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Conservation Agriculture

Training guide for extension agents and farmers in Eastern Europe and Central Asia

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Contents

Figures

Tables

Boxes

Foreword

Agriculture in Eastern Europe and Central Asia is diverse, and has great potential to revitalize the economy of the countries in the region via improved productivity (efficiency) and higher total yield for food, fodder and fibre crops. Conservation Agriculture can rise to the major challenge of making sustainable intensification of production systems a reality.

In order for farmers to transition to appropriate sustainable production systems, the provision of an adequate enabling environment and access to knowledge and services, including extension, mechanization, inputs and market intelligence, are crucial.

Farmer Field Schools are the best place for exchanging experience and knowledge about Conservation Agriculture, building the technical and scientific capacity of national partners, and thus moving towards widespread adoption and uptake of sustainable and viable agricultural practices.

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Abbreviations and acronyms

ACIAR	Australian Centre for International Agricultural Research
CIMMYT	International Maize and Wheat Improvement Center
ENPARD	European Neighbourhood Programme for Agriculture and Rural Development
FAO	Food and Agriculture Organization of the United Nations
GHS	Globally Harmonized System of Classification and Labelling of Chemicals
HHP	Highly hazardous pesticide
IPM	Integrated pest management
NGO	Non-governmental Organization
PMP	Pest Management Plan
SARE	Sustainable Agriculture Research and Education
SOC	Soil organic carbon
SOM	Soil organic matter
VSA	Visual Soil Assessment

How to use this Guide

This Guide is designed to provide coherent technical tools to Farmer Field Schools and extension service facilitators of Conservation Agriculture. Furthermore, the Guide is suitable for use within universities' agriculture curricula.

As a living document, the Guide will be updated regularly, particularly in response to practical experience.

The Guide walks the user through a range of topics necessary for learning sessions with farmer groups. However, this is not a conventional guide or "cookbook". There is no standard formula or "recipe" to be applied in a given context, no list of "ingredients".

Instead, this Guide provides technical guidelines for the sustainable implementation of Conservation Agriculture and, very importantly, offers specific advice for adapting local "ingredients" to the local "taste".

Moreover, it is important to note that this Guide is not intended as a facilitation tool, and the topics are addressed from a purely technical perspective. However, it is written in such a way that anyone will be able to understand it, although certain technical terms are included for the benefit of readers from an agronomic background; explanations of such terms are provided in the Glossary at the end of the Guide.

The Guide is adapted for an eight-module training course for facilitators and trainers.

Facilitators who receive this training will be qualified to run subsequent training courses for other trainee facilitators once they have also implemented Conservation Agriculture systems at field level for a minimum of one season.

1

Introduction

Chapter 1

1. Introduction

In the Eastern Europe and Central Asia region, the low-input cropping systems dominated by cereal monoculture and intensive tillage have a marked negative impact on pressure from diseases, weeds and pests resulting in decreased profit margins. The agricultural model based on mechanical soil tillage, exposed soils and continued monocropping is typically accompanied by negative effects on agriculture's natural resource base to such an extent that future agricultural productive potential is jeopardized. This form of agriculture is considered to act as a major driver of biodiversity loss and to speed up the loss of soil by increasing the mineralization of organic matter[i] and erosion rates.

A large share of the potentially available land in the region is either not particularly suitable for agriculture or locked up in other valuable uses that are important for the healthy functioning of ecosystems (including forests, grasslands, protected areas, human settlements and infrastructure). The vast majority of crop production therefore increasingly depends on raising production per unit area of farmed land.

There is an urgent need to empower farmers to be active protagonists in improving agricultural production systems that harness the benefits provided by ecosystem services, and to build regenerative agro-ecosystems *(Figure 1).*

The vision of the Food and Agriculture Organization of the United Nations (FAO) involves natural resource use and management interventions that deliver multifunctional agricultural

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Figure 1. Farmers participating in a field day demonstration, Tajikistan

landscapes, where communities are supported by the multiple ecosystem services and associated benefits provided by these landscapes.

Conservation Agriculture, a system avoiding or minimizing soil mechanical disturbance (no-till) combined with soil cover and crop diversification, is considered a sustainable agro-ecological approach to resource-conserving agricultural production. While Conservation Agriculture farming systems capable of improving productivity have been developed in the region, the change to a different system and to new ways of doing business carries a perceived and sometimes real risk of failure for farmers. For this reason, the Guide identifies two necessary components for the establishment of effective Conservation Agriculture systems: first, **building of multidisciplinary scientific and technical capacity;** second and most important, close **collaboration with farming communities** – rather than only with farmers – to capitalize on their existing and traditional knowledge.

Agriculture, including Conservation Agriculture, is not a single or uniform technology that can be immediately applied anywhere in a standard manner. Rather, it represents a set of linked principles that encourage the formulation of locally adapted practices, approaches and methods.

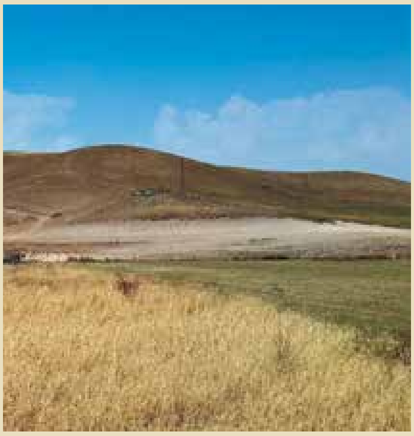
Farmer Field Schools are flexible and have a wide range of applications and are therefore the ideal context for testing, evaluating, validating and finally implementing Conservation Agriculture principles under local specific conditions. Farmer Field School facilitators and extension agents have the fundamental role of listening carefully to farmers; they value their experience and must always take into consideration their knowledge and priorities. They also need to learn how technologies that farmers themselves have selected can best be adapted to local needs and most effectively communicated and promoted.

This Guide aims to provide elements of capacity development to promote and assist in the identification and testing of effective Conservation Agriculture systems for adoption and dissemination through Farmer Field Schools or similar extension systems.

2

The need for change – sustainable production intensification

Chapter 2



2. The need for change – sustainable production intensification

Land degradation and soil fertility deterioration *(Figure 2)* are two of the main causes of agricultural production stagnation and decline in the region. Typically, the risks of soil degradation are underestimated because their symptoms, such as air and water pollution due to erosion, are measured off farm and remain unseen by farmers. In these circumstances, farmers are unlikely to be aware of the problem and take action.

Traditionally, bare soil is considered agreeable to the eye and a farmer with nicely ploughed fields is deemed a good farmer. Seedbed preparation involves several operations, including ploughing, disking and harrowing, aimed at killing emerging weeds prior to seeding the crop and creating a bed to plant seeds. However, from the standpoint of soil health and function, the combination of inversion tillage, failure to apply nutrients at sufficiently high levels to prevent "mining", and low levels of biomass restitution to the soil results in a progressive degradation of the natural soil structure (cohesiveness and aggregation) and fertility. Such degradation is the consequence of both mechanical damage to the soil (compaction and pulverization) and an associated decline in its organic matter content and biodiversity.

The continuous use of ploughs at the same depth and the passage of machinery result in the creation of compact subsurface layers (plough pan). This leads to a breakdown of soil aggregates and a reduction in the pore spaces within the soil that are vital for it to function as an effective medium for plant growth (for the development of plant root systems, oxygen availability and soil water movement). The rate of water infiltration and retention are drastically reduced with a simultaneous increase in surface run-off and loss of soil, nutrients, organic matter and seeds. Loss of organic matter also reduces the chemico-biological processes that

Figure 2. Example of slope erosion leading to gradual degradation of the soil

are important for providing the humic gums which contribute to the stability of soil aggregates and release nutrients for uptake by plants. The activity of soil biota is also negatively affected: most noticeably, earthworm populations with their inherent capacity to aerate the soil and incorporate organic matter to a greater depth are reduced. This in turn may lead to increased production costs and reduced profitability.

However, alternative options to soil tillage do exist.

The most cost-effective agro-ecosystem management strategy for preserving and improving agricultural sustainability involves conserving the soil on the field in the first place and investing in its fertility through agricultural practices that do not diminish the soil organic matter (SOM) and biological activity, as well as the soil itself, while achieving competitive crop yields and biomass *(Figure 3).*

Sustainable agronomic practices – like most stable natural ecosystems – are based on the permanent and total protection of the soil through species diversity and involve:

- maintaining a protective layer of vegetation on the soil surface;
- limiting mechanical disturbance to the purpose of placing seed or fertilizer; and
- adopting economically well-designed crop rotation to guarantee an increase in the quantities of organic matter on and in the soil, in order to provide surface protection and foster soil life, and thus maintain and improve soil structure, reduce rates of erosion and water evaporation, enhance soil moisture-holding capacity, and extend the availability of nutrients to crops.

Figure 3. Crop residues in a field under Conservation Agriculture: farmers need to get used to "untidy" fields, Republic of Moldova

Maintaining the soil in fit condition for the active life processes of the whole soil–plant–water nutrient system is a key factor in improving soils' biotic self-recuperation capacity, sustaining the land's productive capacity and enabling safe intensification of land use.

Challenges to sustainable intensification in Eastern Europe and Central Asia are summarized in *Box 1.* Soil health is addressed in *Section 2.1* and sustainable soil management in *Section 2.2.*

Box 1. Challenges to sustainable intensification in Eastern Europe and Central Asia

- **Land degradation** – a major economic, social and ecological problem. Mountainous and submountainous areas (typically rainfed) are the most vulnerable, but fertility decline can occur also on high quality land. The main underlying causes of the degradation and desertification of arable land include:
  - poor agronomic management related to tillage erosion (which in turn triggers water and wind erosion), soil compaction, overgrazing and nutrient mining; and
  - overall inefficiencies related to land fragmentation and/or abandonment of the land following the fall of the Soviet Union.
- **High cost of production inputs** (mineral fertilizers and herbicides) and widespread unavailability of diverse and improved seed material resulting in:
  - reduced crop productivity; and
  - perpetuating ignorance regarding both the benefits and the modalities of good crop/soil management practices.
- **Lack of machinery** – a widespread problem. The impossibility to serve all communities with the necessary capillarity and flexibility results in highly inefficient crop management and harvest losses.
- **Absence of irrigation.** Where irrigation is available, there is widespread adoption of inefficient irrigation practices.
- **Farmers' lack of knowledge of crop management practices** – a threat for agricultural development.
- **Underdeveloped public extension service.** There is a shortage of staff resources, facilities and funds.
- **Mindset of farmers** – difficult to change. Farmers are used to growing a small number of crop species and are reluctant to grow different crops or change the management practices they are familiar with.

2.1 Soil health related to sustainable agriculture

Soil health is the capacity of a specific kind of soil to function – within natural or managed ecosystems – sustain plant and animal productivity, contribute to the regulation of nutrient, water, carbon and gaseous cycles, and support human health and habitation.

The productivity of a soil depends on its physical, chemical, hydrological and biological properties, which are discussed in this section, and it is widely linked to soil biodiversity *(see Box 4 at page 16).* Soil organisms break down organic matter to use it as food; the process is mechanical (comminution) and chemical (mineralization) *(see Box 3 at page 14).* Any excess nutrients are released into the soil and used by plants; the recalcitrant (indigestible) fraction of the organic matter is reorganized as soil organic matter (SOM), which is less decomposable than the original plant and animal material *(Box 2 at page 13).* In turn, SOM content – especially the more stable humus – increases the capacity not only to store water but also to store (sequester) carbon from the atmosphere, thus increasing the soil organic content (SOC).

Why

It is widely acknowledged that soil degradation is harmful, but the extent of its harmfulness is often not recognized. The benefits of a healthy soil are easily unnoticed, but the costs of an unhealthy soil are manifest. On-farm soil erosion results in increased fertilizer use and reduced yields. Erosion removes the original topsoil from a field and furthers the degradation of organic matter. Consequently, during ploughing, the subsoil becomes mixed with the remaining topsoil with a negative impact, because in mature soils, the subsoil material is not as rich in organic matter and is less fertile.

Degraded soils are at much greater risk from the damaging impacts of climate change due to loss of SOM, reduced biodiversity, increased compaction and increased erosion. In addition, land degradation is itself a major cause of climate change.

Table 1 provides the basic soil principles for climate change adaptation and mitigation.

Table 1. Soil principles for climate change adaptation and mitigation and enhancement of resilience

Assessing the status of soils and its properties ➡	Improving soil water storage
	Controlling soil erosion
	Improving soil structure with organic matter
	Managing SOM for SOC sequestration
	Boosting nutrient management

What

A healthy soil has sufficient depth for plant roots to grow properly, contains lumps and clumps of different sizes, is not compacted, and does not seal after rain; it is alive, is neither too acid nor too alkaline, and is rich in organic matter. This section provides relevant soil health indicators.

Soil texture, structure and water-holding capacity

Water storage in the soil depends on many factors, including rainfall, soil depth, soil texture (clay content) and soil structure. Soil texture is the relative share of the different sizes of mineral particles (sand, silt and clay) which influences its water-holding capacity and ability to retain and exchange nutrients. Soil structure is the arrangement of those particles into aggregates. Unlike texture, soil structure can be modified by agronomic management.

