with sprinklers, despite the increased risk of infection and spread of leaf spotting diseases. Spinach has a relatively shallow root system and thrives on frequent shallow irrigations that maintain a uniform moist soil for maximum leaf production. Between emergence and harvest (60–75 days), 1–3 irrigations are usually required. Irrigation requirements also depend on the soil and climate. It is important to avoid saturated field conditions to prevent rotting of the lower leaves and crowns (Krug, 2003).

Fertilization

Spinach has moderate fertilization requirements. The specific fertilizer application depends on soil type, recent cropping history and the results of soil tests carried out to gain an indication of phosphorus (P) and potassium (K) requirements:

- **Phosphorus** (P) availability is estimated from the level of bicarbonate extractable phosphorus in the soil. Soils > 30 ppm generally do not require additional P, but when planting in cold soils, P is less available to plants and applications of P may be necessary. Apply 56–112 kg ha^{-1} P_2O_5 before planting. Broadcast the fertilizer before the beds are listed. Alternatively, apply in a band 5–7.5 cm wide to the side of and below the seed row after beds are listed but prior to planting.

- **Potassium** (K) availability depends on the level of ammonium acetate-extractable potassium. Soils > 150 ppm generally do not require additional K.
- **Nitrogen** (N) requirements are 90–224 kg ha^{-1}, depending on the length of the growing season and the market destination. A short-season, fresh market spinach crop requires 90–112 kg ha^{-1} N, while a crop of processing spinach requires almost twice as much. Apply about 56 kg ha^{-1} N before planting, plus 1–3 subsequent side dressings or water-run applications. Petiole sampling mid-season can help determine if the fertilizer programme is adequate. When dry tissue analysis reveals < 4 000 ppm NO_3, < 2 000 ppm PO_4 or < 2% K, an application of fertilizer is required to improve quality and yield (Krug, 2003).

Harvesting and post-harvest handling

Spinach is grown for both fresh and processed markets, and market price sometimes determines how a field of spinach is harvested. Fresh market spinach is field-packed. The whole plant is harvested from when it has 5–6 leaves to just before seed-stalk formation. A plant with a seed-stalk is considered unmarketable. Plants are hand-cut and tied in bunches of 8–12 plants. Yields vary widely depending on planting configuration and density: 2 300–4 800 cartons ha^{-1} or 20–43 tonnes ha^{-1} (Krug, 2003).

Given the high surface–weight ratio and a very high respiration rate, cool spinach rapidly immediately after harvest to prevent wilting and weight loss. Spinach is sensitive to ethylene and moderately sensitive to freezing injuries after harvest (Krug, 2003).

Disorders, pests and diseases

Table 4 lists the most common spinach disorders, pests and diseases.[12]

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[12] See Part II, Chapter 5.

TABLE 4

Identification and control of the most common spinach (*Spinacia oleracea*) disorders, pests and diseases

Symptoms	Reasons	Prevention and control measures
Small water-soaked spots on leaves, enlarging and turning tan or brown with a papery texture Lesions coalescing and causing severe blighting in worst cases	Anthracnose – *Colletotrichum* spp.	Plant seeds from disease-free plants Avoid sprinkler or overhead irrigation Water plants from the base to reduce leaf wetness
Poor germination rate of seeds Death of newly emerged seedlings Stunted, yellow plants, particularly lower leaves Poor growth, wilting and collapse of older plants Roots water-soaked and discoloured brown or black Necrotic lesions girdling tap roots	Damping-off – *Rhizoctonia solani* Root rot – *Pythium* spp.	Plant spinach in well-drained soils Carefully manage irrigation to avoid saturating soil Avoid successive plantings in same location
Yellow spots on cotyledons and leaves, enlarging over time and becoming tan with dry texture Purple fungal growth on underside of leaves Curled and distorted leaves when infestation serious	Downy mildew (blue mould) – *Peronospora farinosa*	Plant resistant varieties
Yellowing of older leaves Plants reaching maturity early Premature death of plants Reduced seed production or death of plant prior to seed production Dark discoloration of vascular system	Fusarium wilt – *Fusarium oxysporum*	Avoid planting spinach in soils known to be infested with fusarium Avoid water stress to plants during flowering and seed-set
Chlorotic leaves with necrotic spots, mosaic patterns or ringspots Poor and stunted plant growth	Mosaic virus Cucumber mosaic virus Beet curly top virus Tobacco rattle virus Tomato spotted wilt virus	Practise good weed management around plants
Small soft-bodied insects on underside of leaves and/or stems Secretion of sticky, sugary substance (honeydew) encouraging growth of sooty mould on plants	Aphids: - Peach aphid – *Myzus persicae* - Potato aphid – *Macrosiphon euphorbiae*	Prune out infested leaves or shoots Check transplants for aphids before planting Use tolerant varieties Use reflective mulches to deter aphids from feeding Spray sturdy plants with strong jet of water to knock aphids from leaves Apply biological control with *Aphidoletes aphidimyza* or *Chrysoperla carnea*
Leaves deformed Small holes in newly expanding leaves	Spinach crown mite – *Rhizoglyphus* spp.	Destroy crop residues immediately after harvest
Singular or closely grouped circular–irregular holes in foliage Heavy feeding by young larvae leading to skeletonized leaves Clusters of 50–150 eggs present on leaves	Armyworms: - Beet armyworm – *Spodoptera exigua* - Western striped armyworm – *Spodoptera praefica*	Apply organic methods of control: - Biological control using natural enemies which parasitize the larvae - Application of *Bacillus thuringiensis*

SWISS CHARD (*BETA VULGARIS* VAR. *CICLA*)

Introduction

Swiss chard belongs to the Chenopodiaceae family and has been cultivated in Europe for thousands of years. Its name derives from its extensive cultivation in Switzerland. Swiss chard (Plate 13) is a very good source of vitamin A, K, C, magnesium and manganese.

Plate 13
*Swiss chard (*Beta vulgaris *var.* cicla*)*

Environmental and soil requirements

Swiss chard may be grown under mild to cool conditions. Seeds germinate at 5–30 °C, but 16–24 °C is optimum. Some cultivars grow well in temperatures > 30 °C; others tolerate light frost when plants are young and not fully developed. Chard is, therefore, able to withstand winter temperatures. Temperatures of 4–20 °C for 20–30 days can cause vernalization of young plants, inducing too early flowering (Krug, 2003).

Like other beets, Swiss chard prefers deep, friable, well-drained soils (e.g. sandy loam). High levels of organic matter in the soil are desirable and help ensure adequate moisture supply. Uniform soil moisture is essential for a high-quality crop. Beets are sensitive to damping-off on soils that may flood or have poor aeration. Soil pH should be ≥ 6.0 for a maximum yield (Moreira *et al*., 2003).

Principles of Swiss chard production in greenhouses

Cultivar selection

Most cultivars have either red or white stems. Cultivar selection should be based on market demand, yield values, pest and disease resistance, and growing conditions.[13] For Swiss chard cultivars, refer to the FAO database, Hortivar.[14]

Sowing and planting

With direct seeding, the optimum rate is 250 000–280 000 plants ha^{-1}; with seedling transplants, it is 80 000–100 000 plants ha^{-1}. Row spacing is 10–15 cm and spacing between rows 45–50 cm. Planting on raised beds is recommended.

Irrigation and fertilization

Swiss chard is sensitive to moisture stress, and frequent light irrigations are preferable to heavy applications at longer intervals. In the continental region,

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[13] See Part II, Chapter 4.

[14] Available at www.fao.org/hortivar/.

2–3 irrigations in summer are sufficient. Irrigation is essential: in autumn cultivation, immediately after sowing and during the vegetative growth stage; in spring cultivation, in the second half of the growing period. Recommended fertilizer applications are: 125 kg ha^{-1} N, 25 kg ha^{-1} P and 125 kg ha^{-1} K.

Harvesting and post-harvest handling

Harvest Swiss chard once it is sufficiently large; select young to medium-mature clean leaves and avoid older and yellowing leaves. Take care not to damage the leaves during harvest. In general, 3–4 weeks of regrowth are required before a second harvest will yield adequate volume.

Handle chard like spinach. Given its perishability, store at temperatures as close as possible to 0 °C – at this temperature, it can be held for 10–14 days. Relative humidity of ≥ 95% is desirable to prevent wilting. Moderate air circulation removes respiration heat; rapid air circulation accelerates transpiration and wilting. For precooling, adopt vacuum-cooling or hydrocooling. During transportation, package and top with ice to maintain freshness. Swiss chard is highly susceptible to decay associated with ethylene and damage normally appears as yellowing of the leaves. Freezer burn begins at –0.3 °C. Freezing injury results in water-soaked lesions, followed by rapid decay associated with soft rot bacteria.

Disorders, pests and diseases

Table 5 lists the most common chard disorders, pests and diseases.[15]

TABLE 5
Identification and control of the most common chard (*Beta vulgaris* var. *cicla*) disorders, pests and diseases

Symptoms	Reasons	Prevention and control measures
Water-soaked, brown lesions on leaves Breakdown of centre of leaves	Bacterial soft rot – *Erwinia* spp.	Remove and destroy infected plants Avoid planting in poorly drained soil Rotate crops with corn, small grains or grasses where possible
Dark and white–red lesions on seedling stems Black and greasy lesions Death of seedlings	Damping-off – *Pythium* spp., *Rhizoctonia solani*	Plant in well-drained soil Do not plant until soil is sufficiently warm
Small holes or pits in leaves giving foliage a characteristic “shothole” appearance – young plants particularly susceptible Reduced plant growth Destruction of plant if damage severe	Flea beetles: - *Epitrix cucumeris* - *Phyllotreta striolata* - *Phyllotreta pusilla* - *Phyllotreta ramosa*	Cover plants with floating row covers before beetles emerge Plant seeds early to allow establishment before beetles become a problem Plant trap crops for control – cruciferous plants are best
Slow plant growth Shortened leaf stems Small, curled, yellowed leaves with swollen veins	Curly top – Beet curly top virus (BCTV)	Plant only healthy transplants Remove and destroy infected plants to limit spread Use floating row covers to protect plants from leafhoppers in home garden

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[15] See Part II, Chapter 5.

CULTURAL PRACTICES IN LEAFY VEGETABLES

TABLE 6
Summary of cultural practices of the different leafy vegetables

Vegetable	Plant density (cm × cm)	Added water with irrigation (mm)	N : P : K requirements (kg ha^{-1})	Yield (tonnes ha^{-1})
Lettuce	25 × 25	100–120	110 : 40 : 160	25–40
Endive	25 × 25	80–100	120 : 40 : 150	40
Chicory				
Radicchio heads	25 × 25	80–100	120 : 30 : 140	20–30
Witloof chicory	60–90 × 10–15			
Spinach	25–30 × 15	20–40	180 : 60 : 225	25
Corn salad (lamb's lettuce)	15 × 15–20	20–40	60 : 15 : 50	10
Swiss chard	10–15 × 45–50	60–80	120 : 25 : 125	30–40

NITRATE IN LEAFY VEGETABLES

Nitrate is a naturally occurring form of nitrogen and is an integral part of the nitrogen cycle in the environment. Although nitrate is relatively non-toxic, approximately 5% of all ingested nitrate is converted in saliva and the gastrointestinal tract to the more toxic nitrite and N-nitroso compounds. The concentration of nitrate in vegetables depends on genetic factors, environmental variables (season, light, temperature etc.) and agricultural practices. Most vegetables have low levels of nitrate, but leafy vegetables have much higher concentrations (European Food Standards Authority, 2008).

In order to protect public health, reduce wherever possible the presence of contaminants and ensure market uniformity, the European Commission established maximum levels for nitrate in vegetables (Directive 97/194/EC, 1997). The legislation has been amended several times to date to take into account the differences between varieties, seasons, growing conditions and processing methods (European Community Regulation 1258/2011) (Table 7).

TABLE 7

Maximum permissible levels of nitrate in vegetables (European Commission Regulation No. 1258/2011)

Foodstuff	Harvesting period	Maximum level (mg NO_3/kg FW)
Fresh spinach (*Spinacia oleracea*)		3 500
Preserved, deep-frozen or frozen spinach		2 000
Fresh lettuce (*Lactuca sativa* L.):		
- Leaf lettuce (leaf, romaine, butterhead)	1 Oct. – 31 Mar.:	
	- protected	5 000
	- open-field	4 000
	1 April to 30 Sept.:	
	- protected	4 000
	- open-field	3 000
- Crisphead lettuce (iceberg)	- protected	2 500
	- open-field	2 000
Rucola (*Eruca sativa*, *Diplotaxis* sp., *Brassica tenuifolia*, *Sisymbrium tenuifolium*)	1 Oct. – 31 Mar.	7 000
	1 April – 30 Sept.	6 000

Strategies to mitigate the accumulation of nitrate in leafy vegetables

- Restrict nitrogen doses.
- Apply nitrogen via fertigation to improve nitrogen-use efficiency.
- Partially replace nitrate in the nutrient solution with ammonium, urea, chloride or sulphate a few days prior to crop harvesting.
- Apply organic manure instead of inorganic nutrients within reason.
- Grow plants under controlled environmental conditions with sufficient light intensity.
- Use cultivars with a reduced capacity for nitrate accumulation.

Reduced nitrate content in leafy vegetables can represent added value!

GAP recommendations – Leafy vegetable cultivation

- Respect environmental and soil requirements for leafy vegetable growing.
- Respect specific growing conditions (shorter days, lower temperatures, high relative humidity, lower solar irradiation) and use only cultivars which are adapted to them.
- Schedule vegetable production early enough to ensure yourself seeds or transplants of good quality.
- Avoid over-irrigation of plants to improve nutrient- and water-use efficiency.
- Fertilize leafy vegetables based on the plants' needs and climate conditions.
- Use proper plant densities in greenhouses to avoid worse growing conditions and to improve growth and yield.
- Harvest yield at technological maturity and respect post-harvest handling for each leafy vegetable.

Reduction of pest incidence in protected areas:

- Avoid conditions increasing high relative humidity (which encourages plant diseases).
- Optimize the irrigation programme to prevent marginal leaf necrosis (which encourages botrytis rot).
- Avoid irrigation late in the day when the crop might stay wet for a long time (even overnight).
- Optimize fertilization to reduce nitrate content.
- Remove infected plants and avoid spore dispersal.
- Maintain high levels of general hygiene.
- Remove weeds (potential reservoirs for pests and sources of weed seeds).
- Use steam sterilization for pest and weed control.
- Monitor regularly and control viruses and their vectors (coli fungi, aphids).
- Use virus-free planting material and cultivars with high tolerance of viruses.

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5. Early production of melon, watermelon and squashes in low tunnels

A. Balliu and G. Sallaku

Agricultural University of Tirana, Tirana, Albania

ABSTRACT

Melon, watermelon and squash are important crops in protected vegetable production, in terms of both cultivation area and yield. They can be cultivated in high tunnels and greenhouses, but the most common method is in low tunnels. Most melon cultivars grown under protected structures belong to the Cantaloupe, Galia and Ananas types. Watermelon cultivars may be large or small fruits, with or without or seeds. In high tunnels and greenhouses, melons and watermelons are usually grown vertically, while in small-tunnel growing systems they are grown on the ground. Training, pruning, fruit-setting and fertigation are the most important crop management practices. Grafting is used extensively to increase crop resistance to soil-borne diseases, nematodes and abiotic stresses. The risk of diseases, pests and several physiological disorders could be reduced with proper microclimate control and appropriate crop management.

INTRODUCTION

Low tunnels are widely used for early production of a range of vegetable crops, but they are most effective for cucurbits: melons, watermelons and squashes (Plate 1).[1] Low tunnels – also known as row covers – are simple structures compounded by flexible, transparent or semi-transparent cover materials deployed over simple arched supports. A low tunnel normally encloses a single row of plants (e.g. cucurbits), but it sometimes covers two or more rows (e.g.


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Plate 1
Low tunnels in cucurbit production

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[1] See Part II, Chapter 1.

tomato and pepper). Low tunnels modify the micro-environment around the plants, increasing soil and air temperature and reducing wind. As a result, plants grow faster, fruits mature 2–3 weeks earlier and yields are potentially higher compared with open-field cultivation.

For the production of **high-quality marketable yields** of melons, watermelons and squashes, certain **practices** must be adopted:

- production of good-quality seedlings;
- use of raised beds and mulching;
- selection of proper covering materials; and
- adoption of drip irrigation and fertilization.

ENVIRONMENTAL REQUIREMENTS

All cucurbits (melons, watermelons, squashes) are sensitive to **temperature**. They prefer a hot, dry climate with mean daily temperatures of 22–30 °C. Cucurbits germinate in a minimum soil temperature of 15–18 °C, while the optimum soil temperature for root growth is 20–35 °C. Almost no vegetative growth takes place at air temperatures < 15 °C. Plants grow well at 22–26 °C, while the optimum temperature range for fruit ripening is 25–30 °C. During the whole vegetation period, cucurbits require a total of 2 000–3 000 °C. Relatively low temperatures and short daylight periods promote the formation of more female flowers; on the contrary, at > 35 °C male flowers prevail. There is poor pollination of female flowers when temperatures fall < 10 °C for pumpkins and squashes, < 15 °C for watermelons and < 20 °C for muskmelons.

Melons and watermelons require dry weather and plenty of **light**. A total of about 1 200 hours of sunlight is required throughout the vegetation period. Light is essential during the flowering and fruit-growth period, and insufficient light intensity results in small fruits with low sugar content and reduced flavour. Leaf damage by pests or diseases has similar effects on fruits. Continuous rain or cloudy conditions stunt plant growth and reduce flowering and fruit-setting. When melons and watermelons mature in the rainy season, the sugar content is greatly reduced.

Melons and watermelons are not sensitive to low air **humidity**, but high relative air humidity (RH) can affect pollination and cause poor fruit-setting. Sensitivity to fungal diseases increases under high humidity.

SOIL PREPARATION

Cucurbits are fast-growing plants, but they are very sensitive to environmental conditions. The activity of the root system is strongly influenced by soil temperature and aeration, and for early production, the soil should be light textured, well-drained, warm and fertile. Good drainage and deep ploughing are recommended well in advance of the transplanting period to improve growing conditions.

The use of **raised beds** improves growing conditions for the root system in early plantings. The erection of raised beds is particularly important when sites are characterized by: cold, heavy soils; shallow underground water table; and relatively saline water for irrigation. Raised beds typically have a height of 0.15–0.25 m. In single-row tunnels, the recommended width is 0.6–0.8 m. They may be constructed by hand or machine. Machines are available which simultaneously apply chemical fertilizers, place the drip irrigation lines and install mulching films. Prepare raised beds at optimal soil humidity to ensure that the plastic mulches fit well and do not get damaged when tightened over the bed. In dry weather, irrigate the soil before bed preparation.

MULCHING

Black or clear plastic films can be used for mulching. Black plastic film (Plate 2) works better in soils with high weed infestation, creating almost total darkness on the soil surface and killing the weeds. Clear mulches allow light penetration, providing a 2–3 °C higher soil temperature than non-mulched soil and thus promoting early production. Lay the plastic films over raised beds as early as possible, prior to transplanting, in order to reap the full benefits. Before laying the plastic film, fertilize the soil and ensure that the surface is well prepared and smooth.

Advantages of mulching:

- Soil temperature increases immediately.
- Soil evaporation decreases, resulting in savings in both water and fertilizers.
- Competition from weeds is eliminated or reduced.

The **disadvantage** of plastic mulch is the need to dispose of the plastic sheets at the end of the growing period. Plastic residues remain at length in the soil and contribute to environmental pollution. However, biodegradable plastic mulches have recently become available on the market.


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Plate 2
Black plastic mulching in melon production

ESTABLISHMENT OF LOW TUNNELS

Hoops are used to construct small tunnels. They can be made from metal wire, plastic bars or wood. Place the hoops in the field once the raised beds are established and mulching is completed, at intervals of 2–3 m along the length of the beds. Position each hoop as a semi-oval reaching a height of 0.6–0.8 m. Loop string around the hoops to improve stability. Finally, place the cover over the hoops and fix the edges, usually with a layer of soil along the entire length of the tunnel.

COVERING MATERIALS

Thin (75–110 µm) disposable polyethylene films are the most common covering material for early production of melon, watermelon and squash. Films incorporating UV resistance, energy conservation characteristics and anti-drop additives have recently been introduced, and thicker, multi-season films are also available on the market. Plastic films are usually transparent, but coloured films incorporating additional benefits, such as pest control, are also available.

Low polyethylene tunnels can be vented or unvented:

- **Unvented** tunnels (Plate 3) require manual opening to control heat buildup on warm days. Initially, open and close small windows at both ends of the tunnel. As weather conditions improve and the air temperature increases, introduce side ventilation: make small circular holes in the plastic film, gradually enlarging to improve the ventilation.
- **Vented** polyethylene tunnels have pre-installed slits or circular perforations for natural ventilation. For an alternative vented tunnel system, position two pieces of clear polyethylene lengthways over the hoops; fix each piece at the base at one side of the hoops so the two plastic films meet at the peak. Open the tunnel at the top using clothes pegs to clip the cover to the hoops (Hochmuth *et al.*, 2012).

Sometimes, **non-woven materials** (e.g. polyester or polypropylene) can be used as covering material. They are several millimetres thick and available in a range of widths and lengths. Their field performance is similar to that of polyethylene covers in terms of air temperature beneath the cover. The major advantage is that they can be laid directly on the plants without any need for supporting hoops. Non-woven materials are porous and self-ventilating; moreover, they have good water absorption capacity and therefore help avoid dew formation on the plants.


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Plate 3
Control of heat buildup by gradual enlargement of side ventilation


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Plate 4
Complete removal of covering material to correspond with flowering of first female flowers

Daily aeration, as described, is vital for the successful use of low tunnels. Another critical factor is the timing of **cover removal**. Remove covers when blossoming begins (Plate 4), in order to allow flower pollination by honey bees and other insects. Melons and watermelons have separate male and female flowers on each vine; furthermore, the pollen is heavy and sticky and does not move with wind currents. The physical movement of pollen is, therefore, essential to guarantee fruit-setting on the vine. Introduce bee colonies to the field or its border as soon as flowers appear, in order to ensure adequate pollination and fruit-set as soon as the female flowers appear. Pollination is an even greater concern in the production of triploid watermelons, because their staminate flowers contain mostly non-viable pollen. Use ≥ 3–4 strong bee families per hectare for all vine crops.

TRANSPLANTS, TRANSPLANTING AND PLANT DENSITY

Melon, watermelon and squash can be directly seeded. However, direct seeding is not recommended for early production in small tunnels. On the other hand, preliminary preparation of healthy transplants is highly recommended. Although self-rooted seedlings are widely used, the intensive commercial production of watermelon and melon is currently almost totally based on grafted seedlings. **Grafting** was initially adopted to overcome the heavy plant losses caused by soil plant pathogens (e.g. *Fusarium* and *Verticillium* fungi). However, it is also an efficient method for alleviating the negative impacts of several abiotic stresses, including high salinity, low temperature and drought.[2]

Transplanting is a critical stage of successful cucurbit production. Carry out transplanting on warm days, without strong winds. Before transplanting begins, make small holes or cross-cuttings in the mulching film at the appropriate planting distance. The recommended transplanting depth is ground level – or even 1–2 cm above ground – to avoid exposing the roots to low temperatures at greater depths. At transplanting, the soil must be at almost maximum water capacity, activating the drip irrigation system a few days before transplanting if necessary. Apply a further 1–2 litres of water per plant immediately after transplanting to ensure good root activity and guarantee the quick stand establishment of the transplanted seedlings.

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[2] See Part II, Chapter 6.

Water distribution should be even throughout the length of the row to ensure uniform plant growth. To achieve uniform water distribution, do not exceed the maximum recommended length of irrigation lines and install proper filters at the entrance of the irrigation system to avoid blockage of drippers.

Planting density depends on crop species, soil fertility, type of mechanization and seedling type (self-rooted or grafted). For self-rooted watermelon, planting density is often 5 000 plants per ha, for melon and squash ≤ 9 000 plants per ha. Commercial rootstocks tend to provide higher plant vigour; it is, therefore, possible to reduce the planting density of grafted watermelons by ≤ 50% (Huitrón *et al*., 2011) and of grafted melons by ≤ 60% (Ricárdez-Salinas *et al*., 2010). In all cases, the planting density of grafted seedlings depends on the vegetative power of the rootstock used and of the rootstock–scion relationship. Therefore, the typical planting density of grafted melon and watermelon plants is 3 000–4 000 plants ha^{-1}.

Seedless watermelon requires special care. To ensure fruit-set, plant a male pollinizer variety among seedless watermelons with a ratio of ≥ 1 : 3 seedless plants. Alternatively, plant alternate rows of triploid and male pollinizer in the ratio of 2–3 : 1. It is important to synchronize the appearance of male flowers on the pollinizer cultivar with female flower opening on the seedless cultivar.

PLANT TRAINING AND PRUNING

Under good growing conditions, melon, watermelon and squash grow quickly. By the time flowering begins, they have usually filled all the space in the tunnel; once the plastic cover is removed, the stems spread freely alongside the plant rows and between the row spacings. To keep the space between the rows free for mechanized operations, gently remove the plant stems and direct them alongside the row.

Pruning the main stems of melon and watermelon promotes the development of secondary and tertiary stems, resulting in a higher percentage of female flowers, which potentially improves earliness. However, since the secondary and tertiary stems are fully developed when the covering is removed, this practice is difficult to apply in small tunnel production.

IRRIGATION

Drip irrigation is the most effective method for irrigating cucurbits in small tunnels. In combination with the plastic mulch, there are several **advantages of drip irrigation**:

- increased water-use efficiency;
- uniform moisture supply; and
- facilitated distribution of water soluble fertilizers and pesticides.

Given the high water requirement of cucurbits, frequent irrigation is necessary throughout the growing cycle through to the end of harvest. Irrigation **frequency** depends on soil texture, weather conditions and plant growth stage. On warm days, daily irrigation may be necessary for well-developed plants growing in sandy soils, while in heavy soils, a single irrigation every 2–4 days is sufficient. In general, the heavier the soil, the less frequent the irrigation.

Irrigation needs to maintain the soil moisture at full water capacity. There is a variable relationship between relative yield decrease and relative irrigation deficit for melon and watermelon. According to the Land and Water Division of FAO (FAO, 2015), water deficit during the establishment period of watermelon delays growth and produces a less vigorous plant resulting in yield reduction. The late vegetative period (vine development), flowering period and yield formation period (fruit-filling) are the most sensitive to water deficit. Water deficit immediately before harvest does not seriously affect yield and a reduced water supply during the ripening period even improves fruit quality. Therefore, it is possible to make water savings during the vegetative and ripening periods, but it is important to meet the full water requirements during vine development, fruit-setting and fruit growth. Mild water stress at fruit maturity improves sugar content and aroma in melon and watermelon.

Excessive irrigation can lead to misbalanced soil aeration and lack of oxygen in the root zone, resulting in reduced development of the root system. The first symptoms of water lodging are the appearance of additive roots on the soil surface and the presence of a shallow root system. In extreme cases, there can be complete deterioration of the root system and rapid wilting of the plants. This is more likely to arise in heavy, poorly drained soils, in which case mulching worsens the situation.

FERTILIZATION

Use well-decomposed organic composts or manure to maintain the organic content of the soil, improve its physical properties and enhance the activity of microbial flora. The use of good-quality fertilizers is essential for high yields and quality products.

The fertilization programme of melon, watermelon and squash is based on the amount of nutrients taken up by plants. Table 1 presents the average amounts of major nutrients absorbed by these plants. Cucurbits have high requirements of the three basic elements: nitrogen (N), phosphorus (P) and potassium (K) and of other macro- and micronutrients. It is important to maintain the correct ratio of nutrients, in order to achieve the correct balance between vegetative development and fruit-setting and to obtain good quality fruits. The appropriate N : K ratio also contributes to good quality in terms of sugar content, flavour and aroma.

TABLE 1
Major nutrients taken up by cucurbit crops (melon, watermelon and squashes) in kg tonne^{-1} produce

Crop	N		P_2O_5		K_2O		Average ratio
	Av.	Range	Av.	Range	Av.	Range	N : P : K
Melon	4.4	2.5–6.4	1.3	0.5–2.5	5.7	2.5–8.0	3.3 : 1 : 4.2
Watermelon	2.5	1.7–3.7	1.3	0.8–1.8	3.5	2.7–6.7	1.8 : 1 : 2.7
Squash	4.5	3.8–5.0	3.0	1.6–3.8	9.5	7.7–12	1.5 : 1 : 3.2

Gianquinto *et al*., 2013 (adapted).

The commonly recommended base dressing is 20–40% N, 20–40% K and 60–100% P. Distribute other fertilizer as side dressing or, preferably, through fertigation. If no fertilizer is applied before transplanting, fertigation is imperative and should begin immediately after transplanting. The maximum nutrient requirement is during fruit-setting and fruit growth, and fertilization should be scheduled accordingly.[3]

MAIN PESTS AND DISEASES

Cucurbits are short-cycle (80–110 days), fast-growing species, and thus soft and tender, which makes them very sensitive to pests and diseases. Table 2 lists the symptoms of most frequent and devastating pests and diseases.[4]

HARVESTING

Squashes have several yield flushes and require 3–4 harvests per week during peak production. On the other hand, melons and watermelons tend to ripen evenly and a relatively small number of harvests are sufficient to collect the bulk of the fruit 45–60 days after flowering, depending on cultivar, soil and weather conditions.

As melon fruit ripens, a distinct abscission zone between the fruit stem and the fruit sometimes develops and, as the flesh colour changes, the fruit (with the exception of the inodorous group) emits an aromatic scent at the blossom end. On some cultivars, the netting becomes increasingly pronounced at maturity.

Watermelons do not slip from the vine or emit an odour when ripening. Indicators of maturity are: a change in the “waxiness” of the rind; drying of the tendril closest to the fruit; and a dull, muffled sound on thumping the fruit (Jett, 2006).

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[3] See Part II, Chapter 2.

[4] See Part II, Chapter 5.

TABLE 2

Identification and control of the most common disorders, pests and diseases of cucurbits (melon, watermelon and squash)

Symptoms	Reasons	Prevention and control measures
Main nutrient deficiency symptoms		
Diffuse yellowing of lamina and veins in old leaves Fruits small, elongated, with pale flesh and tasteless	N deficiency	Apply proper fertilization
Shortening of internodes Dwarfing of plants Base leaves reddish green, brown interveined necrosis with yellow halo Fruits small with reddish flesh	P deficiency	Apply proper fertilization
Brown discoloration on edges of young leaves (parasol appearance) Fruits with gritty, bitter flesh	K deficiency	Apply proper fertilization
Arrested growth of terminal bud which becomes desiccated Increased number of glassy looking fruits	Ca deficiency	Apply proper fertilization
Yellowing of basal leaves starting at periphery of lamina, occurring after pricking out and/or during growth, sometimes leading to serious defolation	Mg deficiency	Apply proper fertilization
Interveinal chlorosis of lamina of young leaves, less accentuated along the veins	Fe deficiency	Apply proper fertilization
Main diseases		
Angular spots, oily, turning yellow	Downy mildew – *Pseudoperonospora cubensis*	Use resistant cultivars Avoid high plant densities Use fungicides
White superficial spots on upper part of the leaves	Powdery mildew – *Sphaerotheca fuliginea*; *Erysiphe cichoracearum*	Use resistant cultivars Avoid high plant densities Use fungicides
Wilting of plants	*Fusarium oxysporum* f. sp. *radicis-cucumerinum*	Adopt crop rotation Use resistant cultivars Use grafted seedlings Remove and destroy infected plants
Mottling, sometimes causing gross deformation of leaves Contracted, rolled leaves close to ground Mottling and deformation of petioles Fruit with pitted appearance	Cucumber mosaic virus (CMV)	Use resistant cultivars
Main pests		
Leaf growth halted Small yellow dots on leaves, becoming chlorotic and faded Numerous silky webs	Mite – *Tetranychus urticae*	Save and use natural enemies Minimize pesticide applications
Leaves distorted, shrivelling Honeydew produced	Aphids	Save and use natural enemies Minimize pesticide applications
Small silvery spots dotted with shiny black specks Discoloured silvery patches on leaves, becoming necrotic Fruit with small greyish pits, becoming corky and dull	Thrips tabaci – *Franklinella occidentalis*	Save and use natural enemies Minimize pesticide applications

GAP recommendations – Early production of cucurbits

- Use raised beds (height 15–25 cm) and mulches to increase soil temperature and improve plant stand establishment.
- Lay mulching films as early as possible in the growing period to optimize the effects of increased soil temperature.
- Irrigate before mulching if the soil is dry.
- Use good-quality seedlings, adopting grafted seedlings to reduce the negative effects of soil-borne diseases and of several abiotic stresses.
- Select rootstock based on the main challenges faced and test the rootstock–scion combination before planting a large area.
- Reduce planting density, as well as water and fertilizer supply when using grafted seedlings.
- Settle the transplants at ground level, or little above, to benefit from the higher temperatures at the soil surface.
- Irrigate immediately after transplanting with sufficient water to guarantee rapid establishment.
- Apply uniform irrigation avoiding soil moisture variations along the plant row.
- Use drip irrigation and fertilize with water-soluble fertilizers through the irrigation system.
- Monitor soil moisture throughout the growing cycle.
- Meet full crop water requirements during vine development, fruit-setting and fruit growth stages – only save on water during vegetative and ripening periods.
- Avoid the buildup of air temperature under the tunnel cover, removing the row cover when the first female flowers appear.
- Place at least three active beehives per hectare of production to insure good pollination and fruit-setting.
- Use periodically large quantities of well-decomposed manure to maintain organic content in the soil and activate its microbiological flora.
- Fertilize according to plant demands: use the appropriate NPK ratio to guarantee the balance between vegetative development and fruit-setting; maintain the correct N : K ratio and increase the K supply during the ripening stage to guarantee good quality fruits in terms of sugar content, flavour and aroma.

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6. Root and onion vegetables

J. Gvozdanovic-Varga[a] and V. Rosca[b]

[a] Institute of Field and Vegetable Crops, Department of Vegetable Crops, Novi Sad, Serbia
[b] State Agrarian University of Moldova. CPIU-IFAD, Chisinau, Moldova

ABSTRACT

Traditional greenhouse vegetables, such as tomatoes, cucumbers and lettuce, are common vegetables found almost year-round in supermarkets. Improved quality of life and consumer buying capacity have increased the demand for other commodities, including herbs, roots, tubers, green onions and exotic vegetables. Production practices and technologies for growing less common greenhouse root and onion vegetables are presented to growers in an easily understandable manner. Greenhouse radish, carrot, onion and garlic for green-leaf market-oriented production are included. Guidelines are provided on technologies for growing roots and onions for green leaves in different crop protected cultivation constructions, including greenhouses, tunnels, low tunnels and fields covered with agrotextile materials for temporary frost protection.

RADISH

Introduction

Radish (*Raphanus sativus* L. var. *sativus*) most likely originated in the area between the Mediterranean and the Caspian Sea. Radish is grown mainly for its thickened fleshy root. Small radish is pungent; it is eaten fresh as an appetizer and used to add colour to dishes. Currently radish is a minor crop and markets are quite limited.