Different soil types and textures offer different degrees of water permeability and protection of the SOM. Within the soil matrix, stable forms of SOC, such as humus, can hold up to seven times their own weight in water. Therefore, a soil that has a crumbly structure that breaks easily into separate lumps and clumps will absorb water more quickly than one that is compacted. Sandy soils are the least productive as they are highly permeable due to their larger sand grains and pore spaces and hence have low water-holding capacity and offer limited protection to SOM compared with soils with a higher proportion of silts and clays that attract and retain water and nutrients through chemical attraction.

Soil management can influence water infiltration and the capacity of the soil to reduce soil water evaporation and store water in the profile:

- Sandy soils can be managed productively even in hot, dry climates by adding organic matter, and in irrigated systems by supplying nutrients through drip irrigation.
- Ground-cover management can have significant effects on soil surface condition, SOM content, soil structure, porosity, aeration and bulk density, and can thus influence infiltration rates, water storage potential and water availability to plants.
- Improving soil compaction increases the effectiveness of rainfall, enhancing productivity as well as reducing rates of erosion and dispersion of soil particles, and decreasing risks of waterlogging. Compacted soils or soils with a hardpan may waterlog easily and then dry out quickly.

Bulk density

Bulk density is a measure of the mass of particles in a volume of soil. If bulk density goes up, porosity goes down. It is favourable to have a low bulk density. Optimal bulk density (allowing water, air and roots to move through the soil) depends on soil texture. *Table 2* presents the ideal and problem bulk densities of different soils.

Table 2. Ideal soil bulk densities and root growth limiting bulk densities for soils of different textures

Soil texture	Bulk density (g/cm^3)		
	Ideal	May affect root growth	May restrict root growth
Sand – loamy sand	< 1,60	1,60-1,80	> 1,80
Sandy loam – silty clay loam	< 1,40	1,40-1,75	> 1,75
Sandy clay – clay	< 1,10	1,10-1,60	> 1,60

Higher bulk density does not always mean greater compaction. What is important for effective soil function are soil structure, porosity and aggregate stability, which influence infiltration rate, water and nutrient retention, percolation and drainage of water, soil aeration and load-bearing capacity. Repeated soil tillage can reduce bulk density but destroys soil functions. Conservation Agriculture can lead to an increase in soil density while improving soil processes related to soil health and agricultural productivity.

Soil depth

Deeper soils can hold more water than shallower soils (because they have more room for the water). A deep soil with a good structure can soak up water for a longer period.

A hardpan turns a deep soil into a shallow soil and must, therefore, be removed.

If the soil is shallow, soil must be brought from elsewhere and organic matter added *(see Section 6.1 on the use of cover crops).* In irrigated systems, raised beds increase the depth of the rooting zone.

Soil pH

pH is defined as the negative logarithm of the activity of hydrogen ions in a solution. Soil pH is a measure of the acidity or alkalinity of a soil solution (the mixture of water and nutrients in the soil). A soil pH level of < 7 is acidic, 7.0 is neutral and 7-9 is alkaline. A pH range of 6.8-7.2 is near neutral.

The pH of most agricultural soils is 4.58.5 *(Table 3)*. Areas of the world with limited rainfall typically have alkaline soils, while areas with higher rainfall typically have acid soils.

Soil pH influences soil nutrient availability (i.e. how easily nutrients dissolve and are available for uptake by plants) and biological activity *(see Box 3 at page 14):*

- Acidity reduces bacterial activity and therefore decomposition and nutrient release. Nitrogen-fixing Rhizobium bacteria generally do not do well in acid soils.
- Highly alkaline soils have suppressed biological activity; they are at risk of soil crusting, salinity and accumulation of toxic levels of sodium and other minerals.
- Earthworms prefer a near-neutral soil pH: at a pH < 5 and ≥ 7 their activity is strongly reduced.

Table 3. Soil pH range

<table>
<tr><th colspan="2">pH3</th><th colspan="2">pH4</th><th colspan="2">pH5</th><th colspan="2">pH6</th><th colspan="2">pH7</th><th colspan="2">pH8</th><th colspan="2">pH9</th><th colspan="2">pH10</th></tr>
<tr><td colspan="7">Acidity</td><td colspan="2" rowspan="2">Neutrality</td><td colspan="7">Alkalinity</td></tr>
<tr><td colspan="2">Very strong</td><td colspan="2">Strong</td><td colspan="2">Moderate</td><td>Slight</td><td>Slight</td><td colspan="2">Moderate</td><td colspan="2">Strong</td><td colspan="2">Very strong</td></tr>
<tr><td colspan="2">Peat soils</td><td colspan="6">Mineral soils in sub-humid and humid regions</td><td colspan="6">Mineral soils in semi-arid and arid regions</td><td colspan="2">Highly alkaline soils</td></tr>
</table>

Soil organic matter and soil organic carbon

The most indicative element for soil quality is soil organic matter (SOM). SOM is the organic fraction of the soil comprising dead plant and animal materials in various stages of decomposition; it does not include fresh and undecomposed plant materials lying on the soil surface. SOM primarily contains soil organic carbon (SOC), but also macro- and micronutrients essential for plant growth and some inorganic carbon.

SOC has an impact on the overall biological resilience of the agro-ecosystems and is important for soil physical properties (aggregation, water-holding capacity) and chemical fertility (nutrient availability), and is a sink for atmospheric carbon. SOC enhances soil structure by binding the soil particles together as stable aggregates, and improves soil physical properties, such as water-holding capacity, water infiltration and aeration, favourable for plant health and production. In other words, SOC gives soil its water-retention capacity, its structure and its fertility.

Part of the biomass returned to the soil through processes of decomposition is converted into carbon compounds with a long residence time (i.e. humus and related organomineral complexes). The fraction varies depending on the quantity and quality of the biomass and it is higher in ecosystems with high biodiversity. *Box 2* summarizes soil carbon pools.

Box 2. Soil carbon pools

Soils contain carbon in two forms:

- **Organic** (oxidized carbon) – soil organic carbon (SOC) is the carbon present in the soil organic matter (SOM) and constitutes on average 58 percent of SOM mass.
- **Inorganic** (non-oxidized carbon) – inorganic carbon is present as various minerals and salts from weathered bedrock.

The sum of the two forms of carbon is referred to as **total carbon.**

Soil organic matter (SOM) refers to the organic constituents in the soil: tissues from dead plants and animals, materials under 2 mm and soil organisms in various stages of decomposition. Undecomposed materials on the surface of the soil (such as litter, crop residues, shoot and root residues) are usually more than 2 mm; they are not considered to be part of the SOM and are referred to as organic matter. Compared with organic matter, SOM is generally richer in lignin and poorer in carbohydrates, oxygen and hydrogen, because the mineralization process frees oxygen and preferentially degrades polysaccharides, so that the concentration of recalcitrant, stable compounds increases.

Based on SOM size, state of decomposition, and chemical and physical properties, there are distinct **SOM pools:**

- **Labile pool** (also known as **active pool**) – least decomposed organic matter, that is less than 2 mm (the threshold for organic matter to be considered SOM) but more than 0.25 mm (the minimum dimension for aggregates to be considered macroaggregates). The labile pool comprises mainly young SOM (e.g. plant debris), only partially protected in macroaggregates (which are not stable by definition), and is therefore characterized by a rapid turnover and is sensitive to land and soil management and environmental conditions. Due to these characteristics, labile SOM pools play an important role in short-term carbon and nitrogen cycling in terrestrial ecosystems (in continual flux between microbial hosts and the atmosphere) and can be used as a sensitive indicator of short- and medium-term changes in soil carbon in response to management practices.

- **Particulate organic carbon** – physical portion of SOM that is less than 0.25 mm and more than 0.053 mm (250–53 µ). It is a labile, insoluble intermediate in the SOM continuum from fresh organic materials to humified SOC, ranging from recently added plant and animal debris to partially decomposed organic material.
- **Stable pool** (also known as **recalcitrant SOM**) – organic matter that has gone through the highest level of transformation, that is less than 0.053 mm (< 53 µ). The recalcitrant SOM is incorporated into aggregates, where its further decomposition is protected. It holds moisture and, thanks to its negative charges that retain cations for plant use, it acts as a recalcitrant binding agent, preventing nutrients and soil components being lost through leaching.

In most soils, young and unstable macroaggregates formed by biological processes offer physical protection to carbon and nitrogen, but need to be further stabilized to lead to long-term carbon accumulation. In the carbon stabilization process, first microaggregates are formed within the unstable macroaggregates. These macroaggregates are then broken down further with the liberation of the microaggregates. The processes for the stabilization of aggregates *(Box 3)* include some climate-dependent factors (such as wet-dry cycles), but mainly biologically dependent factors (such as ageing and growing roots that exert pressure, remove water and produce exudates that have a role both as cementing agents and as substrate for further microbial activity). Mechanical soil disturbance (i.e. ploughing) is particularly detrimental for the build-up of SOM, as it disrupts these important biological processes.

Box 3. Soil organic carbon stabilization process

Through photosynthesis, plants draw carbon out of the air (carbon dioxide) to form carbon compounds (carbohydrates). When dead plant and animal material (organic matter) is returned to the soil, it undergoes decomposition. Decomposition of organic matter is a biological process operated by soil organisms; it comprises a series of steps resulting in both mechanical breakdown (comminution) and chemical breakdown (mineralization), as well as biochemical reorganization of complex structures and molecules (polymers). Only the indigestible fraction of carbon (20% in carbohydrates and 75% in lignins, tannins, aromatic amino acids and waxes) enters into the formation of stable SOM **(humification).**

By transforming organic compounds into inorganic compounds, and breaking down carbon structures and rebuilding new ones or storing carbon into their own biomass, the microbial population acts as a functional engine for the turnover of organic matter and the release of nutrients to the soil, and it is responsible for the ability of a soil to provide crops with nutrients.

Essentially, the organic molecules that the microorganisms degrade are made of carbon chains, with varying amounts of attached nitrogen, oxygen, hydrogen, phosphorus and sulphur. The addition of crop residues/organic matter to the soil (i.e. food for microorganisms) stimulates the rapid expansion of soil microorganism populations. All the new microorganisms pursue the carbon content in the organic matter to use it as a source of energy (i.e. to oxidize it through a series of electron transfers in the respiration processes). However, in order to break down the crop residues/organic matter and consume the carbon, the microorganisms need some nitrogen. For example, to maintain their metabolic processes, bacteria need 1 atom of nitrogen (N) every 5 atoms of carbon (C) assimilated, while fungi need 1 atom of N every 10 atoms of C. On average, soil microorganisms have a C/N ratio of about 8/1 for maintenance. However, for optimum health, microorganisms require an additional 16 parts of C for energy (approximately). Therefore, to cover both energy and maintenance requirements, **the optimum diet of microorganisms should comprise crop residues with a C/N ratio of 24~25.**

- If the nitrogen content of the organic residues is too low, the microorganisms use the mineral nitrogen existing in the soil (nitrogen immobilization), thus reducing nitrogen availability to the growing crop throughout the period (weeks) of depletion of the carbon food supply.
- If the nitrogen content of the organic residues exceeds the demand of the microorganisms, inorganic nitrogen (i.e. mineral nitrogen, such as ammonium and nitrate) is released (nitrogen mineralization) and its availability for plant growth increases.

It should be noted that during the decomposition process, microorganisms mineralize and release different products into the soil (not just nitrogen) for further use by other heterotrophs and autotrophs. They include carbon dioxide, water, inorganic compounds (excess nutrients in forms that plants can use) and resynthesized organic compounds (SOM).

Successive decompositions of modified SOM (the waste material produced by microorganisms) result in the formation of increasingly complex SOM, which is less decomposable than the original plant and animal material. Specifically, the carbon stabilization process goes through the following phases:

1. Initial formation of unstable macroaggregates. Young and unstable macroaggregates are formed through biological processes: root growth and fungal, bacterial and faunal activity have a primary role in enmeshing fresh organic matter with exudates and soil particles. Young macroaggregates offer physical protection to carbon and nitrogen from microbial enzymes, but need to be further stabilized. The processes for the formation of water stable aggregates[ii] include[iii] ageing, wet-dry cycles (that cause closer rearrangements of soil particles) and root growth (the roots exert pressure, remove water and produce exudates that have a role both as cementing agents and as substrate for further microbial activity).
2. Subsequent stabilization and simultaneous formation of microaggregates within macroaggregates. During macroaggregate stabilization, partially decomposed intra-macroaggregate organic matter becomes encapsulated with minerals and microbial products forming microaggregates, which lead to long-term carbon stabilization by protection from mineralization.
3. Breakdown of macroaggregates with liberation of microaggregates. In this final stage of the aggregate transformation cycle, the macroaggregates tend to lose labile binding agents and break down to release minerals, highly recalcitrant SOM and microaggregates. In time, the microaggregates may be occluded again within new macroaggregates.