Environmental requirements

Radish is a quick-growing, fast-maturing, cool-season root vegetable. The seed germinates in 3–4 days in moist soil at optimum soil temperatures of 18–25 °C. In winter, germination can take 5–6 days. The minimum temperature for germination is 5 °C. The germination rate declines when soil temperature is < 13 °C. Once the plant has germinated, maintain the air temperature in the greenhouse at 8–10 °C for 5–7 days to prevent plant elongation. During the remaining growing period, optimum air temperatures are: during the day, 12–14 °C (when cloudy) and 16–18 °C (when sunny); at night, 8–10 °C. During the growing period, optimum soil temperature is 12–16 °C to ensure the best quality and root shape. The roots of globe varieties tend to elongate and develop a poor shape in hot weather. Radish is a long-day crop; therefore, on short days it forms good quality roots. Long days can induce flowering or bolting (development of seed stalks); in combination with warm weather, the seed stalk may develop so rapidly that no edible root is formed. Radish becomes more pungent in hot weather.

Variety selection

Commercial seed companies offer a wide range of varieties. Most commercial radish varieties for greenhouse production are round, but they may also be ovoid, cylindrical or turnip-shaped. They can be red, white or a combination of red and white colours, such as pink or purple. Red varieties are the most in demand on the market. The best varieties for out-of-season production in greenhouses or tunnels are early varieties (20–22 days to maturity), with tolerance to light deficiency, bolting and cracking, and adapted to form roots under low temperature conditions, with relatively short lives and firm roots. When selecting a radish variety, growers should consult the national registration catalogue of varieties to check which varieties are recommended for their specific conditions. For EU countries, growers should refer to the Plant Varieties Database, which lists over 300 EU-registered radish varieties for both outdoor and greenhouse production.[1] For the identification of suitable cultivars, refer to FAO's Hortivar database.[2]

Growing technologies

The quantity and quality of the radish yield must be sufficient to justify the expense of indoor production. The growing medium is, therefore, very important. There are two main approaches:

- In-ground culture (Didiv *et al*., 2015) – applied when radish is grown in low tunnels and plastic-covered greenhouses (Plate 1).
- Container culture (organic substrate or soilless) – more common in intensive production in glass greenhouses.

Soil culture

A greenhouse may be erected on quality field soil, which then serves as a media for growing radish. Prepare the soil carefully and amend with organic matter (e.g. well-made compost). Avoid fresh manure, as it can provide excess ammonia and a high content of nitrates in the radish root.

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[1] Available at http://ec.europa.eu/food/plant/plant_propagation_material/plant_variety_catalogues_databases/search/public/index.cfm.

[2] Available at www.fao.org/hortivar.

Plate 1
Greenhouse radish; in-ground culture

Plate 2
Soil preparation with a rotary tiller

Soil preparation

Proper soil management is key to the sustainable production of radish in the greenhouse. When using an in-ground method for the production of radish, avoid the soil compaction that typically occurs during greenhouse construction, through inappropriate use of agricultural equipment, or as a result of frequent or heavy traffic of machines. Soil compaction can increase soil density in surface horizons, with a negative impact on plant growth and yield. Heavy, poorly drained soils are not recommended for radish production.

On sites with compacted soil or poor fertility, make raised beds. Prepare the soil to a fine texture prior to seeding to obtain uniform shape of radish roots. Level the soil surface to ensure uniform depth of sowing. Soil requires good aeration and water management. Radish does not require deep soil preparation. Prepare the soil using rotary harrow or rotary tillers (Plate 2).

Seeds and planting

The 1 000-seed weight of radish is 8–12 g. For accurate spacing of radish plants in the greenhouse, use sized seeds and precision seeders. For indoor production, use large seeds, as they have high germination energy ensuring early plant establishment. Sow with hand seeders or pneumatic precision seeders, either pulled by tractor or professional engine-run (Plate 3).

Seeds should be graded and treated prior to planting. Use seeds with a diameter > 2.5 mm at a rate of 2.5–3.5 g (300–400 seeds) m^{-2}. Seeding depth is 0.5–1.0 cm,

Plate 3
Pneumatic seeder

the space between rows 10–20 cm (or as specified by the seeding equipment) and the space between plants 2–4 cm. At 7–8 days after plant emergence, if plant density is too high, remove poorly developed plants. In the winter, when light intensity is low, reduce density to 250–270 plants m^{-2}; in February–March, increase plant density to 300–350 plants m^{-2}. When buying seeds, consult the seed supplier catalogue and check for specific variety recommendations on plant density and plant spacing – they may differ from conventional recommendations. Plant density must be no greater than the recommended level, especially in a season with light deficiency, as it would affect the quality of the harvest.

When growing radish in fields covered with agrotextile materials, sow seeds as soon as the soil is workable. Spring frosts – even snowfalls – do not usually injure radish crops after plants have emerged under the temporary covers of agrotextile materials. For greenhouse radish, sowing should take place at 10–12-day intervals to ensure a continuous supply of fresh roots to the market.

Irrigation

Before plant emergence, do not irrigate soil in the greenhouse. Radish requires frequent (once every 2 or 3 days) and uniform irrigation for optimal growth and good root shape. Excessive irrigation combined with high nutrient content in the soil leads to to vigorous growth. On the other hand, if the soil is allowed to dry out, radish becomes woody, with a poor texture and taste. After irrigation, ventilate the greenhouse. Control the humidity and avoid fluctuations in temperature in order to prevent plant infections and prevent the radish from splitting or cracking easily.

Fertilization

During the short period of vegetation, radish takes up a high quantity of nutrients. Given the high level of nutrient consumption, a low level of nutrients in the in-ground culture immediately affects both yield and quality of the radish root. Optimize and maintain the supply of nutrients to encourage good production and harvest quality (Rosca and Patron, 1985). Any deficiency of nutrients in the growing media affects plant growth; apply any fertilizers required before seeding. In greenhouses where a watering boom or other sprinkler system is used for irrigation, apply soluble fertilizers with irrigation.

Greenhouse soils amended with compost or manure may not require additional fertilization for good radish plant growth. In soils with low levels of nutrients, application of mineral fertilizers gives good results in terms of both yield and quality. Avoid over-fertilization when growing radish in the greenhouse, as – combined with low light intensity – it can increase the level of nitrates in the radish product.

Pest and disease control

Radish is generally trouble-free. There are no herbicides registered for use on radish to control weeds. In case of pest emergence, adopt biological, mechanical or IPM methods, but pay attention to the timing specifications: most pesticides require a long waiting period before harvest, while radish has a short growth period (Table 3).

Harvesting and post-harvest handling

The average yield is 1.5–3.5 kg m^{-2}; it varies according to the season, variety, substrate and growing conditions. Radish in the greenhouse can be harvested manually or with harvesting machines. Regardless of the method adopted, the necessary harvesting and handling operations are: pulling and bunching, topping, washing, grading and packing (Plate 4).

Bunching is frequently done in the greenhouse when pulling plants, especially for produce destined for the local market. Globular-rooted varieties are tied in bunches of 10–15 plants, and the bunches are packed in plastic and wooden crates. Topped radish is washed and packed in plastic bags and transparent clamshells. For long-distance shipment, radishes are shipped under refrigeration. The recommended short-term storage temperature is 0 °C with a relative humidity of 95–100%. Topped radish packaged in perforated plastic bags keeps for 3–4 weeks. Bunched radish keeps for 1–2 weeks.

Container culture

This system employs plug trays traditionally used for growing vegetable transplants (Plate 5). The most common are plastic trays with an external size of 40 × 40 cm, comprising 64 plug cells of 5 × 5 × 5 cm. The cell size must be sufficient to ensure good plant growth.

Various growing media may be used in container culture, but they must allow for adequate drainage. The most common media are: peat; peat mixed with organic ingredients; and inorganic substrates. Once plants are well established, supply additional nutrients to sustain crop growth.

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Plate 4
Radish: harvesting and bunching (left); washing (centre); packed bunches ready for delivery (right)


ROSCA

Plate 5
Dibbling tray cells


ROSCA

Plate 6
Seeding in plug trays

Wash and disinfect the trays before filling with substrate for growing vegetable transplants. Use a dibbler to make a 0.5–1.0-cm hole in each cell (Plate 5) and plant one seed per cell (Plate 6).

The trays can then be placed on the soil in the greenhouse, but the hydroponic method is increasingly adopted, with trays placed on benches especially arranged for flood and drain irrigation. If available, first put the trays in a germination room for 1–2 days at 18–20 °C. The first flood irrigation is carried out 6–7 days after seeding in trays, when the first plant root exits the tray through the drainage hole. Flood irrigation lasts about 20 minutes. The water level in the seeded tray should not exceed 1 cm (Plate 7).

During the growing season, trays are flooded daily – if necessary, twice a day. As required, inject soluble fertilizers into the irrigation water, adjusting the input to meet the needs of the plants. The environmental conditions (temperature, air and soil moisture, lighting) and harvesting operations are similar to those for in-ground culture.

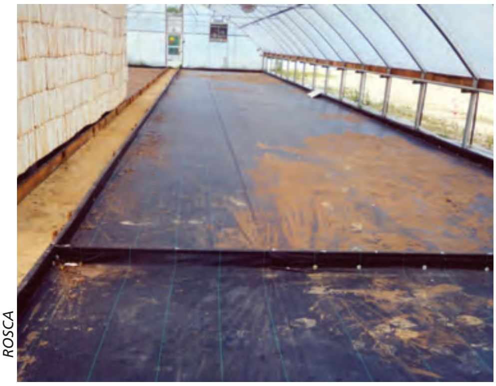
ROSCA

Plate 7
Greenhouse prepared plug system with flood irrigation

CARROTS

Introduction

Carrots (*Daucus carota* L. var. *sativus*) are typically grown as an open-field crop, but gardeners grow carrots also in greenhouses and other indoor constructions to supply the market with early season bunched roots, when there is high demand for fresh vegetables following a long winter season. Carrots come in a variety of shapes, sizes and colours, including orange, yellow, pink, red and purple. With the right varieties and methods, it is possible to have fresh and ready young roots of carrots for cooking and snacking at any time. Carrots can be grown in a greenhouse throughout winter for a spring crop, but they cannot be grown in the greenhouse in late spring and summer as they prefer cool conditions. Solar tunnels and greenhouses, as well as low tunnels, are suitable for growing early carrots.

Environmental requirements

Carrots are a cool season crop and are somewhat frost tolerant; nevertheless, seedlings of ≤ 6 leaves cannot withstand hard freezes. Root growth is fastest at 15–18 °C, while the optimum temperature for seed germination is 18–20 °C. Carrot seeds can germinate at low soil temperatures, but the germination period is shorter at higher temperatures. For example:

- < 5 °C, carrots struggle to germinate.
- < 10 °C, carrots germinate slowly, taking 25–30 days to reach plant emergence.
- ≥ 10 °C, germination occurs after 8–10 days.

The recommended soil temperature for germination is, therefore, ≥ 10 °C.

Carrots have high light requirements and indoor production in November–January is difficult, due to lower light intensity. The greenhouse must be on an open sunny site for early carrots. Carrots like well-drained, fertile soils rich in organic matter. Sandy peat soils provide the best conditions for deep penetration and the formation of uniform roots. The pH value should be 6.5–7.5.

Cultivar selection

There are two main groups of cultivated carrots: the Eastern (anthocyanin) and the Western (carotene) carrot. For indoor production, carotene varieties are recommended, in particular the early varieties, ‘Nantes’ and ‘Amsterdam’ – small, slender, finger-shaped carrots, fast-maturing and adapted as early crops in cold frames, tunnels and greenhouses. Other common varieties are ‘Round’, ‘Chantenay’ and ‘Imperator’. Some growers prefer to grow indoor round-shaped carrots.

Growing technologies

Soil preparation

Clean the soil in the greenhouse of previous crops and weeds. Spread organic fertilizers (e.g. compost, peat or decomposed manure) on the soil before tilling. Carrot responds well to applications of 6–10 kg of compost per greenhouse square metre. Soil preparation is fundamental when growing carrots in the greenhouse. If the soil is very compact, plough before preparing with a rotary harrow. The soil surface must be well levelled to ensure uniform depth of sowing. Carrots grow very well in raised beds (Plate 8).

Seeds and planting

It is recommended to use graded seeds with a diameter > 0.8 mm for indoor planted carrots. Carrots are normally sown straight in the ground and then thinned in stages to obtain the correct spacing. The timing of seeding depends on the type of indoor construction and the planned harvest time. In order to harvest carrots at the beginning of April, it is recommended to sow seeds in December. Similarly, for a harvest at the end of April, seeds need to be sown in January. To harvest carrots in May, sowing is carried out in February. The seeding rate is 1.0–1.2 g m^{-2} at a depth of 1.0–1.5 cm. For a good yield, rows are 12–14 cm apart, with 3–4 cm between plants within rows (5 cm for larger carrots). Seeds can be mixed with sand to facilitate sowing. Some growers mix radish seeds with carrot seeds. Carrot seeds are slow to germinate, while the radish – which germinates and grows very quickly – marks the row until the carrots come up. When the carrot seeds germinate and plant emergence reaches 50%, pull out the radish seedlings. When the plants reach a height of 4 cm, they are thinly spaced to 5–6 cm between plants. Plant density should be 60–80 plants m^{-2}.

Plant care

At emergence of seedlings, irrigation is kept at a minimum. Soil moisture should be constant, especially in the phase of root development, so as to prevent cracking caused by dry conditions. Soluble NPK fertilizers (ratio 1 : 2 : 2) are applied with irrigation at a rate of 1–2 g $litre^{-1}$ of water. Too much nitrogen causes excessive top growth. Since carrots are root crops, the greatest impact on produce quality comes from soil-inhabiting pests (e.g. wireworms, cutworms and vegetable weevils). Other pests (e.g. carrot weevil, carrot rust fly, willow-carrot aphid) affect carrot plants grown in greenhouse. Various pest control approaches – cultural practices (irrigating,


FORIGO

Plate 8
Making raised beds in a greenhouse

weed control, seed and soil preparation) and biological or chemical control – are adopted to limit yield losses. In the case of greenhouse carrot crops, powdery mildew can cause significant damage. This disease occurs in greenhouses with high humidity, a condition favourable for infection. To prevent infection, always ventilate the greenhouse after irrigation.[3]

Harvesting

Indoor carrots are generally ready for harvest after 2.5–3 months, when the root diameter is 1.3 cm and the carrots are succulent with a good colour. Greenhouse carrots are harvested manually: dig gently to expose the top of the root and gently, but firmly, pull the root from the soil. Some growers select only carrots of marketable size and make 2–3 selective harvests. Greenhouse carrots are tied in bunches of 5–10 plants and packed in plastic and wood crates. Yield is about 50–65 bunches per square metre of greenhouse.

ONION

Introduction

Onion (*Allium cepa* L.) belongs to the Alliacae family, which includes perennial and biennial herbaceous plants with well-developed or undeveloped bulbs. The whole plant – both above-ground parts (spring onions) and mature bulbs – are used for consumption. The dry matter content of spring onion is around 12%, of which the majority are simple sugars (80–90%). Spring onion is high in potassium, calcium, magnesium and iron (Gvozdanovic-Varga *et al.*, 2013). Green leaves contain vitamin C and pigments that are antioxidants. The characteristic odour comes from essential oils, which are antimicrobial and the reason for onion's well-known healing properties. The growing period is short, the temperature and light requirements modest, making this species suitable for autumn–winter and early spring production.

Environmental requirements

Onion requires modest temperatures, moist soil throughout the growing season and 70–80% air humidity; it is therefore a suitable preceding crop, cover crop or intercrop in the greenhouse. Temperature requirements are as follows:

- Optimum soil temperature for germination and emergence: 20 °C (≥ 2–3 °C)
- Optimum soil temperature for root formation: 10 °C
- Optimum air temperature for leaf growth: 18–20 °C

The optimum soil temperature for sprouting and emergence is 18–20 °C during the day and 12–15 °C at night. The length of individual growth phases depends mainly on the temperature. At 5–8 °C, sprouting lasts 25–35 days; at 18–20 °C, it

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[3] See Part II, Chapter 5.

TABLE 1

Conditions and systems of spring onion farming in the greenhouses

Production time[a]	Planting date	Object type	Production duration (weeks)	Number of plants m^{-2}	Yield (kg m^{-2})
PS	Oct. – Nov. Mar. – April	Cold agrotextile	4	180–200	4–5
PS, mixed crop, lettuce and onion	Dec. – Jan.	Heating agrotextile	3	60–80	1.5–2
PS	Feb.	Heating	4–5	220–250	4–5

[a] PS = Planting of onion sets.

lasts 10–12 days; and at 20–25 °C, just 3–5 days. Once the onions sprout, maintain the greenhouse temperature at 8–10 °C to allow the roots to develop; temperatures > 20 °C slow the growth. The optimum temperature for foliage growth is 18–20 °C, while temperatures > 25 °C cause excessive foliage growth, elongation and deformity of leaves. Relative humidity in the greenhouse should be 50–60%. Spring onion does not require additional lighting.

Soil requirements

Onion requires fertile and structured soils with good physical and chemical properties and a pH of 6.8–7.5; it will not grow on acid soils.

Growing cycles

In the agro-ecological conditions of SEE countries, spring onion is produced in greenhouses from onion sets (varying in sizes) and transplants. For early planting, onion sets of about 25 mm diameter, or even larger size bulbs, should be used. Transplants grow in late August and are planted in greenhouses in October.

Spring onion farmers use domestic varieties produced from onion sets, i.e. bulbs that are not of standard quality (Cervenski *et al.*, 2013). Onion bulbs of domesticated varieties come in a wide range of shapes and colours (Plate 9), including 'Stuttgarter Riesen' and 'Bianca di Maggio' varieties. Transplants are produced from winter white bulb onion varieties. Winter white bulb onion varieties, such as Silverskin, are grown from transplants.


GVOZDANOVIC-VARGA
GVOZDANOVIC-VARGA
GVOZDANOVIC-VARGA

Plate 9

Onion sets of different colours and sizes for planting

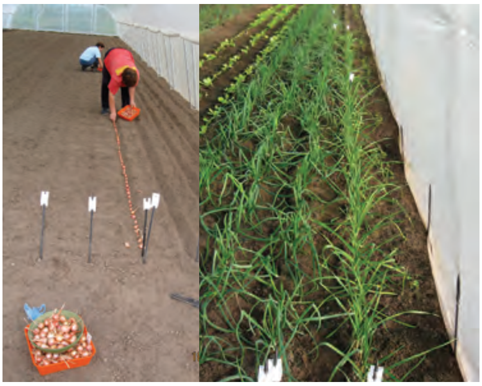
GVOZDANOVIC-VARGA

Plate 10
Successive planting


GVOZDANOVIC-VARGA

Plate 11
Spring onion grown from sets of different sizes

Growing technologies

Soil preparation

Prior to tillage, remove all plant residues and apply organic fertilizers or manure. Perform basic tillage at a depth of 20–25 cm, and prepare the seed bed by crumbling soil at a depth of 8–10 cm, i.e. the optimum sowing depth.

Planting

Spring onions are suitable for successive planting, every 15 or 20 days, prolonging the harvest period. When sets are planted from October to late February, spring onion matures in 30–40 days (depending on the variety and greenhouse environmental conditions). Planting is done in bands of 4 or 5 rows at the following distances: inter-row 20 cm, intra-row 2–3 cm and inter-band 40–50 cm.

Irrigation

After planting and crop emergence, it is important to irrigate well; during crop growth, decrease the irrigation rate. Spring onions require irrigating at regular intervals during crop growth through to transplanting, after which fewer irrigations are required.

Fertilization

Take soil samples at least once per season for agrochemical analysis to understand the specific nutrient requirements. During tilling, incorporate only organic fertilizers (e.g. aged manure or NPK in the ratio 2 : 1 : 3). If necessary, apply a foliar top-dressing with addition of adhesives.

Pests and diseases

The main conditions for successful spring onion farming are use of good healthy planting material and maintenance of high standards of greenhouse hygiene. Due to the short growing period, there are almost no pest and disease problems (Table 3).

Harvest

High-quality spring onion has 6–9 leaves and a long white pseudo stem; it matures 20–45 days after planting, depending on the variety, set size, harvest date and cultivation system. Spring onions yield 1.5–5.5 kg m^{-2}.

GARLIC

Introduction

Garlic (*Allium sativum* L.) belongs to the Alliacae family. The use and cultivation of garlic dates back to the ancient civilizations, thanks to its high biological value, and nutritive and healing qualities. It has a high content of dry matter (35–40%), protein (5–6%) and sugar (22–25%). Of the complex sugars, garlic contains inulin-type fructose polymers (17.4%) (Muir *et al*. 2007) and is safe for diabetics. The foliage of young plants contains vitamin C and minerals. The main ingredients of garlic's essential oils are sulphur compounds, which have antimicrobial effects.

Environmental requirements

Garlic requires a moderate temperature and is resistant to low temperatures and frost. Sprouting begins at 3–5 °C; the optimum temperature for root formation is 10 °C, while it is 16–18 °C for above-ground parts. During the growth period, relative humidity should be 50–60%. The foliage forms during short days; therefore, spring garlic is grown in autumn and winter when days last 10–12 hours.

Growing cycles

Planting begins in early September and lasts until the end of November (Table 2). The later garlic is planted, the longer the vegetation period. Garlic planted in the early period is ready after 40–50 days, compared with garlic planted later (ready after ≤ 60 days). In tunnel greenhouses, garlic sprouts after 10–12 days. In the early stages of development, lower temperatures are required for rooting and sprouting. Optimal temperature is essential for leaf growth in later stages. Garlic contains carotene, and the whole plant is rich in K, Fe, Zn and carbohydrates, while having low energy value. It also contains alliin that has antimicrobial effects.

TABLE 2
Required quantity of cloves depending on size and cultivation system

Planting date	Planting distance (cm)	Number of plants (per m^2)	Quantity of cloves (g m^{-2}) 3 g	4 g	5 g
Sept. – Oct.	50+25+25+25+25+25+25+50	150	450	600	750
	50+25+25+25+25+25+50	125	375	500	625
	50+30+30+30+30+50	100	300	400	500

GVOZDANOVIC-VARGA

GVOZDANOVIC-VARGA

Plate 12
Selection of cloves for planting

Variety selection

Winter garlic and flowering garlic with a shorter growing cycle are used for spring garlic cultivation. Domestic garlic varieties and domesticated populations produce the best results.

Growing technologies

Planting begins in late September and lasts until December (successive planting every 7–10 days). Planting cloves are classified by size (Plate 12). Plant cloves in 4–6-row bands at the following distances: inter-row 25–30 cm, intra-row 4 cm (Table 2). With early planting, the intra-row distance can 2–3 cm. Plant pointed cloves end up with the tip 3 cm beneath the surface. Planting at a greater depth leads to delays in sprouting; if planting is shallow, the cloves protrude from the soil due to intensive root growth and the plant withers.

Irrigation

Water deficit at the root formation stage adversely affects initial plant development. Irrigation is necessary after planting, with enough water to wet the soil to a depth of about 10 cm. After sprouting, adjust the irrigation rate according to the greenhouse air temperature and plant development stage.

Fertilization

Garlic prefers very fertile soils and abundant fertilization with easily available nutrients is required. Prepare the greenhouse (low and high tunnels, plastic greenhouses) by applying appropriate quantities of manure (2–4 kg m^{-2}) and NPK (ratio 2 : 1 : 3) fertilizers (10–15 g m^{-2}). Apply foliar top-dressing of nitrogen or liquid fertilizer complex as the first foliage appears.


GVOZDANOVIC-VARGA

Plate 13
Spring garlic plants grown from cloves of various sizes

Pests and diseases

The basic crop management measure is to plant good healthy cloves. Use of chemicals is limited due to the short growing period (Table 3).

Harvest

Harvesting of garlic takes place selectively, when plants have 3–4 leaves, 40–60 days after planting. Tie in bundles of 3–5 plants. The highest yields are achieved when the crop has formed 5–7 leaves (Plate 13).

WELSH ONION

Introduction

Welsh onion (*Allium fistulosum* L.) is a perennial species used for growing spring onions. It does not develop bulbs, but has pseudo-bulbs with a characteristic elongated and thickened stem and very lush foliage. Leaves are rich in vitamin C and beta-carotene, and the whole plant is rich in K, Fe, Zn and carbohydrates while having low energy value. Welsh onion also contains alliin, which has antimicrobial effects.

Environmental requirements

Welsh onion requires modest growing conditions; it sprouts at 2–3 °C, but the optimum temperature is 18–20 °C. During the growing period, maintain the greenhouse temperature at 15–20 °C during the day and 5–10 °C at night.

Growing cycles

Welsh onion is sown directly from seeds in September and is ready for harvest in November (60–70 days). Growing for transplant production begins in late September, as the crop matures for harvest in December (60–65 days after transplanting).

Variety selection

Use seeds of commercially available varieties (e.g. ‘Savel’, ‘Parade’).

Growing technologies

Welsh onion has good tolerance to low temperatures and lack of soil moisture (drought), thanks to its well-developed root system, which is 2–3 times larger than that of onion. It may be grown by direct seeding or from transplants in tunnel greenhouses without additional heating. Direct sowing starts in early

September with 4–8 g m^{-2} of seed sown in 4–6-row bands and then covered with compost. Inter-row spacing is 15–20 cm; after thinning, leave 2–3 cm of intra-row spacing. Carry out the first thinning when plants have 2–3 leaves.

Irrigation

Maintain optimal soil moisture after sowing and during sprouting. After thinning, irrigation rates depend on the temperature and crop growing stage.


TODOROVIC

Plate 14
Production of Welsh onion in a high tunnel greenhouse

Fertilization

The crop benefits greatly from organic fertilizers (aged manure or compost), grows fast and has lush foliage. Carry out agrochemical analysis of soil and organic fertilizers prior to planting. In seedling production, NPK fertilization (ratio 2 : 1 : 3) is necessary during the intensive phase of growth of the above-ground part of the plant (Plate 14).

Harvest

Spring onion, grown from Welsh onion, is harvested from November to January. Plants should have 4–6 formed leaves, pseudo-stem diameter of 0.6–1 cm and length of 7–10 cm. Tie in bundles of 5–7 plants. Yield reaches 4–8 kg m^{-2}.

GAP recommendations – Root and onion crops production

- When introducing a new crop (root and onion crops) in the production system, gather information on the technological aspects and carry out trials before planting commercial volumes.
- Use domestically registered varieties of short growing season (root vegetables) and local populations (onion and garlic).
- For greenhouse production use only high-quality seeds, treated for pests and diseases.
- Take care to prepare the soil well: it must not be compacted and it requires a high level of organic matter.
- Remember: indoor plants thrive, but pests and diseases are more aggressive indoors than outdoors.

For new crops: gather information, perform trials BEFORE cultivating on a commercial scale!

TABLE 3

Identification and control of the most common root and bulb vegetable disorders, pests and diseases

Symptoms	Reasons	Prevention and control measures
Radish		
Chlorotic angular lesions on leaves slowly turning into necrotic patches Greyish fluffy growth on undersides of leaves	Downy mildew – *Peronospora parasitica*	Disinfect soil using steam Apply balanced N fertilization Adopt irrigation methods that do not wet leaves
Shoot wilting Vascular necrosis	Fusarium wilt – *Fusarium oxysporum*	Use resistant cultivars/hybrids Adopt hygiene and sanitary measures Apply balanced fertilization
White pustules on cotyledons and true leaves	White rust – *Albugo candida*	Remove plant debris and weeds Apply balanced fertilization
Small black–red areas on roots, expanding and merging Roots constricted at sites of lesions	Black root – *Aphanomyces raphari*	Use resistant cultivars/hybrids Remove plant debris and weeds Apply optimal irrigation and fertilization
Brown–yellow circular lesions on root, irregular, merging Cracking of affected tissue	Common scab – *Streptomyces scabies*	Adopt crop rotation Avoid soils with increased pH Use resistant cultivars/hybrids Apply optimal irrigation
Small rounded holes in the foliage Presence of numerous small black beetles Withering and drying of damaged foliage with sieve-like appearance	Flea beetle – *Phyllotreta* spp.	Eradicate weed brassicas Adopt quality tillage Apply adequate irrigation Install insect netting cover Use pheromone traps
Leaves turning yellow, drying up Appearance of honeydew White aphids on lower leaf surfaces, flying when disturbed	Greenhouse whitefly – *Trialeurodes vaporariorum*	Adopt hygiene and sanitary measures Heat empty facility 5–8 days at 25 °C Eradicate weeds Apply optimal fertilization and irrigation
Plant interior filled with tunnels and excrement	Cabbage stem weevil – *Ceuthorrhynchus quadridens*	Adopt quality tillage Install insect netting cover Install ventilation systems

TABLE 3 (cont'd)

Identification and control of the most common root and bulb vegetable disorders, pests and diseases

Symptoms	Reasons	Prevention and control measures
Carrot		
White fluffy mycelial growth on leaves Severe infection of older leaves Plants exhausted by retro vegetation	Powdery mildew on carrot – *Erysiphe heraclei*	Adopt deep ploughing of crop residues Adopt crop rotation Use healthy seed Apply balanced fertilization
Light, watery lesions with soft tissue and rot Withering and wilting of leaves above infected plant parts Formation of white fluffy mycelia with dark spots (sclerotia) under moist conditions.	White mould – *Sclerotinia sclerotiorum*	Adopt deep tillage Disinfect soil or use sterile medium Use less susceptible cultivars Remove infected plants
Radicle and shoot decay and rot Oval dark yellow–black patches on developed leaves Dark, sunken patches on root neck leading to decay of whole plant	Black rot – *Alternaria radicina*	Use healthy and treated seed Adopt crop rotation Remove and eradicate infected plants
Bacterial soft rot on root Softening of tissue Leakage of liquid of unpleasant odour	Bacterial soft rot – *Pectobacterium carotovorum* subsp. *carotovorum*	Sow in well-aerated soils Apply optimal irrigation Apply balanced fertilization with N Avoid mechanical damage to roots
Deformed yellow or red leaves Presence of aphids on leaves Stunted growth and withering	Leaf aphids	Adopt quality tillage Install dense netting cover over ventilation system Eradicate weeds
Curling and withering of leaves Presence of insects in imago and larva stages	Carrot psyllid – *Trioza viridula*	Remove plant debris Adopt quality tillage Remove affected plants Use pheromone traps
Root tunnels of varying length filled with larvae excrement Unpleasant odour Susceptibility to rotting Purple leaves turning yellow and withering	Carrot fly – *Psila rosae*	Install ventilation Remove affected plants Eradicate weeds
Stunted, deformed and woody roots Beard-like appearance of lateral roots Stunted growth of plants Red–yellow spots on leaves Withering and wilting of older leaves	Carrot cyst nematode – *Heterodera carotae*	Eradicate weeds Adopt quality cultivation practices Apply balanced fertilization Apply optimal irrigation Apply fertilization with K to decrease abundance of cysts

TABLE 3 (cont'd)

Identification and control of the most common root and bulb vegetable disorders, pests and diseases

Symptoms	Reasons	Prevention and control measures
Onion vegetables		
Delays in development Leaves pale green Older leaves yellow and dry, starting at the top	N deficiency	Apply adequate fertilization
Reduced turgour of onions Tips of older leaves dying out, but leaves not yellow	K deficiency	Apply adequate fertilization and irrigation
Oval or elongated lesions of various sizes on foliage Greyish discoloration under high moisture conditions	Downy mildew on onions – *Peronospora destructor*	Use healthy seedlings Remove plant debris and eradicate wild plants Apply balanced N fertilization Install ventilation Adopt optimal plant density
Localized lesions on older leaves, initially yellow then dark brown and elongated Black growth in centre of lesions	Purple blotch – *Alternaria porri*	Use healthy seedlings Install ventilation Apply moderate irrigation Apply balanced fertilization
Stunted growth Foliage flattened, shrivelled, deformed Foliage yellow, dried up, straw-like Chlorosis with narrow streaks and stripes Chlorotic spots along leaf blades, wrinkled and curled	Iris yellow spot virus Onion yellow dwarf virus Garlic mosaic virus Leek yellow stripe virus	Use virus-free seedlings Remove infected plants Control virus vector pests Adopt measures benefiting plant growth and development
Stunted growth Spongy bulbs Foliage short and thick with light–dark brown patches	Nematodes	Use healthy seedlings Remove plant debris and weeds Plant marigolds (*Tagetes* spp.)
Foliage silvery and spotted Stem brown and dried off	Onion thrips – *Thrips tabaci*	Eradicate weeds regularly Apply balanced fertilization with extra P and K Apply optimal irrigation Remove plant debris
Outer layers yellow and dried up (onion) Stem soft and shrivelled Larvae on cracked tunica	Allium leafminer – *Napomyza gymnostoma*	Adopt quality tillage Remove individual infected plants Remove wrapping leaves with pupae Install insect netting cover
Foliage yellow, withered, dried off Pseudo stem and bulb soft to touch Plant easily picked from soil Larvae in central part of pseudo stem and bulb	Onion maggot – *Hylemyia antiqua*	Remove affected plants Install ventilation Install insect netting Adopt intercropping with carrot
Silvery-white stripes Larvae inside leaves and bulbs Plants dried off	Leek moth – *Acrolepiopsis assectella*	Adopt quality tillage Remove infected plants and weeds

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7. French bean

B. Benko

Faculty of Agriculture, University of Zagreb, Croatia

ABSTRACT

Despite the advantages of greenhouse cultivation, French bean is rarely grown in greenhouses in South East European (SEE) countries. The reason is the cost of greenhouse heating which entails high fuel consumption. However, there is some cultivation of French bean in non-heated greenhouses. The crop has high temperature requirements; appropriate location and growing period are, therefore, fundamental. Given the short growing season (60–80 days for dwarf French bean), it can be grown in spring or autumn, when temperatures are too low for open-field cultivation.

This chapter presents the environmental requirements, principles of greenhouse production and plant care measures for these minor species according to GAP recommendations.

INTRODUCTION

French bean is a warm season plant that requires fertile, well-drained soil. Traditionally, it is grown in the open field when minimum air temperatures are > 10–12 °C. Lower temperatures inhibit its growth. However, when grown in greenhouses it can be planted 4–6 weeks earlier. The use of greenhouses for French bean production can result in early harvest, increased fruit-set and extended supply to the market. French bean therefore represents an opportunity for producers to become more competitive in the fresh vegetable market.

French bean production in Europe is about 841 000 tonnes, accounting for 3.9% of world production (FAOSTAT, 2013). Average yield is 7.6 tonnes ha^{-1}. In SEE countries, Turkey is the main producer: 73 697 ha and 632 301 tonnes. Although official data on greenhouse production of French bean are not available for most SEE countries, the data from Turkey indicate that there is good potential in SEE countries to expand French bean production.

ENVIRONMENTAL REQUIREMENTS

The soil temperature at sowing time should be > 10 °C. For germination, optimum temperature is 18–22 °C, permitting germination in 8–10 days. The optimum temperature for vegetative growth is 22 °C and for pod formation ≤ 25 °C. After germination, the minimum night temperature is 15 °C. Flowering takes place at temperatures of 15–35 °C; at lower or higher temperatures, flowers and formed pods abort. However, temperatures of 30 °C, with air humidity < 25%, have a deteriorating effect on flowering and pod development (Lešić *et al*., 2004). The temperature sum during the growing period should be 1 800–2 000 °C; this should be combined with relative humidity of 60% to prevent the occurrence of rot (Đurovka *et al.*, 2006).

SOIL REQUIREMENTS

Well-drained, friable, medium-textured, clay loams are suited for French bean production. Growth is strongly reduced by soil compaction. Slightly acid soils are preferable; the optimum pH is 6.0–6.5. More acid soil reduces the activity of *Rhizobium* bacteria.