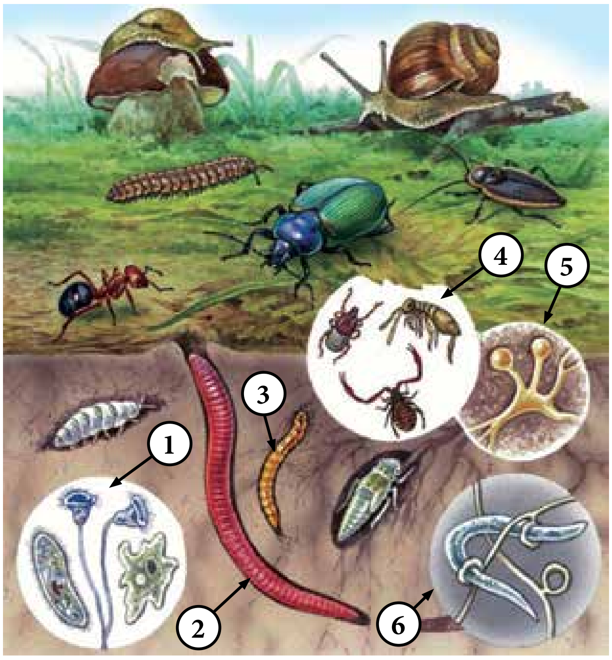
There is a strong linkage between organic matter (e.g. crop residues), superficial SOM accumulation and the consequent SOC vertical stratification, water infiltration, erosion resistance and conservation of water and nutrients. As a result, failure to leave sufficient *(see Box 7 at page 33)* crop residues on the soil (i.e. low organic matter inputs) inhibits SOC stabilization, and this cannot be compensated for by other factors or inputs. It is recommended to leave organic matter on top of the soil, not to mix the litter. Mixing organic residues into the soil promotes the rapid degradation of stable SOC and should be avoided.

Organic matter and soil life

Soil must be living to be productive. Soil is a complex habitat for diverse biota and predator–prey relationships. Soil organisms that spend all or part of their life cycle within the soil or on its immediate surface are responsible for a range of processes vital to the health and fertility of soils in both natural and agricultural ecosystems. *Box 4* provides a brief description of the role of the organisms commonly found in the soil *(Figure 4).*

Box 4. Soil organisms

- **Macrofauna** include vertebrates and invertebrates (e.g. snails, earthworms, soil arthropods) that feed in or on the soil, the surface litter and their components. Macrofauna species are visible to the naked eye. In both natural and agricultural systems, soil macrofauna are important regulators of decomposition, nutrient cycling and SOM dynamics. Their feeding and burrowing activities lead to the creation of pathways of water movement and as a result, leaf litter, fine mineral particles and other materials become buried in the form of castings, eventually migrating slowly to lower soil layers. In summary, soil macrofauna gradually deepen the topsoil layer.
- **Mesofauna** include mainly microarthropods, microflora, microfauna and other invertebrates. The feeding of mesofauna on organic materials accelerates their decomposition.
- **Microorganisms** include algae, bacteria, cyanobacteria, fungi, yeasts, myxomycetes and actinomycetes. Their populations are very sensitive to depth and are disrupted by mechanical soil disturbance. Most soil bacteria need a pH of 6-8 to perform at peak; fungi (slow decomposers) are still active at a very low pH. Microorganisms are able to decompose and transform organic matter into nutrients in forms that plants are able to exploit (mineralization). At the same time, microorganisms reorganize carbon structures into relatively stable forms (sequestration) that act like a sponge retaining water and nutrients for later plant uptake (see Box 3 at page 14).



Source: © Pasechnik (2014)

Figure 4. Soil organisms.
Note: 1 – protozoa; 2 – earthworms; 3 – wireworms; 4 – microarthropods; 5 – fungi; 6 – nematodes.

During the decomposition of SOM, the myriad of organisms in the soil food web release a range of nutrients necessary for plant growth. Many of these plant nutrients exist in the soil in the form of positively charged ions (i.e. cations). The negative charges on the surfaces of clay particles and SOM attract the cations, providing a nutrient reserve available to the plant roots; only a small percentage of the essential plant nutrients remains "loose" in the soil water and directly available for plant uptake. Plants obtain many of their nutrients from soil through cation exchange, whereby root hairs exchange hydrogen ions (H^+) with the cations adsorbed on the soil particles.Clay soils have a higher cation exchange capacity[iv] than silty soils and sandy soils, in addition to greater potential fertility.

How

The number of soil biota decreases rapidly and builds up slowly during the growing season.

Sustainable agricultural systems should preserve all complex biological networks and interactions among roots and the soil food web (fungi, other microflora, micro- and macrofauna in the soil). Tillage operations disturb the soil life and soil organisms are suddenly exposed to the sun, heat and drought. Consequently, tillage reduces soil biodiversity, and higher life forms are more affected than, for example, bacteria. Furthermore, ploughing (using either mouldboard or disc ploughs) at the same depth and the passage of agricultural machines are the primary causes of hardpans or compacted layers.

Conventional methods for obtaining soil physical measurements (e.g. bulk density) using disc permeameters and penetrometers are slow. A rapid farmer-level methodology to evaluate the morphological condition of soils in the field is the Visual Soil Assessment Methodology *(see Box 5 at page 18).*

Visual Soil Assessment (VSA) includes a critical set of measurements linked to land degradation worldwide; founded on strong science, it is simple yet effective. It is based on the visual assessment of key soil state and plant performance indicators of soil quality, presented on a scorecard.

With the exception of soil texture, the soil indicators are dynamic indicators, i.e. capable of changing under different management regimes and land-use pressures. Being sensitive to change, they are useful early warning indicators of changes in soil condition; as such, they provide an effective monitoring tool.

Corrective measures to improve soil health are discussed in *Section 3.1.*

2.2 Objectives of soil and land management for sustainable agriculture

Why

In general, protecting soil with a superficial layer of organic matter improves the capture and use of rainwater as a result of increased water absorption and infiltration and decreased evaporation from the soil surface.

Box 5. Visual Soil Assessment (VSA)

Indicators

Soil texture; soil structure; soil porosity; soil colour; number and colour of soil mottles; earthworms; potential rooting depth; surface ponding; surface crusting and surface cover; soil erosion; soil management of annual crops.

Visual scoring

Each indicator is given a visual score (VS) of 0 (poor), 1 (moderate) or 2 (good), based on the soil quality observed when comparing the soil sample with three photographs in the field guide manual. The scoring is flexible, so if the sample being assessed does not align clearly with one of the photographs but sits between two, an in-between score can be given (i.e. 0.5 or 1.5). Given that some soil indicators are relatively more important in the assessment of soil quality than others, VSA provides a weighting factor of 1, 2 and 3. The total of the VS rankings gives the overall Soil Quality Index score for the sample being evaluated. Comparing this with the rating scale at the bottom of the scorecard allows to determine whether the soil is in good, moderate or poor condition.

The VSA toolkit

The VSA toolkit comprises the following:

- Spade – to dig a soil pit for the drop shatter soil structure test.
- Plastic basin (about 45 cm long × 35 cm wide × 25 cm deep) – to contain the soil during the drop shatter test.
- Hard square board (about 26 mm × 26 mm × 2 mm) – to fit in the bottom of the plastic basin.
- Heavy-duty plastic bag (about 75 cm × 50 cm) – on which to spread the soil, after the drop shatter test.
- Knife (20 cm long) – to investigate the soil pit and potential rooting depth.
- Water bottle – to assess the field soil textural class.
- Tape measure – to measure the potential rooting depth.
- VSA field guide – to make the photographic comparisons.
- Pad of scorecards – to record the VS for each indicator.

When it should be carried out

The test should be carried out when the soils are moist and suitable for cultivation. If in doubt, apply the "worm test". Roll a worm of soil on the palm of one hand with the fingers of the other until it is 5 cm long and 4 cm thick. If the soil cracks before the worm is made, or if you cannot form a worm (e.g. if the soil is sandy), the soil is suitable for testing. If you can make the worm, the soil is too wet to test.

Reference sample

Take a small sample of soil (about 10 cm × 5 cm × 15 cm deep) from under a nearby fence or a similar protected area. This provides an undisturbed sample to assign the correct score for the soil colour and for comparing soil structure and porosity.

Sites

For a representative assessment of soil quality, sample four representative sites over a 5-ha area. Select sites that are representative of the field. Always record the position of the sites for future monitoring if required.Dig a small hole (about 20 cm × 20 cm × 30 cm deep) with a spade and observe the topsoil (and upper subsoil if present) in terms of its uniformity, including whether it is soft and friable or hard and firm. If the topsoil appears uniform, dig out a 20-cm cube with the spade. Any depth of soil may be sampled, but the sample must be the equivalent of a 20-cm cube of soil.

Source: FAO (2008). Visual Soil Assessment (VSA). Field Guides. http://www.fao.org/docrep/010/i0007e/i0007e00.htm

Drop shatter test

Drop the test sample a maximum of three times from a height of 1 m onto the wooden square in the plastic basin. The number of times the sample is dropped and the height it is dropped from is dependent on the texture of the soil and the degree to which the soil breaks up.

Systematically work through the scorecard, assigning a VS to each indicator by comparing it with the photographs (or table) and description reported in the field guide.

This leads to reduced run-off and soil erosion and higher soil moisture throughout the season compared with soils that are disturbed then left unprotected. These benefits are due to three separate processes:

- SOM plays a major role in absorbing water at low water potential.
- Soil protection through organic matter and the high presence of large water-stable soil aggregates enhances resistance against water and wind erosion.
- Water infiltration rate is a function of the initial water content and of soil porosity. Porosity can be influenced by the presence of channels created by roots, and by meso- and macrofauna.

At the same time, agro-ecosystems with high biodiversity (through enhanced complexity of the crop rotation) favour accumulation of carbon.

Roots have a crucial role in the soil ecosystem: they provide the substrate for energy to the biota of different soil strata and thus boost soil biodiversity (increase in number and type of soil biota). Inputs from (deep) rooting systems are ideal for taking carbon deep into the soil, where it is less susceptible to oxidation. Decomposition of old rooting systems adds organic matter at depth, while active roots produce exudates and – notably, in the case of legumes – favourable mycorrhizal[v] associations which promote a larger microbial population in the rhizosphere and facilitate the binding of aggregates. Root fungi, also known as mycorrhizal fungi, are important soil organisms for bolstering the soil cycles governing the give and take between plants and soil *(Figure 5).* Plants with mycorrhizal connections can accumulate up to 15 percent more carbon in the soil. The most common mycorrhizal fungi are marked by thread-like filaments, called hyphae, that extend the reach of a plant, increasing access to nutrients and water. Hyphae are coated with glomalin, a sticky substance that is instrumental in soil structure and carbon storage.

SOC accumulation is a reversible process: with even a single tillage event, sequestered soil carbon and years of soil restoration may be lost. On the contrary, when a soil is not tilled for many years, SOM mineralization in soil surface layers is reduced causing the active fractions of SOM to increase.

What

Constant soil- and water-related features in Eastern Europe and Central Asia include water scarcity (in irrigated systems), drought (in rainfed systems), and soil degradation. With

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Figure 5. Mycorrhizal fungi

regard to soil degradation, when erosion occurs, soil particles are lost, carrying organisms, pesticides and nutrients away with them. When soil is exposed to the impact of weather, it oxidizes and soil organic carbon (SOC) is lost through mineralization. Tillage is the major cause of loss of soil and SOC. In the absence of carbon and critical soil organisms, soil becomes mere dirt, which is an unsuitable medium for plant growth.

In addition, tillage customarily modifies the soil profile. Tillage mixes soil and crop residues in the surface, pulverizes aggregates, increases soil sealing and crusting at the very surface of the soil, compacts soil just below the tillage tool, and leads to a decline in soil organisms, such as earthworms (especially nightcrawler species that make deep burrows into the subsoil).

In order to support soil health, soil conservation measures are needed, ensuring that soil is fertile, and protected from erosion and evaporation. To achieve this, production systems must be non-extractive. Regenerative agricultural practices have the potential not only to boost soil productivity but also to increase resilience to floods and drought.

How

Regenerative techniques allow the soil to rebuild and grow rather than get lost through erosion and include the following:

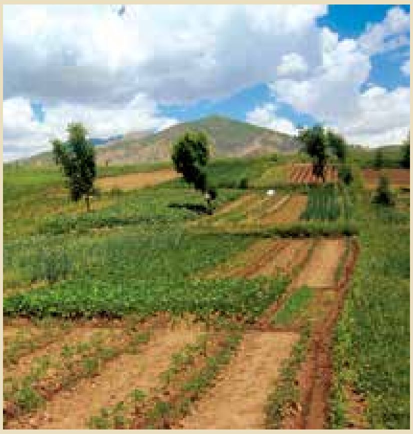
- Seeding fields year round in crops or desired living vegetation, or at least keeping fields covered by organic residues for as much of the year as possible.
- Minimizing mechanical soil disturbance continuously over time.

- Using intensive and diversified crop rotation in order to keep living roots and feed soil organisms responsible for the functional processes (e.g. decomposition and nutrient cycling).
- Keeping the soil uniformly covered (with evenly distributed residue) and shielded from heat, rainfall and wind impact.