PRINCIPLES OF FRENCH BEAN PRODUCTION IN GREENHOUSES

Cultivation schedule and crop arrangement

Early bean is grown from seedlings in heated greenhouses. Sowing takes place in late January and early February, and planting about 20 days later. Harvest is from April to the middle of May. French bean can also be transplanted after the production of other vegetable seedlings through to 15 May, with harvest from the end of June to the end of July, when soil preparation for autumn production starts. Autumn production starts in August and is harvested in October. Depending on the climate, additional or full heating may be necessary during spring and autumn production (Todorović *et al*., 2008). Summer production of French bean is suited to hilly areas with lower maximum temperatures (Lešić *et al*., 2004).

FABEK

Plate 1
Greenhouse French bean sown in rows

For dwarf French bean, rows are 30–40 cm apart with 5–7 cm within the row (Plate 1). Seeds are sown at a depth of 2.5–3 cm. Place irrigation lines between every other row. For pole French bean, rows are 100–150 cm apart with 25–40 cm within the row; alternatively, sowing is in double strips, rows 20–40 cm apart, 40 cm within rows and 80–100 cm between strips (Đurovka *et al*., 2006). Specific distances are necessary to facilitate the establishment of supports since the plants need to climb and wrap around poles.

CULTIVAR CHOICE

There are two types of French bean cultivar: dwarf and pole. Dwarf cultivars do not require trellis systems and normally mature 50–60 days after planting. Pole cultivars require support for plant growth, mature about 80 days after planting and have a longer harvest period. In dwarf cultivars, there are 3–10 joints in the main stalk, which carries an abundance of flowers at maturity. In pole cultivars, there are 11–35 joints in the main stalk, which elongates and wraps, showing unlimited growth (Madakbas *et al.*, 2012).

Factors to consider when choosing cultivars are: growing environment, available space, production goals, market requirements and desired use. Cultivars have different shapes and colours; the pods may be oval or flat, green or yellow. Growers should consult the list of registered varies for their specific country, the Plant Variety Catalogue of the EU or the FAO database, Hortivar.[1]

SOIL PREPARATION AND SOILLESS CULTURE

French bean has a relatively shallow root, and primary soil tillage should be ≤ 30 cm. Depending on the previous crop, soil preparation begins in autumn or spring. Seed bed preparation must provide good soil structure in the seeding layer so that the seeds can be sowed to the proper and uniform sowing depth – a prerequisite for uniform germination. If the surface is not mulched, 2–3 inter-row cultivations are required during the growing season to control weed emergence (Lešić *et al.*, 2004).

In soil culture, French bean is grown by direct sowing; in soilless culture, seedlings are planted in substrate. The most commonly used substrates are rockwool and coconut fibres (Todorović *et al.*, 2008). Table 1 provides the nutrient solution formulation for soilless culture of French bean.

TABLE 1
Nutrient solution formulation for French bean grown in soilless culture

Macroelements	mmol litre^{-1}	Microelements	µmol litre^{-1}
NO_3^-	12.00	Fe^{3+}	10.00
NH_4^+	1.00	Mn^{2+}	10.00
$H_2PO_4^-$	1.25	Zn^{2+}	4.00
K^+	5.50	B^{3+}	20.00
Ca^{2+}	3.25	Cu^{2+}	0.50
Mg^{2+}	1.25	Mo^{6+}	0.50
SO_4^{2-}	1.15		
EC 1.70 dS m^{-1}		pH 5.5–6.2	

Enzo *et al.*, 2001.

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[1] Available at www.fao.org/hortivar.

TRELLISING AND PRUNING

Wrapping of pole French bean plants is labour-intensive and must be done weekly. However, it has advantages:

- increased yield m^{-2};
- reduced risk of disease development;
- easier picking; and
- easier-to-spot mature pods.

French bean is wrapped from a single stem. The side shoots are not removed. The pods should be ready for picking when the plants reach the top of the wire; if not yet mature, the top growth points can grow horizontally along the main wire. In soilless culture systems, beans are wrapped; the secondary side shoots are not pruned, because they contain pods that can be harvested and pruning would reduce yield. Moreover, pruning is not possible due to the high growth rate.

IRRIGATION AND FERTILIZATION

The water requirement for maximum production of a French bean crop cycle (60 days for dwarf varieties, 120 days for pole varieties) is 300–500 mm, depending on climate and soil type. Irrigation frequency (once every 3–10 days) depends on climate, crop development and soil type. Irrigation is critical during and immediately after flowering. French bean is sensitive to salinity (Lešić *et al.*, 2004). Compared with irrigation water with electrical conductivity (EC) of 0.7 dS m^{-1}, EC 1.5 dS m^{-1} results in 25% yield reduction and EC 2.4 dS m^{-1} in 50% yield reduction.

Fertilization is based on soil analysis results and planned yield. The nutrient requirement for a yield of 12 tonnes ha^{-1} is approximately 140 kg N, 35 kg P_2O_5, 150 kg K_2O, 100 kg CaO and 18 kg MgO (Lešić *et al.*, 2004). Incorporating organic matter in intensely-managed greenhouse soil before planting improves nutrient levels, increases soil water-holding capacity, reduces soil crusting issues and mitigates drainage problems. French bean is very sensitive to Mn, Zn and Fe deficiencies; add fertilizers to the soil before planting. Higher rates of phosphate may be necessary for early plantings when the soil is cold or if the soil pH is ≥ 7.5. Application of N may not be necessary because of nitrogen fixation by root bacteria (Plate 2). It is recommended to use seed inoculated with *Rhizobium* bacteria.[2]

Plate 2
Nodules of nitrogen fixation bacteria on French bean root

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[2] See Part II, Chapter 2.

PHYSIOLOGICAL DISORDERS, PESTS AND DISEASES

Early season crops grown in high tunnels or greenhouses are less likely to have pest problems – unless favourable conditions arise. To avoid pest outbreaks requiring chemical treatments, grow healthy plants in a clean environment. Apply only chemicals specifically labelled for greenhouse use and follow directions closely. Table 2 lists the most important French bean disorders, pests and diseases.[3]

TABLE 2
Identification and control of the most common French bean disorders, pests and diseases

Symptoms	Reasons	Prevention and control measures
Chlorotic spots between the veins of young leaves Pods yellow and poorly filled	Mn deficiency	Apply adequate fertilization
Entire plants light green Chlorosis on leaves extending from edges of vessels Young leaves deformed and wrapped Young pods aborted	Zn deficiency	Apply adequate fertilization
Young leaves pale green to bright yellow with profuse irregular necrosis Oldest leaves dark green Death of growing point and abortion of youngest unexpanded leaflets (severe deficiency)	Fe deficiency	Reduce soil or nutrient solution pH Use Fe formulations available with higher pH (e.g. iron chelates) Improve soil drainage and aeration
Flowers and pods aborted	High temperature and light intensity Low relative humidity	Control climatic conditions in greenhouse
Stunted plant growth Reduced pods	Aphids	Maintain standards of hygiene Destroy infected leaves Spray with insecticide
Chewed edges of leaves immediately after emergence	Weevil	Use insecticide when 10% of leaf surface is destroyed or when weevils are > 2–3 m^{-2}
Stippled, distorted and light-coloured leaves	Mite	Apply *Phytoseiulus persimilis* Use insecticides
Stunted plant growth Stem and pods turning red Root thickening	Stem and soil nematodes	Adopt crop rotation Use integrated approach for better plant growth Adopt soil solarization Use resistant cultivars Use grafting Adopt soilless culture
Brown spots on lower leaf side, turning black at end of growing season	Bean rust – *Uromyces appendiculatus*	Adopt crop rotation Use resistant cultivars Burn remains after harvest
Oval dark brown spots on leaves, petioles and stems Spots on pods initially small but growing with time	Bean brown spot – *Colletotrichum lindemuthianum*	Use healthy certified seeds Adopt crop rotation Burn remains after harvest
Wet polygonal brown spots with yellow edges on young leaves Small oval spots on pods	Halo blight – *Pseudomonas syringae* pv. *phaseolicola*	Use healthy certified seeds Adopt crop rotation Use fungicides
Mosaic colouring of leaves Leaves deformed	Bean common mosaic virus and bean yellow mosaic virus spread by aphids	Use healthy certified seeds, nets and mulch Monitor and control aphid vectors Control weeds Use yellow sticky traps

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[3] See Part II, Chapter 5.

HARVESTING AND POST-HARVEST HANDLING

Harvesting of French bean in greenhouses begins 50–60 days after germination, i.e. 8–10 days after flowering (Ilić *et al.*, 2009) at technological maturity. Harvest is frequent: 2–3 times a week. The duration of the harvest period varies depending on the type of bean. With dwarf cultivars, the bulk of the production comes in 3–5 harvests. Planting crops on different dates will extend the season and produce a steady income. During the short growing cycle, yields of 2.5–3.5 kg m^{-2} are possible. Pole cultivars of French bean grown in unheated greenhouses can reach yields of 4–6 kg m^{-2} from 7–12 harvests over 40–55 days (Đurovka *et al.*, 2006).

After harvest, the temperature of the pods should be lowered to 7–10 °C as soon as possible. Optimum storage temperature is 5–7.5 °C, relative humidity > 95%. Under such conditions, French bean can be stored for 8–12 days (Ilić *et al.*, 2009).

GAP recommendations – French bean production

- Adjust nutrient supply based on soil analysis and crop requirements to prevent accumulation, fixation, vaporization or leaching of nutrients.
- Use seed inoculated with *Rhizobium* to increase nitrogen fixation by root bacteria.
- For early production, grow French bean from seedlings in a heated greenhouse.
- Choose dwarf French bean cultivars as a previous or second crop because of their short growing period.
- Grow pole French bean cultivars as a main greenhouse crop because of their longer growing period and extended harvest period resulting in higher yield.
- For pole French bean plants, use a trellising system and wrap plants on a weekly basis to achieve increased yield, reduced risk of disease development and improved visibility for picking mature pods.
- Use black PE-mulch foil to ensure optimal soil temperature during early production, and to avoid inter-row cultivations during the growing season due to weed emergence.
- Position the drip irrigation system under the mulch foil and use for irrigation and fertigation based on irrigation coefficient, plant development stage, physical characteristics of the soil and greenhouse climatic conditions.
- Apply plant protection techniques according to integrated pest management principles and recommendations. IPM combines a number of measures and processes to reduce the use of pesticides.

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8. Kohlrabi and kale

B. Benko

Faculty of Agriculture, University of Zagreb, Croatia

ABSTRACT

Kohlrabi and kale are mesophilic vegetable species with low temperature requirements. They can be grown in simple greenhouses, such as low or high tunnels, or with direct covering of plants. They can be grown in a range of growing periods under different climatic conditions, and therefore offer the potential for year-round market supply. This chapter presents the environmental requirements, principles of greenhouse production and plant care measures for these minor species according to GAP recommendations.

INTRODUCTION

Brassicas have an important place in the human diet thanks to their chemical composition. They are a rich source of glucosinolates – sulphur-containing compounds that impart a pungent aroma and spicy or bitter taste. The breakdown of glucosinolates by plant enzymes results in the formation of biologically active compounds important for human health.

Cole crops have moderate heat requirements. They start to germinate at 3–5 °C, while the optimum temperature for growth and development is 13–15 °C. They are usually grown as spring, autumn or winter crops. Some species can overwinter outdoors, while others need protection during the winter period in the form of a low or high tunnel, or by direct covering of crops.

There are no specific data for greenhouse production of kohlrabi and kale (FAOSTAT, 2013). The variations that exist between SEE countries in terms of open-field production (climatic conditions) show that there is scope for improvement, if greenhouse technologies are adopted. Greenhouse production can positively affect achieved yield and quality, and consequently also producers' profit.

KOHLRABI

Kohlrabi is grown for its thickened stem and young leaves in early spring or autumn. Different cultivars of kohlrabi are available; F1 hybrids are characterized by vigorous growth, high uniformity of technological maturity and high yield. The production cycle from planting to the start of harvest is 40–75 days, and the weight of the thickened stem varies from 70 g in early to 300 g in late cultivars (Lešić *et al*., 2004).

Environmental requirements

The minimum temperature for germination is 3–5 °C, and the optimum temperature is 18–20 °C. For the growth and formation of proper thickened stems, optimum temperatures are 14–20 °C during the day and 8–12 °C at night. The optimum range of relative humidity is 50–70%. The soil temperature at planting should be > 8 °C. The light green or purple stem assumes a spherical or flattened oval shape at technological maturity. Stem thickening begins after the development of 4–7 leaves. Temperatures > 20 °C promote intensive leaf growth (Lešić *et al*., 2004).

Soil requirements

For early spring production, light soils that quickly warm up are suitable. For autumn production, medium–heavy soils with high water capacity are preferable. The optimum pH range is 6.0–7.5. With acid soils, incorporate lime into the soil from the previous crop (Lešić *et al*., 2004).

Principles of kohlrabi production in greenhouses

Cultivation schedule

For late autumn (November) consumption of kohlrabi, the recommended sowing time is late August; for December, sow in late September; and for early spring consumption, sow between the end of December and the beginning of January (Đurovka *et al*., 2006). The growing cycle from planting to harvest is 35–45 days for planting in September/October; 40–50 days for planting in March/April; 60–70 days for planting in January/February; and 65–75 days for planting in November/December.

Seedling preparation

Seedlings for early spring production are produced in heated greenhouses at a temperature of 14–16 °C. Seeds are sown in polystyrene trays, and ≤ 600 seedlings m^{-2} can be produced in 4–5 weeks. Seedlings with 3–5 leaves are planted at the same depth or slightly deeper than they were in the tray.

Planting

When kohlrabi is grown on bare soil, early cultivars – picked as soon as their thickened stems reach the desired size – are planted at a spacing of 25 × 25 cm or 30 × 25 cm, with 13–16 plants m^{-2}. In autumn cultivation, medium–late and late cultivars are planted at a density of 8–12 plants m^{-2}, with spacing of 40 × 30 cm or 30 × 30 cm (Lešić *et al*., 2004). When the greenhouse soil is mulched, it is recommended to plant in 4-row strips with spacing as follows: 20–30 cm between rows, 20–25 cm within rows and 60 cm between strips. Black polyethylene (PE) foil mulch allows the surface layer of the soil to warm faster in spring and results in better growing conditions after planting. Excessively high soil temperatures during the summer–autumn growing cycle can be avoided by using white PE foil mulch that reflects solar radiation (Plate 1).


BENKO

Plate 1
Growing kohlrabi in an unheated greenhouse on different mulches and bare soil

Irrigation and fertilization

Install a drip irrigation system on the soil surface under the mulch foil. For good growth of kohlrabi, uniform irrigation is important. Maintain soil moisture at > 65% of field water capacity by irrigating every 3–4 days with 10–15 mm of water. Dry conditions and high temperatures cause numb conductive bundles to form in the tissue of the thickened stem, making kohlrabi no longer usable.

Kohlrabi has a relatively short growing period through to technological maturity; it is, therefore, important that the necessary nutrients be provided in an easily accessible form. Generally recommended doses per ha are 145–225 kg N, 80 kg P_2O_5 and 180 kg K_2O. The full doses of phosphorus and potassium are applied before planting, while the nitrogen is split into two applications, one before planting and another before stem thickening (Lešić *et al*., 2004). Kohlrabi is usually grown following another crop fertilized with organic fertilizer.

Physiological disorders, pests and diseases

Spring or autumn crops grown in tunnels or under direct covering may have disease problems as a result of high relative humidity or air temperature. On the other hand, direct covering protects plants from most pests. Healthy plants grown in a clean environment are less susceptible to pest outbreaks and are thus less likely to require chemical treatments. Any chemicals used must be strictly labelled for greenhouse use; read and follow the directions for use. Table 1 lists the main kohlrabi disorders, pests and diseases.

Harvesting and post-harvest handling

Kohlrabi is mostly harvested by hand, by cutting with a sharp knife just below the thickened stem. At the same time, all old and damaged leaves are cut off. For

TABLE 1
Identification and control of the most common kohlrabi disorders, pests and diseases

Symptoms	Reasons	Prevention and control measures
Young seedlings wilting and dying	Damping off	Use treated seed Control moisture of substrate in container pots
Cracking	Non-optimal soil moisture	Maintain soil moisture at 65% of field water capacity
Numb conductive bundles	High temperatures and low soil moisture	Shade greenhouse Apply appropriate irrigation
Internal cracking	B deficiency	Reduce soil pH Add compost or organic fertilizer for previous crop
Leaf edges curled Leaves dried Tiny insects covered with waxy coating on leaf undersides	Aphids	Install direct covering Maintain hygiene Destroy infected plants Spray with insecticide
Leaves with many round holes, connecting until entire leaf chewed (strong attack)	Cabbage flea	Install direct covering Spray with insecticide
Leaves turning yellow (chlorotic) from margins inwards Veins within area turning black Infection in main stem turning inside black Plants dying or dwarfed (when young), becoming defoliated (when mature)	Bacterial or soft rot	Grow resistant varieties Rotate crops

spring kohlrabi, there are usually multiple harvests, and only those plants with the required stem thickness are harvested. Hybrid cultivars are more uniform and one or two harvests are sufficient. Greenhouse-grown kohlrabi can reach yields of 2.5–4.5 kg m^{-2}.

Kohlrabi should be stored at temperatures of 0–2 °C and relative humidity of 90–98% (Ilić *et al.*, 2007). Kohlrabi with leaves can be stored for a short period of 2–3 weeks at 0–1 °C and 97% relative humidity (Lešić *et al.*, 2004).

KALE

Kale is grown for its leaves, which are harvested from the base of the plant to the top during winter and early spring (Plate 2). Of all the brassicas, it best survives extreme climatic conditions: high temperatures and drought in summer, low temperatures and snow in winter. It grows in different soil types, but optimal soil gives higher and safer yields. Fertilization with cattle manure has positive effects, but it is even better to grow kale after crops that were abundantly fertilized with cattle manure (e.g. early potato). Other good previous crops are pea and bean.

Environmental requirements

Optimum temperature for seed germination is 20 °C, at which kale emerges after 5–6 days. Temperatures > 30 °C during germination have a negative effect on seedling development. Therefore, during summer it is recommended to do seed germination in climate chambers, where optimum temperature and humidity

Plate 2
Kale plant

can be achieved. Optimum air temperature for growth and development is 15–20 °C, but kale can tolerate summer temperatures > 30 °C. Kale growth stops at 0 °C, but the plant does not die; indeed, kale tolerates temperatures as low as –10 °C and – for short periods (a few days) – as low as –15 °C (Lešić *et al.*, 2004).

Soil requirements

Kale prefers well-drained, fertile soil, rich in organic matter, with pH 6.0–7.2. It is tolerant to slightly alkaline soils (Lešić *et al.*, 2004). When pH is < 6, the soil needs liming. Kale also has fairly good tolerance to soil salinity (Rubatzky and Yamaguchi, 1997).

Principles of kale production in greenhouses

Planting and cultural practices

Kale seedlings are grown in polystyrene trays. Seedlings are grown in February or early March, or earlier in heated greenhouses; they are transplanted when they have 3–4 well-developed leaves. The second most common sowing time is in July with transplanting in late August. Kale seedlings are planted with 60 cm between rows and 40 cm between plants within rows, which gives 40 000 plants ha^{-1} (Lešić *et al.*, 2004).

Cultivar selection

For many cultivars, the stem is usually relatively short, although the stem height of some cultivars can be > 1 m. Short-stem cultivars are easier to cultivate and less likely to lodge, especially when overwintered. Most vegetable kales have an abundance of large upright heavily curled leaves (Rubatzky and Yamaguchi, 1997). Leaves of different cultivars differ in shape, colour and size (Lešić *et al.*, 2004). For cultivar selection, consult the national list of registered varieties; for the EU, refer to the Plant Variety Catalogue. Alternatively, consult the FAO Hortivar database.[1]

Irrigation and fertilization

For normal development, plants require a uniform supply of water throughout the period of vegetation. The optimum soil moisture is about 80% of maximum field capacity. In the absence of water, leaves develop an undesirable waxy coating and the quality and flavour of the leaves decline (Lešić *et al.*, 2004).

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[1] Available at www.fao.org/hortivar.

It is recommended to plant kale after a crop fertilized with organic fertilizers. To achieve a yield of 20 tonnes ha^{-1}, apply 120 kg N, 80 kg P_2O_5 and 180 kg K_2O per hectare. Part of the nitrogen is applied during supplementary fertilizations (Lešić *et al*., 2004).[2] The most important causes of physiological disorders are boron deficiency and calcium deficiency.

Physiological disorders, pests and diseases

Table 2 lists the main kale disorders, pests and diseases.[3]

TABLE 2

Identification and control of the most common kale disorders, pests and diseases

Symptoms	Reasons	Prevention and control measures
Cracked and corky stems, petioles and midribs	B deficiency	Reduce soil pH Add compost or organic fertilizer to previous crop
Underside of internal leaf petioles or midribs turning dark grey or black at or near point where midrib attaches to core	K and P imbalance	Maintain optimal environmental conditions Apply adequate fertilization Use resistant cultivars
Tipburn – collapse of tissue and death of cells	Ca deficiency	Maintain optimal environmental conditions Apply adequate fertilization Plant resistant cultivars
Leaf edges curled Leaves dried Stunted growth Tiny insects covered with waxy coating on undersides of leaves	Aphids	Install direct covering Maintain hygiene standards Destroy infected plants Spray with insecticide
Singular or closely grouped circular–irregular holes in foliage Skeletonized leaves due to heavy feeding by young larvae	Beet armyworm	Implement biological control: - use natural enemies to parasitize larvae - apply *Bacillus thuringiensis* Spray with insecticide
Leaves with numerous round holes, connecting (strong attack) until whole leaf is chewed	Cabbage flea	Install direct covering Spray with insecticide
Young seedlings wilting and dying	Damping off	Use treated seed Allow soil to dry out between irrigations
V-shaped brown lesions originating from edge of leaves Blackening of leaf stems Stems dropping from plant Brown spots on leaves	Black rot (leaf spot) – *Xanthomonas campestris*	Adopt good sanitation practices Adopt crop rotation Use resistant varieties Control cruciferous weed Plant pathogen-free seed
Small dark spots on leaves turning brown–grey Lesions round or angular with purple–black margin Dark brown elongated lesions on stems and petioles	Alternaria leaf spot (black spot, grey spot) – *Alternaria brassicae*	Plant only pathogen-free seeds Rotate crops Apply appropriate fungicides Control disease when present

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[2] See Part II, Chapter 2.

[3] See Part II, Chapter 5.

Harvesting and post-harvest handling

Kale is harvested for its leaves. There is no precise maturity stage, although leaf size is an important criterion. It is ready for harvest 50–90 days from seed emergence – more if overwintered. Plants can be harvested over a long period by removing the outer leaves and allowing young leaves to grow for subsequent harvests. However, sequential harvesting is labour-intensive, and single harvests of the entire rosette of leaves are also done by hand or machine. Harvested plants and foliage are handled in bulk for processing, or tied into bundles for the fresh market (Rubatzky and Yamaguchi, 1997).

Entire rosettes have improved sustainability and a longer shelf-life. Kale is stored at 0 °C and high relative humidity (95–98%) for ≤ 4 weeks (Lešić *et al.*, 2004). Rubatzky and Yamaguchi (1997) reported that kale is not usually stored for more than 1–2 weeks. It should be free from ethylene during storage to avoid premature senescence and tissue injury. To retain freshness it may be packaged with ice.

GAP recommendations – Kohlrabi and kale production

- Adjust nutrient supply based on soil analysis and crop requirements to prevent the accumulation, fixation, vaporization or leaching of nutrients.
- Produce kohlrabi and kale from seedlings grown in polystyrene trays. Seedlings for winter–spring production should be grown in a heated greenhouse; for summer–autumn production in a well-ventilated and shaded greenhouse, given their low temperature requirements.
- Use black PE-mulch foil to ensure optimal soil temperature during early production.
- Use white PE-mulch foil during summer–autumn production to avoid high soil temperatures.
- Position the drip irrigation system under the mulch foil for uniform supply of water throughout the growing period to prevent the creation of conductive bundles in thickened stems of kohlrabi or expressive waxy coating and reduced flavour of kale leaves.
- Apply plant protection techniques according to integrated pest management principles and recommendations. IPM combines a number of measures and processes to reduce the use of pesticides.

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9. Early potato

Ž.M. Ilin,[a] B.Đ. Adamović,[a] S.Z. Ilin[b] and D. Žnidarčič[c]

[a] Department for Field and Vegetable Crops, Faculty of Agriculture, University of Novi Sad, Serbia
[b] Institute of Field and Vegetable Crops, Novi Sad, Serbia
[c] Department of Agronomy, Biotechnical Faculty, University of Ljubljana, Slovenia

ABSTRACT

The harvest area of potatoes in South East Europe is about 580 000 ha with a production of about 11 000 000 tonnes. It is estimated that 20–25% of all harvested area is used for early potatoes. Early potato is of high biological and nutritional value, and is suitable for growing on small family-run commercial farms. In the continental area of South and South East Europe, new potato matures for harvest in late May, June and early July. In recent years, early potato has reached the market 20–25 days earlier thanks to the adoption of specific cultivation practices and growing technologies, as well as an increase in financial input per unit area. As the first spring vegetable, early potato is considered a supreme biological and economic crop. The first precondition for high, stable and quality production of early potato is the choice of very early-maturing cultivars with high yield potential, good adaptability and stability. The second precondition is the planting of equally sprouted and certified seedlings with mulching and crop covering with agrotextiles. In the continental area of South and South East Europe, apart from early potato farming in temporary protected areas – for example, direct crop covering with or without mulching and in low plastic tunnels – early potato is also grown in large plastic tunnels without additional heating. Early potato is planted in mid-February in the Mediterranean area. This is 30 days earlier than in the continental area, and when covered with agrotextiles it can be harvested even earlier. This chapter presents some biological and agrotechnological aspects, such as biological needs, fertilization, irrigation, harvesting and storage of early potatoes.

INTRODUCTION

The potato crop area in South East Europe (SEE) is about 580 000 ha with a production of about 11 000 000 tonnes (FAOSTAT, 2013). An estimated 20–25% of all potato-growing areas are intended for early potatoes. In addition to conventional production, early potato is grown in temporary and permanent protected areas.

Early potato is of high biological and nutritional value, and is suitable for growing on small-scale family-run greenhouse farms. When cultivation adheres to good agricultural practice (GAP) guidelines, the crop is of agronomical, agrotechnical, biological, environmental and especially economic importance.

ENVIRONMENTAL REQUIREMENTS

Potato is a widely distributed crop owing to its extreme adaptability and stability; it can be grown on various soils and in a range of climates (Ilin *et al*., 2000b). Several authors report that early potato has moderate temperature requirements. Above-ground plant parts can sustain low temperatures of between –1 and –1.5 °C for short periods. Late spring frosts (≤ –2 °C for long periods) damage delicate foliage, and represent a hindrance to cropping in continental SEE (Plate 1). On the other hand, temperatures in Mediterranean climate regions rarely fall below 0 °C, and temporary protected areas (agrotextile covering) provide adequate protection. When large tubers are planted, stems and foliage sometimes rebound from secondary buds; early potato then reaches the market with a delay of 15–25 days, coinciding with early potatoes conventionally grown without pre-sprouting. The increased supply causes prices to fall, reducing profitability per unit area.

The minimum soil temperature for successful potato sprouting and emergence is 7–10 °C; however, the optimum temperature is much higher at 14–16 °C or even 18–25 °C (Table 1). Under optimal soil moisture conditions, early potato sprouts emerge at the following soil temperatures:

- 7–10 °C, in 30–35 days
- 10–12 °C, in 25–27 days
- 14–16 °C, in 18–22 days
- 18–25 °C in 12–13 days
- 27–28 °C in 16–17 days

Plate 1
Negative effect of low temperatures when early potato starts to emerge

When pre-sprouted tubers are planted, emergence is 6–10 days earlier under the same environmental conditions. The root system forms at soil temperatures > 7 °C. Potato must root as early and as firmly as possible, as young, well-rooted plants are more tolerant to drought, nutrient uptake is better and above-ground growth more intense. Above-ground plant parts and tubers form at 15–20 °C. Optimum temperature for intensive tuber bulking is 16–19 °C. Soil temperatures > 20 °C slow tuber bulking, 29–30 °C abruptly decrease yields and tuber growth stops, while > 42 °C plants die (Table 1).

TABLE 1
Effect of temperature on growth and development of early potato (°C)

Critical minimum air temperature	Minimum soil temperature for germination and emergence	Optimum soil temperature for germination and emergence	Optimum air temperature for vegetative growth	Optimum soil temperature for tuber formation	Growth and development stop	Growing period ends
–2	7–10	14–16 (18–25)	15–20	16–19	29–30	> 42

Early potato also has moderate requirements regarding air relative humidity; optimum air humidity is 75–80% (Ilin *et al*., 2002). Early potato prefers warm, light to medium-heavy soils, deep and fertile with favourable physical and chemical properties. Early potato cultivation is not recommended on moist, poorly-drained, cold and heavy clay soils.

SOIL REQUIREMENTS

Early potatoes grow on most soils, but when harvesting is done mechanically, harvesting under adverse weather conditions is easier in lighter and medium-bodied soils. Potatoes grow on both organic and mineral soils. The minimum pH requirement is 5.5, and a pH of < 4.8 leads to impaired growth. Alkaline conditions can have a negative impact on skin quality and highly alkaline conditions can induce micronutrient deficiencies. For mineral soils, the general recommendation is a pH of 6.0–7.0.

METHODS OF EARLY POTATO PRODUCTION IN GREENHOUSES

Early potatoes are produced in the open field using standard technologies. The time of removal of early potatoes depends on the earliness of the particular variety and whether or not the planting material was sprouted before planting. A relatively new technology is early potato production in protected areas – temporary (Plate 2) and permanent (Plate 3):


ILIN

Plate 2
Temporary protected area


BUGARČIĆ

Plate 3
Permanent protected area

- **Temporary protection** – plants are uncovered immediately before extracting the young potatoes. Techniques include agrotextile coverings with or without soil black film mulching, and low and semi-high plastic tunnels from which the plastic film is removed before harvesting the young tubers.
- **Permanent protection** – the crop is grown in high plastic tunnel greenhouses of dimensions: height 3.6–4.2 m, length ≤ 8 m, width 5–6 m.

EARLY POTATO PRODUCTION TECHNOLOGIES

Quality of seed potatoes

Physiologically young seed potato gives a smaller number of sprouts than physiologically mature, resulting in fewer initiated tubers. Additionally, appearance of a single sprout on the top of the tuber during germination is another reliable indicator that the seed is physiologically young. This is called apical dominance, and removal of the apical bud stimulates sprouting from other dormant eyes, which will significantly increase the number of stems, stolons and tubers per seed potato. Physiologically old, or senile, seed potato is of low potential biological value and should not be used for further reproduction. If for any reason farmers decide to do so without pre-sprouting the tubers, they will also keep unwanted hair sprout tubers. Some tubers may even become knobby. Planting physiologically old seed potatoes, results in slow emergence and growth of the stems and foliage. Such plants develop poorly and this ultimately results in a serious drop in yield (Plate 4). Therefore, only physiologically mature certified virus-free seed potatoes should be planted.

Pre-sprouting seed potatoes

In early potato farming, the tubers are allowed to sprout before they are planted. It is important that the sprouts do not grow too fast and long, which would make them susceptible to breakage during handling. Therefore, they are left in well-ventilated areas exposed to diffuse light, temperatures of 12–15 °C and relative humidity of 85–90%. Pre-sprouting speeds up physiological and biochemical processes within the tuber and increases the quantity of nutrients around the buds. Sprouts will then quickly start to grow, first from the main bud

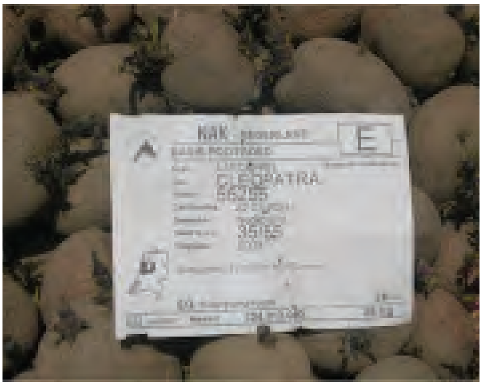
ILIN

ILIN

ILIN

Plate 4

Physiologically young seed with evident apical dominance (left); hair sprout tubers of low potential biological value (centre); physiologically old seed with knobby tubers of very low biological potential value (right) and subsequently from several lateral buds, extracting nutrients from the parent tuber's reserve. The planted potato lives on its own for a while; water and nutrient uptake from the soil solution commences once the plant has rooted.



ILIN

Plate 5
Physiologically mature and certified seed tubers with quality germination

For early potato production in plastic tunnels, pre-sprouting takes place in November and December, and under direct covering (agrotextile) in December or January. The practice takes 30–60 days (30–35 days for very early and early cultivars, 35–40 days for medium-early cultivars, ≤ 60 days for medium-late cultivars). Sprouting seed potatoes should be checked 2–3 times, and damaged or diseased tubers discarded, especially those with weak, elongated and hairy sprouts. The optimum temperature is 18–20 °C over a period of 7–10 days for all buds on a tuber to break dormancy. Quality sprouted tubers have short (0.5–1.5–2.0 cm), stout, tough, green or purple sprouts (Plate 5). Pre-sprouted potatoes emerge 10–15 days earlier and plants grow stronger and mature 2–4 weeks before non-sprouted ones (Ilin *et al*., 2002).

Crop rotation

Early potato is the first crop in rotation and should be fertilized with manure. Previous crops include any legumes, spinach and winter lettuce. Thanks to the early harvest, cover crops grow successfully in the same season with a very low investment input. Soon after harvest, the soil is tilled for the cover crop (e.g. cabbage, cauliflower, kale, Brussels sprouts, kohlrabi, beet, cucumber, gherkin, green beans and sweetcorn). Potato is a good preceding crop for all vegetables – with the exception of tomato and eggplant. Note that it should not be planted on the same spot for at least 4 years.

Soil preparation

Seedbed preparation starts at the end of the previous season when harvest residues are removed by disking or shallow ploughing. Primary tillage is performed to a depth of 30–35 cm in the autumn, and then pre-plant tillage is done in the early spring as soon as the soil moisture conditions are appropriate.

Planting early potatoes

It is recommended to use only healthy and certified seed potatoes. Small tubers saved from the previous season should not be used due to potential virus threats (causing ≤ 60% yield loss) and the likelihood of environmental and age-induced degeneration. High-quality seed potatoes grow tough and stout sprouts, sprouting and emergence both occur quickly, and both above-ground plant growth and tuber development are intense. Early cultivars initiate tubers 10–15 days after the emergence of sprouts from the soil. When early potatoes are cultivated with mulching and direct agrotextile covering, the crop is ready for harvest 55–60 days after planting; in plastic tunnels, harvest takes place around 50 days after planting.

The size of the early potato seed bed depends on the earliness of the particular cultivar. Very early and early cultivars are usually planted at 60–70 × 23–25 cm, and medium early at 60–70 × 27–30 cm with a planting depth of 6–10 cm. The quantity of seed potatoes to be planted depends on the tuber size. Generally, tubers for planting are 50–60–70 g in weight and 28–55 mm in diameter (more often 35–55 mm). A crop area of 1 ha is planted with 2 400–3 000 kg of seed potatoes. On smaller areas, planting is done manually. In temporary protected areas, 4-row semi-automatic planters are used; in plastic tunnels > 3.6 m high and 8 m wide, 2-row planters are usually used.