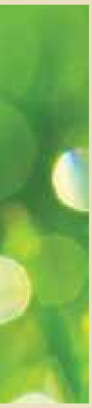
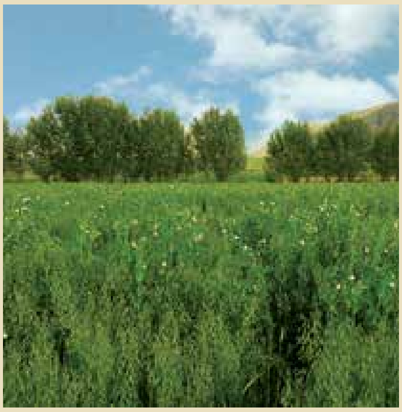

3

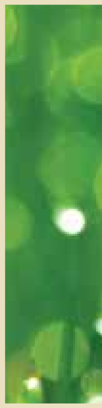
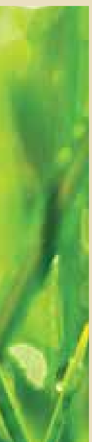
Conservation Agriculture – objectives, principles, practices

Chapter 3




3. Conservation Agriculture – objectives, principles, practices

Why

The three Conservation Agriculture pillars support a wide range of functions:

- **Prevention of soil degradation and erosion.** The rehabilitation of the land's agro-ecological productivity potential and soil-mediated ecosystem services establishes a virtuous cycle of soil and land development.
- **Production of abundant above- and below-ground biomass to protect the soil:**
  - The soil receives physical protection from the weather (impact of raindrops, force of the wind and heat from solar radiation), with a consequent reduction in soil and nutrient erosion (hence improved soil productivity), water evaporation, temperature fluctuations, and surface sealing and crusting.
  - Cover crops in a no-till system provide a food source and habitat for soil organisms.
  - Organic materials (e.g. bacterial waste products, organic gels, fungal hyphae, worm secretions and casts) have adhesion properties and therefore contribute to soil aggregate formation and stability, and improve soil trafficability. In contrast, when aggregates are disrupted, microorganisms (mostly bacteria and fungi) start consuming the youngest carbon pool, the major (i.e. temporary and transient) binding agents become lost and the soil is dispersed. Further, when macropores are disrupted, the remaining recalcitrant carbon bonds with soil cations, creating cohesion forces that lead to soil compaction.

- **Balancing of the C/N ratio during crop rotation.** The rotation between cereals (high in carbon) and legumes (high in nitrogen) means that the cropping pattern can provide sufficient nitrogen together with structural carbohydrates (e.g. lignin) to enable nitrogen from decaying surface residues to be released gradually and serve as a source for the subsequent crop *(see Box 8 at page 54).* In contrast, a high concentration of slowly decomposable crop residues alone causes temporary soil nitrogen immobilization, while only residues with a low carbon/nitrogen (C/N) ratio (e.g. legumes) improve nitrogen availability, but decompose too quickly to guarantee the necessary soil protection.
- **Maintenance of active "soil biological infrastructure".** Intensive crop rotations[viii] provide abundant, varied organic matter (i.e. nutrients, and hence substrate, rich in carbohydrates and nitrogen) to keep soil biota active, foster diversity of genera and species, and enhance their functional roles.
- **Control of weeds, pests and diseases.** The diversified rotation of complementary plants is an effective phytosanitary strategy.
- **Realization of economic sustainability.** Savings in energy (fuel, labour) and capital (wear and tear) translate into a reduction in production costs, with effect from the first year – in contrast with all other soil management practices, which usually have a delayed impact on farm revenues. Note that crop diversification is also recommended for economic stability and sustainability.
- **Preservation of soil nutrients.** The organic matter accumulation–mineralization cycle is the functional engine of Conservation Agriculture, as it helps to restore and maintain soil fertility and reduce soil erosion.

- **Soil moisture conservation.** A superficial layer of organic matter on the soil improves the capture and use of rainfall through increased water absorption and infiltration and decreased evaporation from the soil surface. In contrast, heavy raindrops break up soil aggregates on the surface, and fine particles clog up and seal the pores, thus preventing water from being absorbed.
- **Off-site functions.** The reduction of sediment load in surface waters is very important, especially in regions with steep slopes in combination with high rainfall intensity.

It should be noted that modification of the soil profile needs time to develop and, what is more, it can be rapidly damaged by just one tillage pass. Hence the **importance of long-term Conservation Agriculture.**

What

Conservation Agriculture is a resource-saving agricultural production system that aims to attain production intensification and competitive yields while enhancing the natural resources base. It achieves this through compliance with three linked principles implemented with locally formulated adapted practices together with other good production practices, including crop, nutrient, water and pest[vi] management practices *(Figure 6).* The three linked principles:

- Continuous minimum mechanical soil disturbance with direct seeding (i.e. no-till).
- Permanent soil organic cover with crop residues[vii] and/or cover crops to the extent allowed by water availability.
- Species diversification through varied crop rotations, sequences and associations.

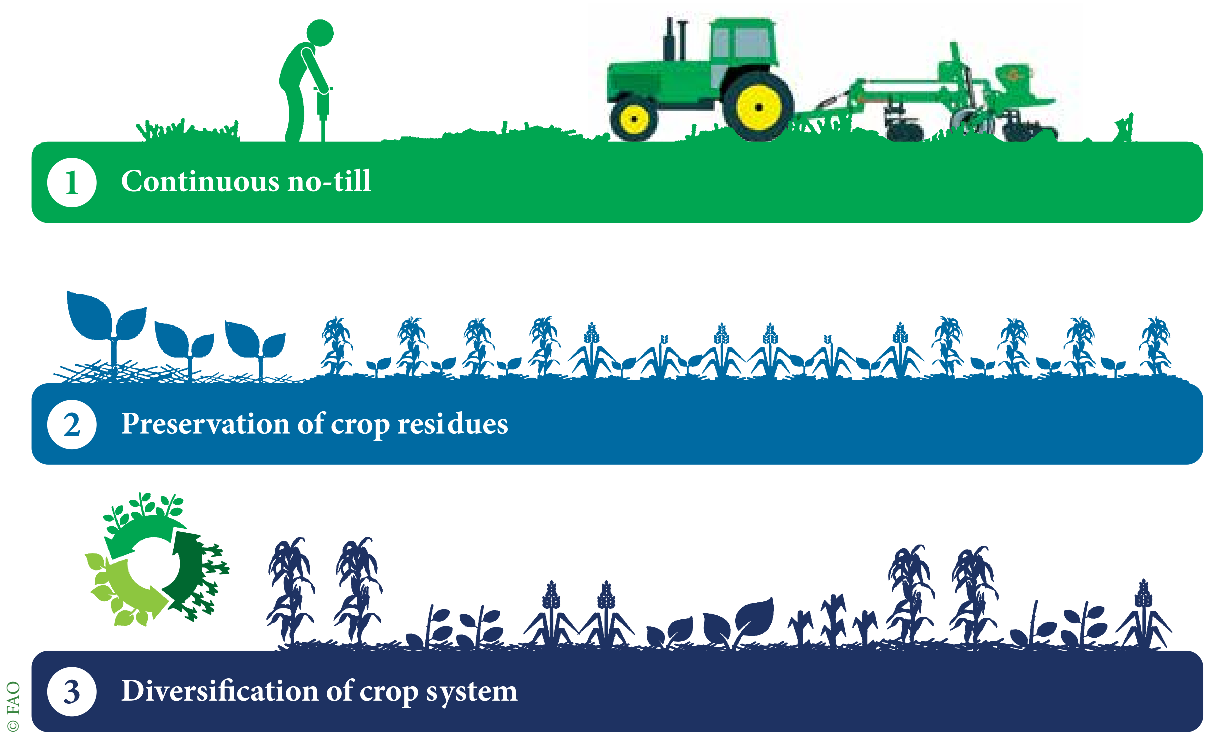


Figure 6. Three principles of conservation agriculture

3.1 Constraints and solutions to the introduction and adoption of Conservation Agriculture

What

Studies on the status of Conservation Agriculture in Eastern Europe and Central Asia have allowed to define **the challenges faced by Conservation Agriculture adoption** throughout the region, including:

- Farmers' inability to identify most suitable diversified crop rotations.
- Shortage of suitable implements/field equipment.
- Lack of knowledge about Conservation Agriculture systems – both among extension and technical staff, and at decision-making levels:
  - Cultural background is of great consequence: where tillage is deeply rooted culturally, lack of knowledge about Conservation Agriculture systems and their management makes it particularly difficult for farmers to produce crops without ploughing. Conservation Agriculture is much more than simply seeding into sod; it is more difficult to implement than tillage.
  - Most farmers are capable of mechanically incorporating chemical nutrients into the soil, burying weed seeds and recreating a temporary soil structure on a seasonal basis – a precarious environment favourable for crop growth. However, no-till requires a different approach to agronomic management. Fewer farmers know how to set up a crop rotation aimed at producing adequate biomass by crop successions, providing soil nutrients, reducing weed growth in time, diminishing pest incidence and producing competitive yields.
  - Farmers need specific knowledge about how to profitably fit cover crops into the crop rotation and they require experience to be able to choose the right implements (especially no-till drills) for specific on-farm conditions. In the case of combined livestock and crop production in a Conservation Agriculture system, additional techniques and management skills are required.

- Insufficient biomass production in semi-arid areas due to low rainfall, short growing periods and competition for use of crop residues (mainly for use as feed). Fields left bare at the end of the dry season induce soil degradation and continuous decline of crop yields.

The above challenges should be regarded as opportunities to transform agriculture and adopt systems that are more sustainable than tillage-based ones; moreover, they represent opportunities for achieving multiple environmental objectives.

How

In order to be successful, Conservation Agriculture cannot be adopted without detailed planning (at least one year in advance). Farmers need to develop an adequate level of knowledge to ensure that all aspects of the new production systems are considered. This section provides important operational recommendations and addresses the role of policies.

Before starting:

- **Perform soil inspection and analyses** to detect nutrient, pH and drainage status. As Conservation Agriculture relies on soil life, soils must reach a condition in which life can develop. Physical and chemical soil limitations should be corrected before starting Conservation Agriculture. This is especially true in degraded/depleted soils where some sort of amelioration investment might be necessary to rehabilitate them. In particular, in the case of:
  - nutrient deficiencies – use cover crop residues and mineral fertilizer;
  - acid soils (pH < 6) – apply lime to raise the pH; this needs to be done before starting Conservation Agriculture, as lime reacts more intensively when it is incorporated in the soil;
  - compacted soils (of either pedogenetic compaction or plough pans or heavy disk pans) – subsoil using a subsoiler (or a ripper for shallower compaction layers) to remove hardpans/plough soles; and
  - rough and uneven field surface and microreliefs – level the fields to allow seeding at an even depth; the final tillage operation before changing to Conservation Agriculture must eliminate traffic furrows (usually with a subsoiler shank), furrows and ridges left by a cultivator, and erosion rills (depending on the depth of the rills, using a disk harrow or a plough), leaving the surface of the fields levelled (usually with an offset disk harrow); precision levelling can be better achieved through laser guidance.

- **Control any problem weeds.** In the case of herbicide use, take time to learn to identify and use herbicides correctly to avoid health hazards and to ensure the effectiveness of the treatment. This includes understanding the calibration of the herbicide applicator.
- **Plan and plant a varied crop rotation for the initial years** with the aim of producing the maximum possible amount of crop residues under the local agro-ecology *(see Section 6).* The choice of crop depends on:
  - what seeds are available;
  - what grows well in the area; and
  - whether farmers can sell the produce.

  When planning crop rotation, consider also the following:

  - Avoid initiating Conservation Agriculture in fields where crop residues have been burned – burning crop residues is the worst possible condition, and removing them is the second worst condition.
  - Start Conservation Agriculture after a crop in which good weed control can be achieved.
  - Ensure that the harvest of the previous crop (whether a market crop or a cover crop) leaves enough residues on the soil surface.

- **Gain experience:**
  - In mechanized systems, avoid making large capital investments at an early stage; consider that specialized drills may be available on a rental or demonstration basis.

- No-till planting is a one-pass operation: mistakes or poor performance during the planting operation can be very costly.
- Take time to practise on a small portion of the field to acquire operational skills for seeding uniformly at the exact predetermined depth. Begin by planting into low residue; with more experience, plant into more residue.
- Start by developing a Conservation Agriculture system on a small area (10 percent of the farm size) in order to gain experience and adjust to new habits and timetables. The technology can later be applied to the whole farm.
- If possible, talk to experienced Conservation Agriculture farmers, and learn from their experiences and mistakes.

In all systems:

- **Perform routine soil inspections and analyses** of nutrient status and pH. During soil sampling, pay attention to the following:
  - Span the whole row width with a specialized broad, flat (vertical) sampler in order to avoid the distortion of the results due to fertilizer concentrations in the row (alternatively, a high number of random samples can be taken).
  - Take samples at: 0-10 cm and 10-20 cm, to take account of the high nutrient concentration at the soil surface (due to nutrient recycling through surface residues); and at 20-40 cm, to identify factors which will impede root development.

- **Adopt integrated disease and pest management.**
- **Include diverse crops in the rotation** to combine the benefits of individual species, taking care to include species that produce large amounts of biomass, as well as species with deep, strong roots that help avoid soil compaction and/or break hardpans. Crop diversification strategies include growing different crop species as pure stands in sequence or as crop mixtures *(see Box 11 at page 73).*
  - In small-scale food production (not in production for seed multiplication purposes), it is recommended to use a mix of varieties in association to reduce the risk of complete crop failure: if one variety fails to perform, the other will compensate.
  - In cover-crop-based systems, crop associations allow the inclusion in the mix of small amounts of valuable varieties (with expensive seeds). Mixes may include between two and four species with different habitus (e.g. bushy, creeping) and different root types (e.g. fasciculated, tap roots). For example: *Brassica rapa* and oat or oat and peas *(Figure 7)* work well in a mix, as they have very different root types.

Additional benefits related to higher species diversity include renewed opportunities for expanding to niche markets in the region *(Figure 8).* Diversified crop rotations will become increasingly important considering the market potential for crops such as oilseed crops (rape, mustard, safflower, sunflower), annual grain legumes (pea, chickpea, lentil), forage legumes and cereals (durum wheat, barley, oat, millet, cereal rye, buckwheat). Farmer Field Schools can introduce their members to profitable new ideas, and help farmers work out what to produce, how to produce it and how to get it to market *(see Box 6 at page 31).*

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Figure 7. Oat and pea mixtures for production of high-quality feed, weeds suppression and recycling of nutrients in the soil

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Figure 8. Cucumber relayed in maize to control weeds

Box 6. Farmer Field Schools and economic empowerment

It is hard for individual smallholders to buy inputs and sell their outputs efficiently, as they may be at the mercy of traders. As part of a group, farmers can buy in bulk and negotiate better prices. Dealing with groups of farmers, rather than with individuals, means that buyers, processors and traders have lower handling costs and can buy larger amounts.

Checklist for market surveys:

- **Production and market potential:**
  - What are the main crops grown and livestock reared at present?
  - What other crops or livestock could the farmers produce and sell?
  - What products do customers want? How do they use the products?
  - What are the advantages of these crops or livestock in terms of yield, quality, price and seasonality? What are the main production problems?
  - Is the product graded? Into what grades? What quality standards exist? What effect do different quality standards have on the price?
- **Input supplies and financing:**
  - What inputs are needed? Can farmers obtain them easily? Are they the right quality?
  - Do input suppliers provide advice to farmers? How good is the advice?
  - Do farmers have money to pay for the inputs? Do farmers have savings?
  - Can farmers get credit? What are the available sources of credit? Do buyers provide credit to farmers, and on what conditions?
  - How easily can farmers buy or hire equipment?

- **Begin Conservation Agriculture at harvest.** Following harvest of the previous crop, in order to ensure soil coverage (through to planting):

  - leave crop residues in the field;
  - keep residues well spread;
  - plant crops at the optimum spacing; and/or
  - plant cover crops either intercropped or relayed.

  The above measures protect the surface from sealing/crusting and help prevent loss of precious water and soil. Plants and mulch slow down the flow of water on the surface, giving it time to soak into the soil. At the same time, roots and organic matter increase the number of pores and channels through which more water can infiltrate.

- **Plant early and ensure a dense crop after emergence.** These measures contribute to good ground cover. Conventional farming systems have long-established schedules: in irrigated areas, if the soil is dry, farmers traditionally irrigate, till and then seed; in rain-fed areas, they typically wait for the first rains in autumn to germinate the weeds; they then kill the weeds and finally seed.

Conservation Agriculture offers advantages in terms of seeding:

- Flexibility – farmers may plant as soon as the previous crop is harvested and the weather permits seeding operations.
- Water-use efficiency – in dry climates under rainfed conditions, early seeding of cereal crops allows for greater water-use efficiency through the growing season: early sown crops make use of the first rains to establish rapidly in the autumn, continue growth early in spring when temperatures are cooler and more soil moisture is available, and avoid heat stress and moisture deficits (e.g. during the grain-filling stage) in early summer.

  However, early seeding practices must also take into consideration the possibility of late spring frost or early autumn frost events, especially where legume crops are concerned (when not grown for mulch production). Weed control in early sown crops is described in *Section 5.2.*

  Conventional seeding rates currently adopted by farmers in the region are often unduly high (against the advice of extension agents), leading to excessive competition between plants. This is especially detrimental where water availability is limited and/or the cost of seeds is high. In Conservation Agriculture, it is important to:

- calibrate the seed drill accurately; and
- use quality seed material of adapted varieties.

- **Replace the crop sequence as soon as soil carbon accumulation decreases.** The replacement sequence should be new and more intensive to increase the return of fresh organic matter in time and space; it will feed soil life and improve the soil structure.
- **Optimize crop residues.** Crop residues are often not sufficient to provide complete coverage of the ground, especially in the case of competition for other uses. In many countries in the region, stubble grazing by livestock after the harvest is common practice. Light stubble grazing does not harm soil fertility, because sufficient crop residues remain and there is a return in the form of dung and urine. However, since fencing is not commonly used, stubbles are usually overgrazed – or even grazed against the wishes of the crop producer. *Box 7* provides guidelines reflecting concurrent uses of crop residues.

  In semi-arid areas:

  - avoid uncontrolled stubble grazing;
  - identify alternatives to free-roaming livestock that are agreed on in the community; and
  - ensure that the residues left are sufficient to cover the soil *(Figure 9)* and to avoid soil compaction through trampling.

  Any surpluses may be sold – however, only excess straw should be removed from the field. Straw can have a good market price and maintaining it in the field may be per-

Box 7. How much residue can be removed from the field?

Ideally, 100 percent of the surface should be kept covered. Complete shading of the ground with small-grain residue requires approximately 3-3.5 tonnes/ha of residue.

However, in practice, **the amount of crop residue to be retained depends on the local climate, soil and type of residues.** For example, in cold climate areas characterized by low evapotranspiration in summer and absent/limited incline, the quantity of residue would need to be reduced to avoid excessively thick crop residues delaying the spring warming and drying of poorly drained soils, leading in turn to delayed seed germination.

In general terms, research shows that it is possible to remove up to 50 percent of the crop residue while achieving higher profitability, maintaining adequate soil health and buffering the effects of unpredictable weather.

The objective is to maintain ground cover of at least 30 percent, which translates into minimum residue of:

- 1 tonne/ha on moderately heavy soils;
- 1.5 tonnes/ha on medium textured soils; or
- 2.5 tonnes/ha on sandy soils.

As a rule of thumb, 1 tonne of wheat harvested produces about 0.7 tonnes of residue (depending on cultivar, weather conditions, insects or diseases). For example, a wheat or barley yield of 2-3 tonnes/ha provides enough straw to allow for partial grazing/exporting while leaving sufficient ground cover. On the other hand, grain legumes, such as lentil or chickpea, do not produce protective ground cover, especially when plants are pulled out and taken from the field at harvest.

Figure 9. Soil protected by wheat residues, Tajikistan

ceived as an economic loss. On the other hand, keeping the soil covered reduces the costs of applying fertilizers and herbicides and these benefits can compensate for the unachieved sale of straw. Economic losses resulting from reduced sales of straw can also be compensated for by increased yields.

Policy and institutional role in supporting the adoption and spread of Conservation Agriculture

While the approaches towards sustainable intensification based on Conservation Agriculture are very promising, the specific technologies vary depending on local conditions and farmers' needs.

It is important that governments and institutions also provide the necessary support. They must be dynamic, able not only to respond to farmers' varied and changing needs but also to reduce any risks during the changeover period. Policies need to focus on:

- facilitating national development strategies aimed at adapting Conservation Agriculture to farmers' needs and upscaling it;
- encouraging stakeholder engagement through national and regional platforms;
- bringing together suppliers and purchasers to work as a team with government field staff and others in response to farmers' needs and requirements;
- supporting Farmer Field Schools, which have an important role, providing opportunities to achieve the goal of Conservation Agriculture by encouraging farmers to group together and making suppliers (of inputs and technical advice) aware of potential opportunities;
- promoting technologies and capacity building with technical extension programmes (to further ensure accessibility and affordability of the required inputs and equipment); and
- facilitating procurement with credit lines.

For the foreseeable future, **supporting the adoption and uptake of Conservation Agriculture in the region should remain a high priority** in the efforts of FAO, donors and local partners.

4

Equipment and machinery in Conservation Agriculture

Chapter 4

4. Equipment and machinery in Conservation Agriculture

Evidence worldwide shows that the widespread adoption of Conservation Agriculture practices is unlikely without the right equipment: specialized equipment suitable for seeding in untilled and mulched soils (i.e. in the presence of stubble and/or a cover crop), and for controlling and managing cover crops and crop residues must be readily available and affordable.

When new technologies are extended to farmers, **the conditions must be right:** if farmers are to adopt innovations, they must want to, they must know how to and they must be able to follow recommendations. If no-till machines or service providers are not available, farmers will not be able to follow the recommendations.

This chapter describes the equipment needed for weed management *(Section 4.1),* crop residue management *(Section 4.2)* and no-till seeding *(Section 4.3).*

4.1 Weed management

The following equipment for herbicide application is available:

- Operator-carried weed wipers – best suited for small-scale farms. No specific knowledge is required concerning the application of agrochemicals and they carry a lower risk of spray drift[ix] and crop damage compared with sprayers.
- Operator-carried knapsack sprayers – popular, but difficult to use properly. Training is necessary for correct operation. For large area coverage, they can be adapted with multi-nozzle spray booms; for inter-row weed management in row crops with total herbicides, they can be adapted with a spray shield to avoid crop damage.
- Spraying equipment (for manual or animal traction and also suited for single-axle tractors and four-wheel tractors) – see *Section 4.2* and *Box 9 at page 56.*

4.2 Crop residue and growth management

The management of cover crops and residues is a vital component of Conservation Agriculture; it requires careful selection and operation of the equipment.

Roller-crimpers for cover crops management

A roller-crimper to flatten and kill cover crops and leave the plant residues on the soil surface is an essential tool for cover crop management and contributes greatly to reducing herbicide rates in the no-till system *(Figure 10).*

The roller-crimper usually consists of a round drum with equally spaced, preferably chevron-patterned, blunt blades around the drum. The cover crop is crimped with the blunt blades – preferable to sharp blades that would cut the cover crop and dislodge residue that might interfere with seed soil contact at planting. Moreover, cut plants can produce regrowth, while crimped and flattened plants usually dry out and die. The use of

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Figure 10. Roller-crimper flattening cover crops, Tajikistan

curved blades on the roller drum alleviates vibration and allows higher operation speed. Rollers can be mounted at the front or the rear. Rolling and planting can be done in a single operation (saving time and energy) by using a front-mounted roller and rear-mounted drill.

The roller-crimper is not very expensive and can often be made locally or by the farmers themselves. Alternatively, similar artisanal implements can be adapted; for example, steel bars can be welded on top of the discs of an old disc harrow.

Different crops respond in different ways to rolling, and the timing of the operation also depends on the crop type. Preliminary research shows that some crops should be rolled during flowering to ensure termination. In some cases, one pass may not be adequate. Other crops may regrow: depending on the objectives, this regrowth and extra biomass may or may not be desirable. It is important that practitioners experiment with different crops and mixtures, testing different termination dates in their respective environments.

Spraying equipment

Spraying equipment requires special attention. Sprayers range from 20-litre backpack, single-nozzle types to self-propelled versions with up to 40-m booms and tanks of 2 000 litres or more *(Figure 11).* All sprayers use hydraulic atomizing spray nozzles. On large farms, pesticides[x] can be applied through the drag system: two tractors drag a line of nozzles fed from a hose attached to a cable (≤ 100 m) between them. Spray planes are another option, but aerial application of herbicides carries a high risk of drift, resulting in environmental contamination of non-target areas and health hazards for the adjacent population; it is, therefore, not encouraged.

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Figure 11. Herbicide application with boom sprayer, Turkey

Spot-spraying can be done manually using backpack sprayers or lances coupled to the tank of a boom sprayer (isolating or removing the booms). Some equipment using rotary nozzles is also available, enabling controlled droplet application at much lower volumes than with hydraulic nozzles. Precision spraying tools (where sensors open only those nozzles on a boom that would cover live weed plants) can significantly reduce the amount of herbicides used for weed control, particularly when using non-selective herbicides in pre-emergence situations (common in no-till operations to reduce populations of broadleaf weeds in cereal crops and grass weeds in legume crops).

Choosing the correct nozzle is very important, as it can save time and money. Furthermore, it is important to check the good functioning of the nozzles: no dripping, correct position, even distribution and optimal drop size (avoidance of drift). Worn nozzles need to be replaced. Further considerations on the operation of spraying equipment are given in *Box 9 at page 56.*

Harvesting machines

The even distribution of plant residues is very important, as excessive residue in the centre and too little at the edges of the harvested width results in the poor performance of seeding and spraying equipment. Grain harvesting machines equipped with a well-designed device to spread the straw and chaff evenly over the entire cutting width are good options for handling grain crop residues *(Figure 12).*

Of the residue passing through a combine and falling to the ground, one portion comprises whole parts (e.g. wheat straw, whole corn stalks, legume stems) and another portion is made up of (or broken into) small pieces of material (chaff) that are either blown out or dropped out of the back of the combine.

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Figure 12. Soybean harvesting and plant residues spreading across the field, Kazakhstan

Combines with heads of more than 6 m make it difficult to spread the residue evenly over the entire width of the harvested swath. The solution is to install a straw spreader and a chaff spreader. The spreader attachment, by design, spreads whole pieces of residue. The chaff spreader typically uses two spinning discs with rotating bats to throw the chaff in all directions behind the combine. Measures should be taken during construction of the combine to ensure that the straw dropping down at the centre is not thicker than that at the sides of the combine passes and that heaps of straw are not left when the spreader blocks. The performance of straw spreaders can be improved by increasing the speed and transmission power (for example using a double belt), or by increasing the size of the paddles on the spreader discs to increase the blowing effect.