Mulching foil

Mulching is an old cultivation practice used to prevent weed growth, retain soil moisture, increase soil temperature, and promote microbiological activity and mineralization of organic matter in soil. When mulching foil is applied, early potatoes can be harvested ≤ 10 days earlier. When using mulch foil in the early potato emergence stage, note: first, that all stems must emerge from the soil and foil and, second, that frost has a greater impact on soil covered with mulch foil. It is, therefore, important to combine mulching with direct crop covering using agrotextile. Before harvesting, the mulch foil is removed manually or mechanically and recycled.

Agrotextile coverings

Agrotextiles are an important tool in early potato farming. Polypropylene synthetic materials made from continuous poly propionic fibres are appropriate. There are a range of materials available on the market with various trade names but the same basic properties. Agrotextile provides favourable microclimatic conditions for crops, allowing the transmission of light, air and water. It is very lightweight (17–60 g m^{-2}) and highly elastic, easy to handle and apply. The pressure exerted on the plants is virtually the same as that applied by a dew drop (10–17 g m^{-2}). Adoption of agrotextile brings many **benefits**:

- Minimal temperature fluctuations – soil and plants are heated under the fabric during the day, while at night they cool gradually.
- Uniform water distribution to plants and soil – drops of water from irrigation or rainfall permeate the micro-openings in the fabric.
- No crust formation – the soil dries gradually.
- Avoidance of condensation – there is continuous evaporation through the micro-openings and when the temperature drops, the water in the openings

forms a thin layer of ice, releasing energy and preventing the plant organ damage typical of cold weather.

- Good protection from heat – the white material reflects direct sunlight.
- Protection from adverse effects of wind and hail (Plate 6).
- Physical barrier against harmful insects and diseases.

When handled and used with care, agrotextile can be used for 2–3 years. It is UV-stabilized, easily recycled and comes in various widths (1.2–12.75 m) and lengths (100–500 m).[1]

Plate 6
Protecting early potatoes from hail

Irrigation requirements

Potatoes favour cold and humid weather. During the initial stages of growth and development, immediately after emergence and in the rooting phase, potato has low water requirements. As stems and foliage grow, water requirements increase, peaking during flowering and tuber bulking.

The lower limit of optimum soil moisture for successful early potato farming is 70–80% of field water capacity. Early potato loses 260–280 mm of water through evapotranspiration during the growing season – i.e. the exact quantity of water needed for successful early potato farming. In a dry spring, there is usually a rainfall deficit (40–60 mm); in an extremely dry spring, the deficit can reach as much as 120–160 mm. This lack of rainfall should be compensated for by 1–4 watering treatments (Plate 7). Timely irrigation increases early potato yield by 30% on average (Ilin *et al.*, 2000b, 2002; Maksimović and Ilin, 2012).

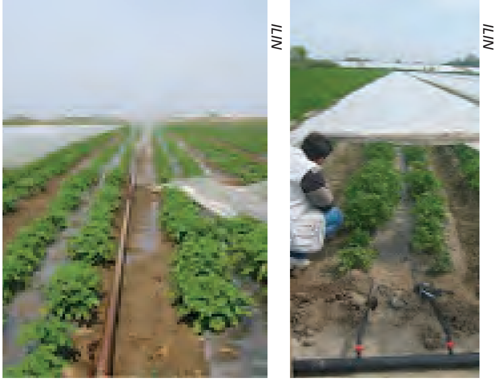


Plate 7
Sprinkler irrigation of early potato (left)
Fertigation of early potato in temporary protected area with agrotextile cover (right)

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[1] See Part II, Chapter 1.

Fertilization

Fertilizer application depends on various factors, including:

- specified nutrient content – primarily nitrogen using the N-min method;
- crop nutrient removal rates per unit of yield (tuber, stem and leaf);
- planned or desired yield; and
- N quantity released through mineralization during crop growth.

There is high positive correlation between early potato yield and irrigation on the one hand, and mineral N from mineral and organic fertilizers on the other hand (Ilin *et al*., 2002). Fertilization has a significant effect on both yield and quality. Under no-irrigation conditions, a 10-tonne yield of early potato tubers removes 30.2 kg N, 4.7 kg P and 31.4 kg K on average. Under irrigation, a 10-tonne yield removes 28.7 kg N, 4.7 kg P and 30 kg K. Optimum results are achieved when early potato is fertilized with 40 tonnes ha^{-1} manure + $N_{80}P_{80}K_{80}$ (Ilin *et al*., 2002). Similar recommendations for early potato were published in France: $N_{120–150}P_{100–150}K_{200–250}$ (Wichmann, 1992). These recommendations for nutrients, especially nitrogen, comply with the EU Directive (Council Directive 91/676/EEC of 12 December 1991, Article 5, 4).

The whole amount of organic fertilizer, plus one-quarter to one-third nitrogen, and two-thirds P_2O_5 and K_2O, are applied during basic tillage. The remaining quantities are mixed into the soil before planting. In a **temporary protected area**, the whole amount of organic fertilizer, plus one-third to one-half NPK fertilizer, are applied during basic tillage, and the rest in 3–4 treatments via fertigation at 15-day intervals (Plate 7). In a t**unnel-type protected area**, organic fertilizers are applied during basic tillage (4 kg manure m^{-2}), and the whole amount of NPK fertilizer is applied through fertigation in five equal treatments at 10-day intervals.

PHYSIOLOGICAL DISORDERS, PESTS AND DISEASES

At physiological maturity, potatoes register numerous causal agents: *Phytophthora infestans*, *Alternaria solani*, *Rhizoctonia solani*, *Verticillium dahlia*, *Sclerotinia sclerotiorum*, *Pithium species*, *Helminthosporium solani*, *Spongospora subterranean* subsp. *subterranean*, *Colletotrichum coccodes*, *Streptomyces scabies*, *Erwinia carotovora* subsp. *carotovora*, *Erwinia carotovora* subsp. *atroseptica*, *Clavibacter michiganensis* subsp. *sepedonicus*, *Phytoplasma*. There is widespread occurrence of numerous pests: *Leptinotarsa decemlineata*, *Myzus persicae*, *Macrosiphum euphorbiae*, *Circulifer tenellus*, *Tetranichus urticae.*

Given the early yield of young potato, physiological disorders in the tubers are generally avoided, although there can be sporadic occurrence of macro and micro element deficits in light, sandy soils or when there is inadequate fertilization with organic and mineral fertilizers. Most viruses are the result of degeneration due to successive years of farmers using their own, virus-infected, planting material.

TABLE 2

Identification and control of the most common early potato disorders, deficiencies and diseases

Symptoms	Reasons	Prevention and control measures
Tuber physiological disorders		
Sprouts developed from apical buds on young tuber due to high temperatures and temperature fluctuations	Heat sprouting/ young tuber chaining	Avoid environmental stress Adopt proper planting, hilling, fertility and irrigation practices to encourage uniform vine and tuber growth
Formation of knobs when secondary growth occurs at lateral eyes on young tuber due to loss of apical dominance	Knobby tubers	Avoid major fluctuations in nitrogen availability Maintain available soil water content > 70%
Growth cracks caused by irregularities in young tuber growth in response to fluctuating water supply	Tuber cracking	Maintain uniform, adequate soil moisture and nutrient levels throughout tuber bulking
Nutritional balance		
Plant stunted and older Lower leaves light green	N deficiency	Apply optimal fertilization
Formation of lush vegetative mass Plants sensitive to disease Small numbers of fine young tubers formed Pollution of environment	N excess	Apply optimal fertilization
Plants remaining in growth phase Maturation process delayed Stem, leaf veins and petioles turning purple	P deficiency	Apply appropriate fertilization
Plants intoxicated Pollution of environment	P excess	Apply optimal fertilization
Burning and drying of leaf edges	K deficiency	Apply appropriate fertilization
Chlorosis between leaf veins	Mg deficiency	Apply appropriate fertilization
Diseases		
Mild mosaic with poorly expressed enrollment or deformity of leaves (depending on strain of virus and susceptibility of variety)	Potato virus X (PVX)	Plant certified seed
Extremely mild mosaic Expressed necrosis of leaves (depending on strain and variety)	Potato viruses Y and A (PVY, PVA)	Plant certified seed
Potato leaf roll/tuber necrosis Twisting of upper youngest leaves Leaves erect, brightly coloured, base or margin (depending on variety) indigo or reddish Most prominent symptoms in plants with secondary, chronic infection	Potato leaf roll virus (PLRV)	Plant certified seed
Twisting of leaves, leaf margin chlorosis (symptoms of primary infection and most common) Mosaic, deformation and bright colour of leaves Necrosis of petiole leaves and stems, even stunting of plants (depending on variety)	Potato virus M (PVM)	Plant certified seed
No or very mild symptoms Light mosaic during growing season, withdrawing and becoming masked Leaves slightly lighter and no change in general appearance of plants	Potato virus S (PVS)	Plant certified seed

Early potatoes can be infected by many different viruses, resulting in low yield and reduced tuber quality. Viruses that have the greatest impact on young potato production include the luteoviruses (PLRV), potyviruses (PVA, PVV, PVY), potexviruses (PVX) and carlaviruses (PVM, PVS). A diagnosis is often possible from the symptoms, which include mosaic patterns on leaves, stunting of the plant, and leaf or tuber malformations. However, symptoms are not always visible, due to interactions between the virus and the potato plant, growing conditions (e.g. fertilization, climate conditions) or the age of the plant when it is infected.

In addition to the most harmful and widespread diseases, PVY and PLRV, there is incidence of other potato viruses in Serbia and SEE: potato virus X (PVX), potato virus S (PVS), potato virus M (PVM), potato virus A (PVA) and potato aucuba mosaic virus (PAMV). In addition, tomato spotted wilt virus (TSWV) is a potential threat to potato production in Serbia and SEE (Krstić, 2014, 2015).


BUGARČIĆ

Plate 8
Removing the plastic foil from plastic low tunnel-type and sprinkle irrigation of crops before early potato harvest


GAVRILOVIĆ

Plate 9
Early potato grown in high plastic tunnel

EARLY POTATO HARVEST

Early potatoes are obtained from early varieties or are harvested at the beginning of the season in the country of origin. "Early potatoes" have the following characteristics (UNECE STANDARD FFV- 52, 2009):

- harvested before complete maturity;
- marketed immediately after harvest; and
- skin easily removed without peeling.

In the SEE region, early potato is harvested and marketed from late March to early July. In Mediterranean climate areas, harvest begins in late March or early April. In continental areas, early potato is cultivated in tunnels (Plates 8 and 9) and can be harvested from 20 April; if grown in temporary protected areas, harvest is 5–15 May. Conventionally farmed early potato without pre-sprouting is harvested around 10 June. The yield of early potato depends on the cultivation practices, cropping system and harvest date, but is usually 10–15 tonnes ha^{-1}, with each plant yielding 200–300 g (Ilin *et al*., 2002). Prior to harvest, the agrotextile is removed, above-ground plant parts discarded, and the mulch foil lifted either manually or mechanically. After harvest, early potato tubers are gathered, washed, packed and marketed (Plate 10).

Plate 10
Early potato sold at green market

STORAGE

The tubers are harvested with a soft, thin and immature skin that rubs off easily. Care must be taken during harvest, washing, packing and distribution to green markets and stores, because young tubers are susceptible to damage. Early potatoes have relatively high water content and a significantly lower dry matter content than physiologically mature potato tubers. The respiration rate of immature tubers at harvest is about four to five times greater than that of mature tubers. To minimize losses due to respiration, early potatoes are usually stored briefly in refrigerator cars without controlled atmosphere. They can also be stored for short periods on family farms before transportation or in cold storage areas of mini- and mega-market stores prior to display and selling. The ideal short-term storage temperature is 4 °C. Inappropriate storage conditions lead to rapid deterioration of quality (within a few days).

Early potatoes are SAFE for consumption – NO PESTICIDES are used.

Early potatoes ensure CONTINUITY in the supply to consumers until potatoes from conventional production in open fields are harvested.

GAP recommendations – Early potato production

Permanent protection – the most expensive, but the safest system for early production – high plastic tunnel without additional heating and cooling.

Temporary protection – mostly uniform large young tubers, but moderate yields – mulched soil with or without agrotextile cover.

- Use quality, certified, virus-free planting material.
- Check seed potatoes for sprouting and remove damaged or diseased tubers, especially those with weak, elongated and hairy sprouts (usually infected by viruses).
- Maintain ideal conditions for germination:
  - first 7–10 days 18 °C, thereafter 12–15 °C;
  - diffuse light;
  - relative humidity 85–90%.

- Apply organic fertilizers manufactured and managed on farms. Alternatively, use industrially-manufactured pelleted or granulated bio-organic fertilizers. For optimum yield, apply a rate of 40 tonnes ha^{-1} manure + $N_{80}P_{80}K_{80}$ at appropriate intervals:
- In temporary protected area – the whole amount of organic fertilizer and one-third to one-half of NPK fertilizer during basic tillage, the rest in 3–4 treatments through fertigation at 15-day intervals.
- In tunnel-type protected area – organic fertilizers during basic tillage and the whole amount of NPK fertilizer through fertigation in five equal treatments at 10-day intervals.
- Apply optimum planting distances:
  - very early and early cultivars – 60–70 × 23–25 cm
  - medium-early cultivars – 60–70 × 27–30 cm

- Plant at optimum depth of 6–10 cm.
- Maintain optimum soil moisture of 70–80% of field water capacity.
- Harvest early potatoes before they are completely mature and market immediately.
- Store at an ideal temperature of 4 °C to avoid quality deterioration within a few days.

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10. Strawberry

P. Lieten[a] and N. Gallace[b]

[a] *Fragaria Holland, the Netherlands*
[b] *Proefcentrum Fruitteelt, Belgium*

ABSTRACT

Strawberry production in South East Europe is dominated by open-field production, with tunnel production accounting for < 1% of the total cultivated area. Protected cultivation offers a wide range of benefits to farmers, although investment costs can be high. This chapter explores the advantages and also the potemntial disadvantages of protected strawberry production.

INTRODUCTION

Strawberry production in South East Europe (SEE) is still dominated by open-field production, harvested from mid-May to early July. In 2014, under tunnel production was still limited, accounting for < 1% of the total cultivated area (Table 1), and with tunnels located primarily in Macedonia, Slovenia and Romania. In contrast, the last 20 years have seen much of Western Europe progress from open-field to some form of protected cultivation. In the near future, the same evolution is expected to take place in Eastern Europe.

Protected cultivation systems allow strawberries to be produced outside the main cropping season, avoiding the traditional peaks in June. Moreover, protection of the crop from wind, rain and hail improves yield and fruit quality, reduces dependence on chemical intervention and improves integrated pest control. The extension of the production period enables continuity of supply, resulting in a longer sales period and increased profitability. Domestic strawberries fetch premium prices early and late in the season compared with imports. Finally, out-of-season production allows growers to spread labour requirements more evenly over a longer period.

On the other hand, production under tunnels requires higher investment and growers need more skills and technical knowledge. A range of physiological issues typically arise in tunnels, such as fruit malformation, fruit splitting, tip burn, lack of colouring, insufficient chilling and sunburn; these problems are often attributed to irrigation or to climatic factors, such as temperature, humidity and solar irradiance.

TABLE 1

Overview of strawberry production in SEE countries (2014)

Country	Area (ha)	Tunnel (%)	Field (%)	Main varieties
Belarus	6 200	0	100	Vicoda, Vimazanta, Kimberly, Honeoye, Senga
Bosnia and Herzegovina	1 200	0	100	Clery, Arosa, Maya, Marmolada, Miss, Elsanta
Bulgaria	600	10	90	Selva, Elsanta, Maya, Darselect, Clery, Alba, Cesena, Camino Real
Czech Republic	450	< 1	99	Honeoye, Darselect, Rumba, Korona, Polka, Malwina, Florence
Hungary	450	< 1	99	Clery, Asia, Alba, Joly, Marmolada, Honeoye
Kosovo	250	10	90	Elsanta, Alba, Maya, Roxana, Asia, Honeoye, Albion
The former Yugoslav Republic of Macedonia	800	40	60	Elsanta, Alba, Maya, Roxana, Marmolada, Senga
Moldova	250	10	90	Gorella, Senga, Charlotte, Elsanta, Marmolada, Polka, Selva, Cireine
Motenegro	350	0	100	Clery, Antea, Arosa, Joly, Rumba, Madeleine, Honeoye
Romania	2 000	27	73	Selva, Elsanta, Maya, Darselect, Clery, Alba, Cesena, Camino Real
Serbia	7 000	< 1	99	Clery, Joly, Arosa, Antea, Rumba, Honeoye, Maya, Elsanta, Senga
Slovakia	600	< 1	99	Honeoye, Darselect, Rumba, Korona, Polka, Malwina, Florence
Slovenia	1 10	75	25	Clery, Asia, Arosa, Joly, Capri
Ukraine	1 600	4	96	Clery, Arosa, Alba, Asia, Roxana, Sonata, Elsanta, Florence, Albion

ENVIRONMENTAL REQUIREMENTS

Temperature

Strawberries prefer a moderate climate with temperatures of 8–25 °C, as strawberry plants turn dormant at < 5 °C. Root development requires a minimum temperature of 8 °C, while good vegetative growth can be achieved with daytime temperatures of 14–16 °C.

During **flowering**, a minimum temperature of 10 °C at night and 18 °C during the day must be maintained to achieve good fruit-set, ensure good pollen quality and stimulate the activity of the pollinating insects. Night temperatures of < 6 °C during flowering cause pollen germination to be reduced, resulting in increased incidence of misshapen and split fruits. Daytime temperatures of 20–24 °C allow maximum CO_2 uptake (photosynthesis) and growth, while temperatures of > 26–28 °C may cause the stomata to shut down resulting in reduced photosynthesis. High night temperatures hinder fruit flavour development and firmness, while too low night temperatures can cause irregular coloration, white shoulders, green tips or fruit cracking. During harvesting, night and daytime temperatures should be 8 and 18 °C, respectively. Ventilation is necessary as soon as tunnel temperatures rise to > 22 °C during the day and > 10 °C at night.