Chopping the straw consumes more energy than just spreading it and, in most of the region, straw choppers are not needed: small residue is subject to movement by wind and water; in arid and semi-arid climates it is quickly decomposed. However, management of the straw (i.e. chopped and spread vs spread as whole stalks) should be coherent with the type of no-till seed drill used, as it may conflict with the good functioning of some furrow openers: chisel-type furrow openers usually require chopped straw, while disc-type equipment works better on whole straw.

Stripper headers or pickers, which spin backwards as the combine moves forwards, strip the grain off the crop or pick the cobs from the plant leaving the stalk intact and standing. Planting with disc openers in standing residue is usually very easy and the residue can then be flattened behind the seed drill. An additional benefit is the reduced bulk entering the combine, which results in significantly improved capacity and efficiency.

4.3 No-till seeding

The process of seedbed preparation without ploughing or tillage requires seed drills to:

- cut through crop residues;
- penetrate the soil (also compacted soils) to the optimum seeding depth;
- place seeds accurately, closing the furrow and ensuring good soil-to-seed contact; and
- apply mineral fertilizer slightly deeper than the seed furrow and slightly offset to the side.

This section presents a brief overview of the machinery and equipment available for no-till seeding.

Manual seeders

- Jab planters *(Figure 13)* insert a preset amount of seeds and fertilizer into the soil. They are commonly equipped with a double tip to apply fertilizer at the same time as the seed. Both fertilizer and seed flows are adjustable. To operate, they are jabbed into the ground with the point closed; the handles are then pulled apart, allowing seed and fertilizer to drop into the seeding hole; on closing, the seed and fertilizer points are recharged.
- Li-seeders *(Figure 14)* are formed like a two-pronged hoe. In the place of the hoe blade are the points for the seeds and fertilizer, which are released (in preset amounts) with each strike of the hoe.

Figure 13. No-till seeding with a jab planter, Tajikistan

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Figure 14. Li-seeder

Animal-drawn seeders

Animal-drawn seeders are mainly used by farmers in Africa and South Asia. However, they could be used in the mountainous areas of Eastern Europe and Central Asia, where the size of farms is limited and farmers use animals such as oxen or horses for field work or transport tasks *(Figure 15).*

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Figure 15. Animal-drawn seeders

Most animal-drawn seeders are single-row types, pulled by a single horse/mule or a pair of oxen. When equipment is drawn by horses or mules, the metering mechanisms must be designed to take into account the generally higher traction speed of these animals compared with oxen. Two-row versions are also available. In general, animal traction no-till planters are only available for large-grain row crops and not for small-grain cereal crops, which require much narrower row spacing.

Most animal-drawn seeders have a residue cutter disc/wheel up front (to remove build-up on the blade), followed by a fertilizer knife and an eccentric double disc for the seed. Seed distribution can be with a horizontal perforated disc or similar mechanical metering device. Some models use discs commonly available from large manufacturers; this facilitates local availability when different spacing is required for new crops. Some versions have depth wheels for both seed and fertilizer, while others have only one for seed. Their position and size are variable. Furrow-closing mechanisms are also varied and sometimes absent. The quality of fertilizer distribution varies depending on the model.

Single-axle walking tractors

Most animal-drawn no-till row crop seeders can be pulled also by single-axle walking tractors *(Figure 16)* the working principle is the same as for animal-traction seeders. However, there are also varieties specially designed for single-axle walking tractors, which cover up to four rows (although usually used for just one or two rows). Particularly in Asia, a number of low-cost no-till seed drills have been developed using chisel furrow openers or discs and, depending on the residue conditions, cutting discs for clearing the path for the furrow openers. In some cases, the operator can stand on a rear platform for additional weight to facilitate the working of double-disc furrow openers.

Figure 16. Single-axle walking tractor

For small-grain crops and narrow row spacing (e.g. for wheat and rice) and in situations with heavy residues, no-till seed drills for up to six rows (1-m working width) have been developed. Some designs operate as strip-till seed drills, opening the seed furrow with narrow rotary harrows driven by the engine power take-off. In other cases, the residues are chopped ahead of the furrow openers – a necessary action, given the limited capacity of single-axle tractors to carry weight or to pull, which limits the residue-handling capacity of common tractor no-till drill designs.

Tractor-mounted and tractor-drawn seed drills

Undisturbed soils are denser and tougher to penetrate during the first few years of conversion to Conservation Agriculture. Also, the presence of stubble on the soil surface creates an additional obstacle for seeding. For these reasons, most no-till seed drills are heavier than conventional ones. The additional weight allows the seed drill to maintain the desired seeding depth in rough soil conditions and on heavy residues. However, some companies produce drills weighing as much as 2-3 tonnes and requiring high-horsepower tractors.

Due to their heavier weight, tractor-mounted models are limited to small units: about 2-3 m working width for small-grain seed drills and up to six rows for row crop precision planters. Larger units are tractor-drawn with their own transport wheels and vary from 4- to 40-row units; for small-grain seed drills, they may have a working width of up to 24 m.

The main components of all seeders are described below:

- **Frame/chassis.** The frame is composed of toolbars, a tractor hitch system and a mechanism to force the openers into the soil to the proper depth and ensure seed-depth control. In row crop planters, this mechanism comprises adjustable-depth gauge wheels (adjacent to the seed furrow openers); in small-grain seed drills, it is a pressure-adjustable press wheel (behind the seed furrow openers). In either case, pressure is transferred from the equipment weight to the single-row furrow openers individually. Most common seed drills use pressure springs *(Figure 17).* Penetration depth of the seed disc is adjusted by the lower stop of the rear pressure spring to ensure that sufficient pressure is resting on the depth control wheels to close and compress the seed slot. It is important that the machine, when working, does not rest on the limiting bolts of the drive wheels. The upper stops of the rear pressure springs control only the position of the furrow opener units when the seeder is lifted to avoid touching the ground; they do not control pressure and must never touch the support when the seeder is working. More sophisticated seed drills use hydraulic pressure with electronic seed depth sensors to adjust the necessary pressure to the specific soil conditions.
- **Box/hopper.** Some models have one box for the seeds and a separate box for the fertilizer; in other models, the boxes are combined.
- **Seed distribution mechanism.** In general terms, the seed distribution mechanism consists of a ground drive and metering system for each box, and tubes that deliver the desired amount of seed and fertilizer to the row seeding system. The drive wheel only receives the pressure required to drive the metering systems; it does not support any

Figure 17. Penetration/depth control mechanism: 1. Pressure spring for cutting disk and fertilizer depth; 2. Limiting bolt of drive wheel; 3. Pressure spring for seed depth.

further weight. The metering system requires calibration to vary the rate of seed and fertilizer delivery independently of the ground speed. The basic types of seed distribution mechanisms available are as follows:

- Seed drills releasing a constant flow of seeds into the seed row. In seeders over 4 m wide, the constant flow is metered by mechanical devices fed by gravity from the seed box spanning the entire width of the equipment. Large seeders often use fans to assist the flow.
- Precision mechanisms delivering single grains to specific planting positions in a row. The metering of the seed into the seed tube can be mechanical (with perforated horizontal discs, inclined discs/finger wheels, or vertical wheels with small cups). Different designs result in different levels of accuracy and seed damage.
- Pneumatic precision mechanisms using vacuum to suck the seed onto perforated discs. These have a high level of accuracy, do not require that the holes of the discs exactly match the size and shape of the seed, and result in less seed damage, but they have higher maintenance requirements to keep the vacuum in the system.
- Air seeders blowing the seed out of a central seed box (which may also be on a separate trailer behind the seeder), through tubes, into the furrow opener. Air seeders are not in general use in the region, since small grains are usually sown with the traditional drill mechanism or with multi-grain-size universal machines.

- **Row seeding system.** *Figure 18* indicates the elements comprising a row seeding system.
- **Soil openers.** Soil openers cut a continuous furrow/slot into the soil. Various types exist, suitable for a wide range of seeding conditions and budgets:

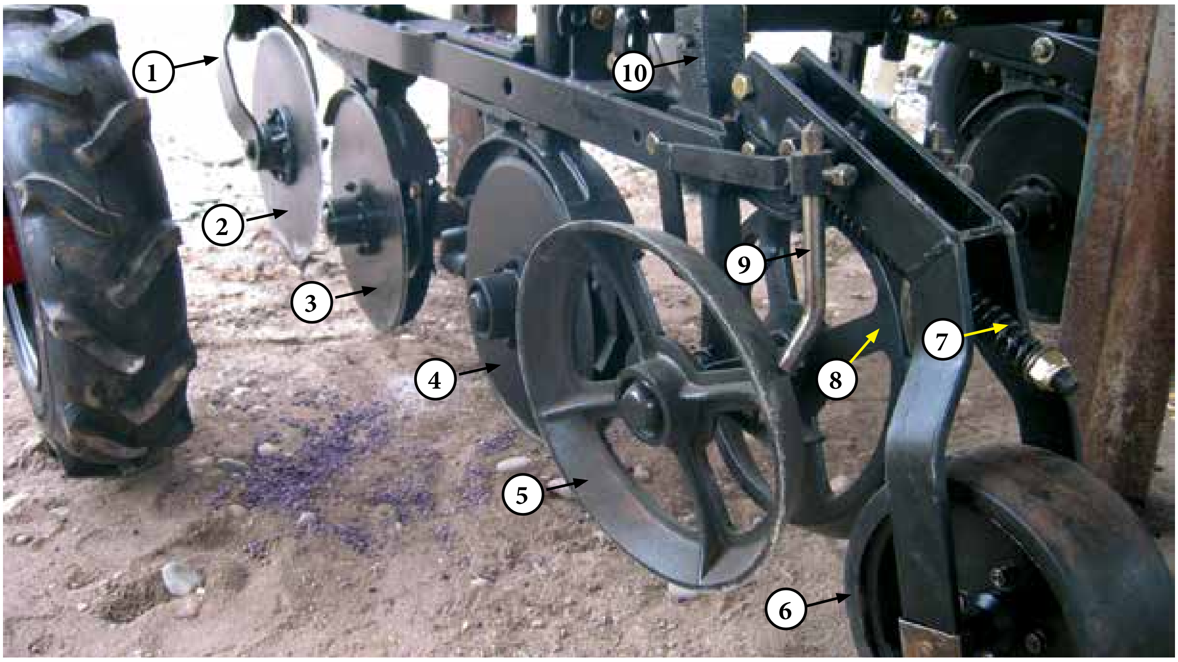

Figure 18. Components on a row crop furrow opener unit: 1. Depth control of cutting disk and fertilizer; 2. Cutting disk; 3. Fertilizer disk; 4. Seed disk; 5. Seed-Depth control wheel; 6. Presswheel; 7. Pressure control; 8. Control for furrow closing; 9. Scrappers; 10. Depth-control for seed

- Double disc openers have the major advantage of producing minimum soil disturbance, making just a slit for seed placement. Consequently, weeds are not stimulated to germination and few come to the surface. Further, double discs have a relatively low draught power requirement (thus, fuel consumption is low). On the other hand, to ensure clean cutting of residues and good penetration in hard-setting soils, they usually require high pressure, which entails the use of heavy equipment (usually 200-250 kg per row). In **staggered double-disc openers,** the leading edge of one disc is slightly in front of the other. The leading disc cuts the residue and soil acting as the coulter, and the trailing disc opens the seed furrow, thus eliminating the need for a coulter to cut residue, even in heavy residue conditions. Performance is further improved if the trailing disc has a smaller diameter than the leading one. With the staggered design, weight requirements can be reduced to about 100 kg per row. As the discs wear over time, a gap develops and residue and soil become wedged between the discs. Therefore, proper maintenance (i.e. sharpening or adjusting) is essential to ensure optimum seed placement. Good quality double-disc openers must be made with high quality steel: thin, but sharp and durable without bending or breaking. However, this often results in the very high cost of double-disc openers.
- **Slot shoe openers** slide under the residue and lift it out of the seed furrow. They require a coulter in front to avoid clogging problems from residue wrapping around the opener. Shoe seed openers are not suited for shallow planting into cover crops, as they would drag cover crops all over the field *(Figure 19)*.
- **Chisel or tine openers** are usually cheaper and more durable. They require less equipment weight, but come with relatively high soil disturbance and a related loss of soil moisture. They are usually used on hard-setting dry soils (e.g. in rainfed areas).

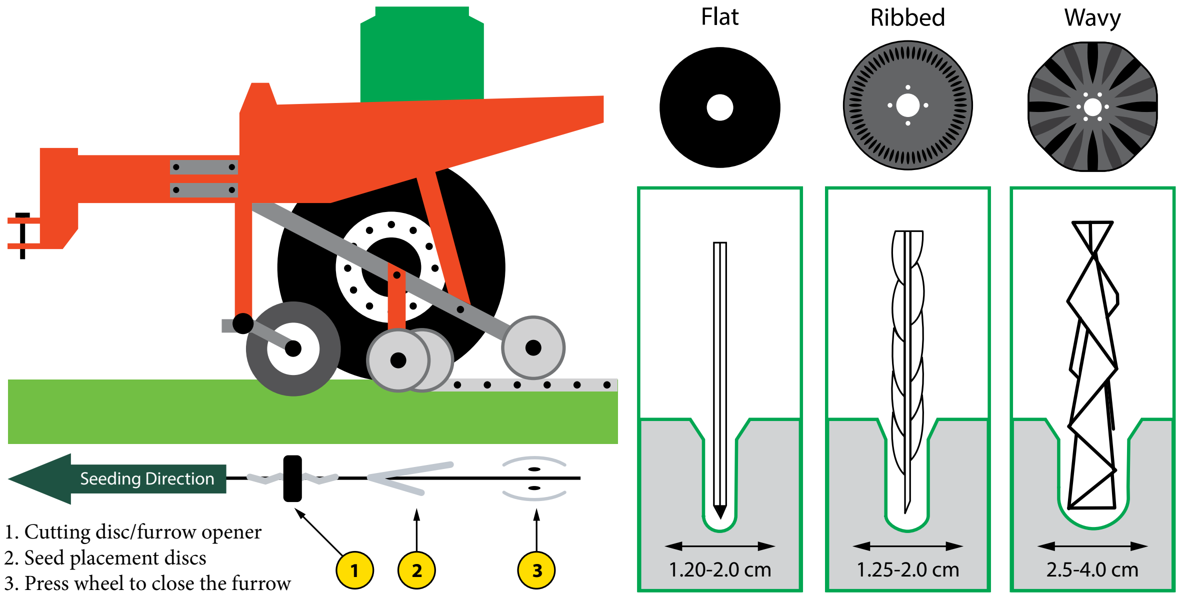

Figure 19. Schematic drawing of the seed placement mechanism of a no-till planter

- **Fertilizer coulters/applicators.** Coulters deliver fertilizer into the furrow. For some forms of nitrogen fertilizer, such as urea, surface application results in high volatilization rates. Therefore, nitrogen should be placed in the soil. This can be done in one operation with the seeding. However, seed contact with the fertilizer in the seed furrow must be avoided. Therefore, the fertilizer is usually inserted in front of the seed furrow opener, slightly deeper than the seed furrow, and ideally slightly offset to the side (to avoid seed falling into cracks left by the fertilizer coulter). Fertilizer coulters have the following basic variants:
  - **Guillotine knife coulter** closely coupled to the residue-cutting disc with a small V-shaped guillotine attached to the knife that acts as a disc cleaner (smaller in heavier soils): always use a guillotine knife coulter coupled with a fertilizer boot for maize and cotton, and for seeding into desiccated pastures and thick residue layers.
  - **Knife coulter behind the residue-cutting disc** *(Figure 20)* for use on hard, dry and compacted soils.
  - **Offset double discs with different diameters** receiving fertilizer in the gap between the discs *(Figure 21)* for use on soft soils or with difficult residues. The offset discs can work with or without a cutting disc, but it is difficult to offset the seed disc from the fertilizer coulter (risk of seed burn from contact with K or N fertilizers).

As for seed metering systems, the fertilizer applicator needs to be calibrated.

- Furrow-closing devices. Closing devices cover the seed and ensure good seed-soil contact, which is essential for germination and seedling emergence. The principal types of furrow-closing wheels used to move the soil back into the seed furrow are:

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Figure 20. Chisel type furrow openers for fertilizer

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Figure 21. Double disc type furrow openers for fertilizer

- paired slanting wheels often mounted in a V-shaped configuration (with adjustable angle and pressure) to simultaneously close the seed furrow and establish seed-soil contact;
- a single slanted metal press wheel; and
- a single rubber-covered press wheel.

To firm the seed in the bottom of the seeding furrow, a narrow seed-firming wheel or sweep may also be present directly behind the seed tube and in front of the furrow-covering device.

In addition, **disc seeders** specifically include the following components:

- **Residue-cutting discs/coulters.** A residue-cutting disc/coulter may be positioned in front of a double-disc furrow opener, with the function of cutting the residue. Coulters can be straight/smooth (most common), rippled or fluted. In general, wider ripples or flutes on the coulter increase soil disturbance and require more weight for penetration. Rippled coulters perform less tillage with less weight, but allow for higher speeds. To avoid tracking errors on slopes and curves, the coulters should be mounted close to the seed furrow opener. To prevent the formation of air pockets that could dry out the soil, the coulter should be operated at slightly less than the seed placement depth.

- **Row cleaners.** Small residue may adversely affect the performance of furrow openers, because coulters designed to cut through residue may instead push small residue pieces into the seed furrow (hair-pinning).
  - If **residues are chopped,** row cleaners may be used to sweep residue away from the opening discs of the seeding units. It is important that row cleaners move only residue, not soil: if soil is disturbed in the row, it will dry out and crust over.
  - If **residues are not chopped,** row cleaning devices are not necessary. In particular, fingered row cleaners should be avoided as the cover crop would wrap around the fingers.

It is of the utmost importance to **increase the accessibility and affordability of locally made no-till implements.** Where adequate machines are not on the market, it is possible to use modified machines(old seeding equipment); it is only necessary to purchase new those units that come into contact with the soil, resulting in a significant reduction in costs. In any case, farmers are encouraged to **make modifications** (e.g. row cleaners or coulters) to **facilitate field adjustment and ensure proper seed and fertilizer placement.**

5

Operations in Conservation Agriculture systems

Chapter 5

5. Operations in Conservation Agriculture systems

For all operations in mechanized systems, flotation tyres and controlled traffic should be used to prevent soil compaction. *Sections 5.1* to *5.4* describe the operations in order of occurrence. *Section 5.5* and *Section 5.6* discuss considerations of phytosanitary management and nutrient management insofar as they refer to Conservation Agriculture; they do not refer to tillage-based technologies and do not aim to be exhaustive.

5.1 Crop residue management

Crop and cover crop residues have to be managed properly in order to fulfil their functions *(Section 6.1).* Direct seeding without soil cover can be worse than ploughing, as it favours soil compaction, poor plant nutrition and weed proliferation. As residue management in Conservation Agriculture is completely different from in tillage-based systems, farmers planning to adopt the technology must undergo a change in mentality. The following factors must be considered:

- Cereals should be cut higher than in tillage-based systems: optimum height approximately 25 cm. In some areas, this method helps avoid soil erosion and facilitates the collection of snow *(Figure 22).*
- Grain legumes should be harvested by cutting; the plants should not be pulled up and uprooted.
- Crop residues should never be mixed with soil to avoid/minimize nutrient immobilization and unavailability for the subsequent crop during the early part of the growing season *(see Box 8 at page 54).* Residues incorporated in the soil surface decompose more quickly than those left on the soil surface, and nitrogen immobilization can occur very early in the season.

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Figure 22. Snow trapped by standing crop residues, north Kazakhstan

Box 8. C/N ratio for crop residue management

C/N ratio is the nitrogen content in relation to the carbon content in the crop residue. It is a good indicator of whether nitrogen immobilization or mineralization will occur as a consequence of the residue decomposition process:

- Low C/N ratio < 25: crop residue decomposes easily and quickly releases organic molecules (e.g. polysaccharides and nitrogen). To avoid unwanted rapid nitrogen release, plant legumes together with grasses. After killing a balanced mix, nitrogen release can be more gradual.
- High C/N ratio > 25: the residue is likely to rob the crop of nitrogen. Incorporation of the residues further favours nitrogen immobilization.

When no crop roots are present to absorb excess nitrogen, some nitrogen storage in the microbial population may be useful for keeping excess nitrogen tied up.

To avoid unwanted nitrogen immobilization deficiencies during the subsequent growing season:

- wait 1–3 weeks after killing a crop with a high C/N ratio and before growing the next crop;
- supplement with a more readily available nitrogen source (when a delay is not practical); or
- grow different cover crops together to lower the C/N ratio of the total biomass produced.

C/N ratio is influenced by the crop type and species, and by when the cover crop is killed:

- The C/N ratio of mature **legume** residues is generally low; it varies from 9 to 25 and is typically well below 20 (i.e. the guideline threshold where rapid mineralization of nitrogen in the residue occurs). For example, the C/N ratio of hairy vetch averages 13.
  Early establishment of legume cover crops results in greater biomass and nitrogen production. Legumes have their maximum biomass nitrogen accumulation before the flowering stage (Section 6.1). Termination of legumes at early- to mid-blossom stage results in maximum legume nitrogen release to the succeeding crop.
- The C/N ratio of most **grasses** (including small grain) is mostly dependent on **the timing of termination of the grass cover crops:**
  - Early termination results in a lower C/N ratio – typical of young plant tissue – and in the rapid decomposition of a smaller amount of residue, reducing ground coverage.
  - Termination at flowering usually results in C/N ratio > 30, which would increase nitrogen immobilization. For example, the C/N ratio of cereal rye varies from 15 in young plants, to 25 at the flag leaf stage to 36 at flowering.
  - Delaying termination until flowering generally increases C/N ratio and average above-ground dry matter accumulation.
  - Delaying termination until after flowering increases C/N ratio but does not increase biomass production.

Cover crops can be managed to supply different types of crop residue to the soil at different times of the year depending on intended use and specific goals (Section 6.1).

- It is fundamental to ensure even distribution of crop residue on the ground after harvest; uneven distribution may prevent accurate functioning of seed drills and spraying equipment. It is therefore recommended to mount combine harvesters with a straw and chaff spreader *(Section 4.2).*
- In dry climates with low biomass production, straw chopping is neither necessary nor desirable: the chopped straw will be blown away and will decompose more rapidly.

5.2 Pre-seeding cover crops and weed management

Cover crops management

Depending on the geographic area, species and management, cover crops may die off during the dry season or winter kill, allowing subsequent seeding without any special treatment.

More persistent or perennial and upright species can act as weeds if not controlled. Therefore, farmers should have a method for controlling the cover crop before it competes with the next crop. This can be done in the following ways:

- **Pre-seeding mechanical termination using a mechanical roller.** Specialized equipment can be used to control and manage the residues of cover crops *(Section 4.1):*
  - **A roller-crimper** flattens and breaks (crimps) the stems of the plants, which then dry within a few days. The cover crop is flattened parallel to the direction of planting, forming a dense mat on the soil surface. The crimping action facilitates cover crop desiccation. Roller-crimpers should cross the direction of future seeding rows. This helps avoid seeder problems arising when tall-growing cover crops lodge in multiple directions after chemical termination. The roller-crimper is a viable way to kill cover crops using fewer or no herbicides. Without herbicides, it works best with tall-growing cover crops (e.g. oat, cereal rye and wheat) terminated at flowering stage or later (dough stage). Combined with non-selective herbicides at half the recommended rate, it is as effective as using the herbicide at the full recommended rate to kill all cover crops. However, applying non-selective herbicides at reduced rates could lead to weed resistance *(see Box 9 at 56).* Therefore, it is safer to eliminate completely the use of non-selective herbicides with a roller or to use non-selective herbicides at the labelled rate (with or without rolling) in the context of diversified crop rotations.
  - **A vertical flail chopper** or **horizontal rotary chopper** flattens, for example, cotton or maize stalks. Horizontal rotary choppers may produce windrows. Seeding diagonally across windrows helps to reduce clogging.

- **Pre-seeding chemical control by spraying herbicides.** The chemical desiccation of cover crops and weeds is discussed in *Box 9,* the equipment in *Section 4.1.*
- **Controlled grazing of crop residues.** When farmers own livestock, controlled grazing provides the crop producer and/or the neighbours with some short-term benefits, including an increase in soil N through livestock manure and urea, while terminating the cover crop.

Weed management

One of the biggest differences between Conservation Agriculture and tillage-based agriculture lies in weed growth dynamics and control.

Weed control is one of the major objectives of tillage and it does not require specific knowledge, because soil inversion controls most weeds mechanically by simply burying

Box 9. Chemical desiccation for cover crops and weed management

- Verify that water is clean and free of suspensions: clay and organic matter absorb the spray chemicals and reduce effectiveness; fine sand or other particles can clog nozzles.
- Spray during vigorous growth, because stressed plants do not absorb herbicides effectively.
- Spray early in the morning after the dew has dried (rain, dew or other moisture will dilute the herbicide, reducing the absorption of the active ingredients) or late in the evening (this is usually when the wind speed is lowest) in order to give the weeds enough dry time with only the herbicide on them. Avoid the middle of the day when temperatures are high and humidity is low.
- Apply the correct rate of herbicides: the greater the live root mass, the higher the application rate. Recently germinated plants, with small root mass, are easily controlled with low dosages of contact herbicides.
- Test sprayers before use for correct operating pressure, nozzle overlap and individual volume/time discharge (calibrate for application volume). In order to maintain the correct rate throughout the spraying operation, the sprayer must be calibrated to have the exact, intended output of product and water. This is probably one of the most difficult, time-consuming tasks, as each nozzle has to be checked and calibrated individually; any nozzle varying more than 10 percent from the average output must be replaced (with the same type, number and colour).
- Apply systemic desiccant herbicides as large droplets. Low-volume applications improve herbicide absorption and sprayer efficiency, but require higher skill in application.
- In the case of a heavy green mass at desiccation (cover crop or weeds), allow up to 3 weeks between spraying and seeding, to enable dissipation of allelopathic[xi] products from root decomposition.