Under conditions of high solar radiation and temperature, strawberries become over-ripe and are prone to sunburn. In the event of high radiation (≥ 800 Joules cm^{-2}) and high temperatures (> 26 °C), shading can help maintain fruit size and fruit firmness. Shading can be achieved by applying a chalk-based coating on the polyethylene film or by covering the tunnels with a shade net placed outside the plastic cover.

Humidity

In plastic tunnels, in cases of **high humidity** and insufficient ventilation, strawberry plants typically become very vigorous. However, under high humidity conditions, flowers become wet and pollen is not released or it is sticky, inhibiting insect pollination. Fruits grown under high humidity conditons are more susceptible to post-harvest fungal contamination (*Botrytis cinerea* and *Rhizopus* spp.).

Low humidity leads to reduced leaf development and reduces fruit size and yield. On the other hand, in **low humidity** conditions, fruit-set and fruit quality improve, with firm berries characterized by a longer shelf-life and improved colour. However, low humidity increases susceptibility to spider mite and mildew, which results in soft fruits with a short shelf-life.

Recommended relative humidity depends on the growth stage:

- Vegetative development: 70–75%
- Flowering and harvest: 65% (for good fruit-set and fruit quality)

SOIL PREPARATION

Strawberries prefer **well-drained** soils, free of nematodes and root pathogens (*Phytophthora fragariae*, *Phytophthora cactorum* and *Verticillium dahliae*). Good soil conditions can be achieved through **cover crops**, including:

- barley (*Hordeum vulgare*) and ryerass (*Lolium*);
- marigolds (*Tagetes patula*) and mustard (*Sinapis alba*) – where field fumigation is restricted, because when planted prior to strawberry production they keep nematode populations (*Pratylenchus penetrans*) under control; and
- Brassicacea – they have a positive effect against verticillium wilt.

Strawberries generally prefer soil that is slightly **acidic**, but the optimum pH depends on soil type since soils vary greatly in their chemical, physical and biological characteristics. Optimum pH is considered 5.5–6.2 on sand, 5.8–6.4 on sandy loam and 6–6.8 on loam. Soils with higher amounts of organic matter can tolerate a lower pH.

High salinity should be avoided as it can cause marginal necrosis and tip burn, reduced growth and lower yield.

Plate 1
Fruiting of the 'Rumba' variety in a tunnel

VARIETY SELECTION

Short-day cultivars – 'Clery', 'Darselect', 'Rumba', 'Joly' and 'Elsanta' – are the most important cultivars for early tunnel production. Note that early varieties, such as 'Flair', 'Rumba', 'Clery', 'Darselect' and 'Honeoye', are especially vulnerable to frost. The planting density adopted depends on the plant type and strawberry variety used. Hortivar – the FAO database on the performances of horticultural cultivars – can be used for easy retrieval and comparison of information.[1]

ESTABLISHMENT OF TUNNELS

Construction

Polyethylene plastic tunnels are widely adopted in strawberry production throughout the world. Growing strawberries under tunnels can advance the **spring** harvest by 2–3 weeks compared with crop outdoor cultivation, and extra heating with gas burners or tubes can advance the harvest by an additional 2 weeks. In areas with sufficient radiation, double-skinned tunnels can be used to accumulate additional heat and provide frost protection. Tunnels can also be used for **autumn** production or to protect everbearing varieties from rain and hail in the **summer** months.

The dimensions and construction of polyethylene tunnels vary according to the region. The framework is formed by shaped galvanised hoops located on screw pegs drilled into the soil every 2–3 m. The iron hoops are 30–40 mm in diameter with an average wall thickness of 2.5 mm. The hoops are covered with polyethylene, which is held in place by ropes secured at both ends of the screw pegs. Tunnels may be either single-span or multispan:

- **Single-span** structures are 5–6 m wide and have a ridge height of 2.75–3 m. The sides can be rolled up when the heat becomes excessive. Temporary tunnels are easily built and dismantled.
- **Multispan** structures are larger with greater air volume and they are sometimes equipped with automatic ventilation. The width is 6–8 m and the ridge height usually around 4 m. Multispan structures often become permanent tunnels in time and are subsequently used for growing strawberries in substrates.

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[1] Available at www.fao.org/hortivar/.

Plate 2
Placing the tunnel hoops over the field

Plate 3
Summer-planted frigoplants covered by hoops

Plastic films

Historically, clear polyvinylchloride (PVC) film was used for strawberry tunnel production. However, once polyethylene (PE) films were developed, they began to replace PVC because of the **advantages of PE**:

- Increased life span – as a result of higher elasticity.
- Better flexibility with reduced likelihood of rupture – as does not become so brittle over time.
- Increased diffused light and less transmisson of direct radiation, resulting in less risk of sunburn on leaves and fruits.

In addition, nowadays, most PE-films contain UV-stabilizers and anti-condensation additives. For early-season (spring) production, 6–12% ethylvinylacetate is usually added to the PE-films to increase heat retention, potentially advancing the harvest by an additional 5–10 days. These PE-films transmit around 85–90% of the infrared radiation and only 20% of the light in the tunnel is diffuse.

In summer and autumn production, on the other hand, tunnels are used as a rain cover. The plastic films, therefore, need to have other characteristics to avoid direct radiation, which causes sunburn and excessive heat. Plastic films without ethylvinylacetate and characterized by lower infrared light transmittability (45%) are used, resulting in 80–90% of the light in the tunnels being diffused and leading to lower plant and air temperatures.

It is important that all films used in the strawberry production transmit UV-B waves (290–315 nm) – important for the orientation of pollinators such as bees and bumblebees. On permanent structures, plastic films with a thickness of 180–200 µ are used; the life span is 4–5 years. On temporaty tunnels, film is 150 µ thick; the life span is just 1 or 2 seasons.

PLANTING

Planting system

While matted row planting systems are common outdoors, raised bed sytems are standard practice in tunnel production. Beds are usually placed at a height of 15–25 cm. **Polyethylene** (30–50 µ) is used as mulch to reduce weed growth and the use of herbicides. Black polyethylene heats up the soil and is the standard for early strawberry production, while white polyethylene is preferred for summer plantings targeted at summer and autumn crop production, because it keeps the soil cooler than when under black polyethylene. However, white polyethylene still transmits light, and weeds start growing under plastic mulch. Therefore coextruded white-on-black is used: white up and black down. White-on-black is more expensive, but it has advantages: no weeds grow underneath and it is less prone to tearing when the plastic is laid while making the beds.

Beds are usually spaced at 1.5 m with two plant rows per bed and 40 cm between plants. For single rows, the **bed spacing** is 1 m. Drip irrigation is laid under the plastic mulch in the middle of the bed. The number of beds under each tunnel depends on the width of the tunnels and the particular planting system (single- or double-row). For example 5-m "walk-in" tunnels can cover 3 double beds (6 rows), 2 double beds in the middle and 2 single beds on the sides, or 5 single beds.

Plant density

Planting density often needs to be adapted to the plant type and strawberry variety used. A plant density of 3.5–4 plants m^{-2} is average for most varieties. Freshly dug, bare-rooted plants are lifted from the nursery between mid-July and mid-August. Fresh leaf-on plants are planted on raised beds with double rows 40 cm apart. The spacing between plants in a line varies between 25 and 33 cm, depending on the variety.


LIETEN

Plate 4
Plants derunnered in the summer

Frigo plant types are lifted directly from the nursery in December and January. After digging, the runners and leaves of the runner plants are trimmed and the plants are graded into various size categories, depending on the diameter of the crown. A+ runner plants have a crown diameter of > 15 mm and have already differentiated 2–3 inforescences. Traditionally, A+ cold-stored plants are planted in May and June for programmed cropping. Plants are usually set in single rows with 25-cm spacing and the beds 1 m apart. The flower trusses are pinched out or harvested about 6 weeks after planting. The plants are overwintered for the main crop the following spring. In some areas, cold-stored A+ runner plants are established at high density (6–8 plants m^{-2}) in February–March under tunnels for early production with large fruits.

Fields are covered with temporary portable tunnels in January and February. In areas without risk of snow damage, tunnels can be raised in November. During the winter, plants are also covered with fleece or perforated plastic for frost protection and to advance the harvest period. This type of protection is normally taken off when the first flower buds emerge; however, during periods of night frost, covers are replaced to avoid damage. In periods of night frost, it is advised to postpone the laying of a straw cover between the raised beds, as this can reduce the emittance of long-wave soil radiation which helps protect flowers from night frost.

POLLINATION

Wind pollination and self-pollination are insufficient to maximize fruit-set. For optimal pollination, it is necessary to introduce bees (*Apis mellifica*) or bumble bees (*Bombus terrestris*) in the tunnels. Bumble bees are less sensitive to reduced light intensity and lower temperatures, and are quite active at temperatures > 5 °C. On the other hand, bees need higher temperatures and increased light intensity to become active. Therefore, it is recommended to introduce bumble bees at the beginning of flowering, when temperature and light levels are still low; one colony is sufficient for 3 000 m^{-2}. Bees can be introduced at a later stage, during flowering.

At the beginning and at the end of flowering, when there are not many flowers in bloom, only a small number of bumble bees or bees should be placed in the tunnels to prevent "over-pollination". Fruit malformation can occur if there are too many pollinators in proportion to the number of available flowers. The fruits develop asymmetrically with a characteristic groove. Over-pollinated flowers can be recognized as follows:

- Petals characterized by brown-coloured marks
- Anthers broken off
- Pistils damaged and brown-coloured

IRRIGATION AND NUTRITION

For good plant establishment and vegetative development, frequent overhead **irrigation** with a reliable sprinkler system is advisable during the initial growth period. For satisfactory growth and good fruit quality, irrigation water must have low electrical conductivity (EC) and be particularly low in iron and boron.

General **fertilizer** recommendations for strawberries are difficult to make because of varietal differences, cultural practices and regional climatic variations within South East Europe. In most countries, the need for fertilizer input is based on soil tests which take into account organic matter, tillage and pH, and especially the influence of soil fumigation on soil nutrient availability and cover crops prior to planting. Moreover, soil sampling and analysis systems differ from country to country, and there is variability in the general recommended input (kg ha^{-1}):

- N: 70–120
- P_2O_5: 25–40
- K_2O: 100–140
- MgO: 30–50

Soil analysis must be performed regularly to establish the availability of mineralized N in the soil; fertilizer can then be applied accordingly. About 30% of N is applied after planting in the summer and autumn. The other 70% is applied via drip irrigation at the beginning of spring when growth commences. A minimum level of 70–80 kg N_{min} ha^{-1} is required at planting and during growth in spring. In autumn, 30 kg N ha^{-1} is usually sufficient. In spring, loamy soils and soils with high organic matter still have a relatively high N content due to mineralization. Sandy soils need higher amounts of N (35–60 kg ha^{-1}) in autumn.


LIETEN

Plate 5
Drip irrigation under the plastic reduces leaching and provides strawberry plants with fertilizers

Water and nutrients are supplied mainly through drip irrigation. Concentrated stock solutions are made with soluble fertilizers; they are then either diluted in a mixing tank or injected directly into irrigation pipes.

The **pH** of the nutrient solution must be maintained in the range 5.2–5.6 with nitric acid or phosphoric acid. **EC** must be 0.8–1.2 mS cm^{-1} in the nutrient solution and 0.6–1.0 mS cm^{-1} in the soil, depending on soil type, variety and climatic conditions. Low EC in the root environment can cause decrease in skin firmness and reduced shelf-life; it can also induce fruit cracking.

Benefits of protected strawberry culture

- Reduced chemical input of fungicides, herbicides and insecticides.
- Less leaching of fertilizer out of the soil.
- Improved management of nutrition (based on soil analysis).
- Out-of-season harvest with higher prices fetched for growers.

PESTS AND DISEASES

Table 2 lists the main strawberry disorders, pests and diseases.

Tip burn

Strawberries grown in polyethylene tunnels are very susceptible to leaf and flower tip burn, resulting from a physiological disorder. Symptoms are necrosis and crinkling of the young unfolding leaves. Under severe conditions, sepals show marginal necrosis and the central part of the receptacle can turn black due to damage to the central pistils, resulting in typical cat-faced fruits. Tip burn occurs when there is a lack of calcium absorption and transportation to the growing tissue of new developing leaves and flowers.

Tip burn is caused primarily by environmental conditions; secondary factors are unbalanced fertilization, variety susceptibility (Clery, Asia, Alba) and plant type (frigo plants). On dry, compact and excessively fertilized soils, root growth is very often impeded; calcium uptake is reduced by excessive concentrations of competing cations, in particular Mg, K and NH_4. Emerging leaves under such conditions are more prone to tip burn.

Tip burn is a widespread problem in tunnels because of the large diurnal fluctuations in water potential and temperature. Calcium only moves in xylem and depends on the waterflow arising from root pressure at night. Tip burn usually appears under the following **environmental conditions**:

- increasing air temperature;
- increasing light intensity and photoperiod (during early summer and in controlled environments under artificial light);
- higher relative humidity; and
- fast cell growth (frigoplants).

Sudden changes in **climatic conditions** from overcast weather with high relative humidity to sunny conditions with a large vapour–pressure deficit often aggravate the symptoms of tip burn. To pre-empt these abrupt climatical changes, roots have to be sufficiently developed and active. Prevent tip burn in young leaves by increasing relative humidity during the dark period and maintaining a large vapour–pressure deficit in the atmosphere during the day. Continuous high relative humidity (due to insufficient ventilation), excessive misting and free water accumulation on the strawberry plants all reduce transpirational flow of calcium.

On cloudy days, stimulate transpiration by ventilation and minimize irrigation. On sunny days it is important to avoid large fluctuations in temperature and humidity. It is important to close vents and tunnels in the early evening to increase humidity at night and favour the buildup of root pressure.

TABLE 2

Identification and control of the most common strawberry disorders, pests and diseases

Symptoms	Reasons	Prevention and control measures
Pale green to yellow leaves, especially in older leaves New leaves remaining green but small	N deficiency	Apply adequate fertilization
Marginal necrosis of oldest leaves Tip burn Small berries	High salinity Cl, Na, S, B	Use good-quality water with low salinity Irrigate frequently Apply adequate calcium
Youngest leaves cup downwards, edges scorched Death of growing points Tip burn Cat-faced fruit	Ca deficiency	Control climate and growing conditions Apply adequate Ca fertilization Avoid excessive application of fertilizers Use water of good quality: low salinity, low K, NH_4, B
Pale green to yellow chlorosis with green veins on the newest leaves	Fe deficiency	Reduce soil or nutrient solution pH Use Fe formulation available in higher pH (e.g. iron chelates) Improve soil drainage and aeration
Mottled chlorosis of middle leaves	Mn deficiency	Reduce soil or nutrient solution pH Use Mn formulation available in higher pH (e.g. chelates) Improve soil drainage and aeration
Flower and fruit abortion Malformed fruits	Fruit overload Low light intensity Extreme high and low temperatures High relative humidity fluctuations	Control climate conditions
Wilting of plants	*Phytophthora cactorum* *Phytophthora fragariae* *Pestalotiopsis*	Adopt crop rotation Use resistant cultivars Use soilless culture Avoid wet lands and over-irrigation Use preventive fungicides
Stunting of plant growth	Nematodes (*Meloidogyne* spp.) *Verticillium dahliae*	Rotate with Brassicacea Use resistant cultivars Use soilless culture Implement soil disinfestation (e.g. steaming)
White superficial powdery spots on leaves and fruits	Powdery mildew caused by *Sphaerotheca macularis*	Use resistant cultivars Avoid fluctuation of humidity and drought Implement preventive use of fungicides
Fruit rot	*Botrytis* *Gnomonia* *Mucor* *Rhizopus*	Avoid overhead irrigation Use drip irrigation Improve air circulation Reduce air humidity Use resistant cultivars Apply preventive fungicides from early bloom onwards
Misshaped bronzed fruits	Thrips	Use preventive predators (*Amblyseius, Orius*, *Hypoaspis*) Monitor and control with yellow sticky tape Adopt weed control
Stippled, distorted and light-coloured leaves	Spotted mite (*Tetranychus*)	Apply *Phytoseiulus persimilis* Use insecticides
Stunted plant growth Crinkling of leaves Bronzing of green fruit and flowers	Strawberry mite (*Tarsonemus*)	Maintain standards of hygiene Remove infected plants Apply *Amblyseius cucumeris*

HARVESTING AND POST-HARVEST HANDLING

Strawberries should be picked when orange–red, depending on the market requirements. Frequent harvests (2–3 times per week) are required. The duration of the harvest period varies depending on the cultivar: early varieties are harvested in 4–5 weeks, while late varieties are higher yielding and the harvest can last 6–7 weeks.

Immediately after harvest, fruits should be placed in the shade or preferably refrigerated. Under optimum storage conditions – temperature 3–4 °C, relative humidity > 95% – strawberries can be stored for 3–5 days.

GAP recommendations – Strawberry production

- Perform regular soil analysis – in order to adjust nutrient supply according to crop requirements and prevent the accumulation, fixation and leaching of nutrients.
- Choose root-disease-tolerant cultivars.
- Apply black PE-mulch foil – in order to ensure clean fruits, supress weed growth and reduce leaching of nutrients.
- Install a drip irrigation system under the mulch foil – to be used for irrigation and fertigation.
- Introduce bees in the tunnel – in order to optimize pollination.
- Monitor and adjust relative huimidity and temperature in tunnels – in order to prevent occurrence of tip burn.
- Apply integrated pest management (IPM) principles and recommendations – in order to optimize plant protection and reduce the use of pesticides.

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