Caution: Herbicides can carry risks for humans, the environment and crops, and should always be carefully used. Annex 4 provides the FAO Environment and Social Standard on Pest and Pesticide Management of the FAO Environmental and Social Management Guidelines as a reference. Non-selective herbicides should be used at the labelled recommended rate: lower rates may not completely eradicate the weed, increasing the chance that the weed will produce seed; such seeds are more likely to be resistant to the herbicide. Changing herbicides from year to year or using different herbicides within the season (pre- and post-emergence) can prevent the build-up of resistant weed species.

them. Stopping ploughing, on the other hand, requires other measures of weed control, including regular observation of the development of weed populations. This is particularly important during the transition period in the first 2-3 years, as the seed bank in the soil is well filled. To deplete the weed seed bank, it is crucial to avoid seed-set and requires an integrated approach:

- **Biological/agronomical.** Conservation Agriculture is based not only on not tilling the soil, but on a combination of carefully managed interventions:
  - **Crop rotation:** the wider the rotation, the more efficient the weed control.
  - **Species selection:** species that provide rapid and dense ground cover smother weeds. In particular, sufficient grasses should be included to produce a large quantity of slowly decomposing residues (e.g. cereal rye, sorghum, radish and high biomass legumes, such as hairy vetch). Weed suppression by the mat of rolled cover crop residue depends on the cover crop, the weed species and height, and the density (thickness) of the cover crop mat. Small weeds are not killed by rolling.

- **Use of cover crops:** cover crops can be used to suppress weed germination either physically or allelopathically (i.e. releasing compounds that inhibit weed seed germination and growth), favouring pre-emergence and growth of the main crop.
- **Crop succession:** the successive crops in the rotation should produce adequate biomass to shade out weeds and/or outcompete weeds by fast growth and dense canopy cover.
- **Seeding:** early seeding gives crops a better chance to compete with weeds; dense seeding provides a better ground cover, resulting in shading out and suppression of weeds. Although narrow spacing between the main crop rows can hinder establishment of a relayed cover crop, it reduces weeds.
- **Residue management:** a precondition for effective weed control is that the residue is evenly spread.

- **Chemical** *(see Section 4.1 and Box 9).* The decision whether to apply herbicides and the choice of herbicide depend on an evaluation of susceptibility: survey the weed spectrum and the stage of growth. If specialized guides for local (country or region) weeds are not already available, extension agents/facilitators in the Farmer Field School are encouraged to produce one for the most frequently occurring weeds, including recommendations for the specific conditions of the Farmer Field School farmers.

A weed guide should include:

- descriptions of the weeds;
- pictures of the seeds and of the seedlings at maturity;
- a list of all the officially registered herbicides available in the country;
- details of the weeds' sensitivity to each herbicide (no action, sensitive, very sensitive); and
- explanations of the modalities and precautions for application.

Herbicide application requires many considerations:

- The ideal time for chemical spraying depends on the chemical product characteristics and on the field conditions – level of infestation, growing stage of weeds and weather conditions (wind, rain, temperature).
- As in no-till systems in semi-arid and arid areas, it is difficult to provide sufficient ground cover (because of low biomass production and livestock competition for crop residues); farmers tend to rely on chemical weed management. Weeds not properly controlled in the pre-seeding phase are very costly to eliminate at a later stage with selective herbicides. In the presence of heavy weed infestations, it may be advisable to wait for the first rains to allow the weeds to germinate and to control them with a non-selective herbicide (while they are still young and small) immediately before sowing.
- Under arid climatic conditions, non-selective herbicide application in pre-seeding may not always be recommended; on the other hand, waiting for sufficient weed growth would delay sowing the crop by several weeks and, therefore, selective and specific post-emergence herbicides are often the best option in dry climates in the absence of major weed problems.

- Secondary weed regrowth may require an additional application of selective herbicides.
- For specific weeds, it may be necessary to mix selective herbicides with the desiccant. Check the local weed control recommendations and a chart of compatibility for active ingredients and spreaders.
- For legumes, care must be taken to ensure that grassy species are efficiently controlled.
- For cereals, almost all herbicides need to be applied at the very early growth stage when the crop and weeds are at the 2-5-leaf stage.
- Spot application is recommended when problem weeds are concentrated in isolated patches, as is often the case with grasses and perennials. A knapsack sprayer is used and the operation – if correctly done – is quite effective and less costly than spraying the entire field with a tractor-mounted boom sprayer. It should be done before the overall desiccation, or later as a complement to eliminate misses.

Effective weed management includes retaining the weeds in the field for soil cover. With careful prevention of new weed seed production and targeted elimination of perennial (especially grassy) weed species, weed pressure will slowly decline.

5.3 No-till seeding

Timely seeding of crops is essential to grow more crops during the growing season. No-till seeding operations are carried out on desiccated vegetation (cover crops or weeds) or on rolled cover crops *(Section 5.1)*. This reduces the time needed for soil preparation, allows early seeding and extends the growing period by up to 4 weeks per season *(Figure 23)*.

Figure 23. Maize seeding at wheat harvest, Tajikistan

Early seeding is particularly important in dry climates. At the beginning of the season, it is crucial to lose no time for seedbed preparation so that the entire cropping season can be used and precious and scarce rainwater is not lost. The summer crop can be planted directly (even on the same day) after the harvest of the winter crop, avoiding loss of soil moisture.

<u>All systems:</u>

- Seeding must be timely for both the main crop and the cover crop.
- Broadcast seeding is often the least successful seeding method and requires an increase in the seeding rate compared with other methods. Small-seed species (e.g. clover) tend to establish better by broadcasting compared with large-seed species.
- In dry climates seeds can be placed deeper (6-8 cm) in order to avoid germinated seeds wilting during dry spells.
- If residual nitrogen is low, additional N fertilizer should be considered for small-grain covers.
- Covers should be terminated 2-3 weeks ahead of the seeding date to prevent problems associated with allelopathy, pests and seeding operations.

<u>Mechanized systems:</u>

- Before the seeding operation begins, drills must be levelled along the seeding line so that both fertilizer and seed can be adjusted to the desired depths. Seed is usually placed at a depth of 3-6 cm, depending on the crop species. However, in cold climates and in the case of early sowing in dry conditions, deeper placement is recommended.
- In general, cover crops (particularly cereals) need to be terminated 2-3 weeks ahead of seeding to allow plant material to dry out and become brittle. The seeding equipment can cut through dry brittle cover crop residue more easily than through semi-dry cover crop residue, which is tough and hard to cut, and can end up being hair-pinned or dragged as implements cross the field.
- If the main crop is not sensitive to the allelopathic chemicals of the cover crop, seed the main crop directly into the live cover crop, then kill the cover crop.
- If hair-pinning occurs, suspend seeding. Hair-pinning of residue occurs when coulters push it into the soil rather than cutting through it, resulting in reduced seed-soil contact. It can occur on very wet soils, with tough residues, and with wet or wilted residues (even for residues that have been on the surface for weeks), especially if planting takes place in the morning when residues are still moist from precipitation or dew.
- In order to cut through thick amounts of residues, disc openers should be adopted. They must be operated at a reasonable speed (6 km/h); in hard or dry soils, the speed should be reduced. Discs must be checked for irregularities and sharpness to prevent clogging.

<u>Irrigated permanent raised bed systems:</u>

Conservation Agriculture is compatible with bed planting in irrigated **permanent raised bed** systems, and appropriate machinery can easily be developed. Crops can be sown on pre-formed permanent beds 60-90 cm wide by 15-30 cm high, with 1-3 defined planting rows per bed *(Figure 24)*. The beds are permanent in the sense that they are retained for many seasons for successive crop rotations. The furrows (unplanted space) between the beds supply the irrigation water and drainage and the tracks for wheels of machinery.

Figure 24. Configuration of conventional planting systems (left) vs raised beds (right)

Initial formation of beds requires tillage *(Figure 25)*. Subsequently, no additional tillage is used except for during the periodical reshaping of the beds. This operation also serves as mechanical weed control in the furrow areas. During bed preparation and planting operations, the equipment handles more than one row at a time. It is therefore essential that tractor drivers learn to keep the furrows/beds in straight lines with absolutely equal spacing, and to stay within the established furrows.

Furrows should be kept clean from excess residues (to improve water flow and avoid clogging). Harrowing should be done approximately 1-2 weeks after planting the second crop on

Figure 25. Preparation of permanent beds

the beds, depending on the amount of crop residues left, which in turn varies according to the crop, yield and amount removed for fodder or other purposes. Fertilizer can be applied as needed – both banded and top-dressed – even after crop emergence.

For salinity management in irrigated arid climates, Conservation Agriculture on raised beds is beneficial for soil water and salt dynamics.

Flat top beds:

- Raised beds provide better opportunities to leach salts from the furrow. If the beds are wetted from both sides, water moves from the two furrows towards the centre of the bed, and the salts move with the water and accumulate in the upper centre of the bed:
  - In single- and triple-row beds, care should be taken not to plant seeds in the centre of the bed.
  - In double-row beds, seeds are planted near each shoulder of the raised bed, away from the area of greatest salt accumulation.
  - In alternate rows, the salts accumulate near the non-irrigated shoulder of the raised bed. In this case, seeds should be off-centre, single-row planted on the shoulder of the bed closest to the watered furrow.
  - Surface mulching decreases soil water evaporation, increases infiltration and reduces the upward movement of salts (to the root zone) through capillary rise in response to evaporation gradients.

Sloping beds (i.e. non-flat tops):

- Seeds are planted on the sloping side. The seed row is placed just above the height of the waterline.
- Irrigation should be continued until the wetting front has moved well past the seed row.

Permanent raised beds are equally accessible and beneficial (sustainable and profitable) to small- and large-scale farmers. *Table 4* summarizes the main advantages of bed planting and furrow irrigation compared with tillage-based flooding irrigation systems.

Table 4. Comparison of Conservation Agriculture on raised beds vs tillage-based flooding irrigation systems

Indicator	Raised beds	Correlated benefits
Water-use efficiency	Improved up to 30%	▪ Yield potential of narrow beds is higher than wider beds.
Yields	Same or higher	
Field access	Easy, allowing for:	▪ Increased fertilizer efficiency due to fertilization when and where most needed by the plants (e.g. in the case of wheat, access by machinery with no compaction of beds allows for N fertilizer applications by banding at first node, or as top-dress application later). ▪ Reduced herbicides use due to mechanical weeding between rows. ▪ Easy seed multiplication and certification due to row planting.
Farmgate income	Higher, due to:	▪ On average 25% savings on operational expenses, including up to 60 litres/ha/year lower fuel consumption per unit area per unit output.

5.4 Post-planting operations

After sowing, selective herbicides (the same as for conventional tillage) are recommended as appropriate. Local (country or regional) information should be sought.

Post-planting operations in the row must use the same number of rows as the seed drill and follow in its tracks – as for any other operation in mechanized systems.

5.5 Phytosanitary management

When the same crops are repeated on the same land each year, diseases, weeds and pests tend to decrease profit margins *(Figure 26).*

Some farmers use a bare fallow period after a period of crop production to help eliminate crop-damaging pests or diseases, allowing the land some "rest" in the belief that it will regenerate its original state of productivity. However, leaving a field unused, or bare, for even a few weeks makes it vulnerable to wind and water erosion, as well as to harmful weeds that deprive the soil of nutrients, thus negating any benefits of not seeding a crop. Fields left fallow have no energy source for the soil other than spontaneous weeds, which ensure a continued supply of weed seeds. Consequently, rather than recovering the soil food web, this practice further degrades the soil organic matter, potentially resulting in severe soil erosion and run-off, and nutrients leaching when the rains start after the dry season.

A fallow period should therefore be avoided. However, if farmers are reluctant to give up the practice, tillage should be replaced by heavy grazing in early autumn to reduce weeds.

Figure 26. Barley crop badly infested with common wild oat, a noxious weed, Issyk-Kul, Kyrgyzstan

It is important to diversify crop successions within the rotation:

- Rotate among grass, legume and broadleaf crops.
- Switch between crops that have different pests and diseases.
- After shallow-rooting crops, plant deep-rooting crops (to take up leftover nutrients).

Crop rotations induce changes in the composition of the soil biota (not only of diseases). They stimulate growth of highly diverse microflora and microfauna that are antagonistic to pathogens due to the effects of competition and antibiosis (biological control), contributing to the maintenance of soil health (prevention). Several fungal and bacterial species act as biological control agents of root pathogens and, in general, contribute to the maintenance of soil health. For example, fluorescent *Pseudomonas* strains can suppress soil-borne plant pathogens (such as pathogenic bacteria and *Fusarium* spp.).

The higher the number and the wider the diversity of crops and genera involved in a rotation, the greater the biodiversity and the better the potential for biological control of diseases, pests and weeds through cutting the build-up of inocula or populations. It should be noted that barley-alfalfa is an example of a common crop succession in one year, but barley-alfalfa followed by barley-alfalfa is not a rotation, it is a repetition of a crop succession.

The recurrence of the same crop in the same field is determined by the complete decomposition of its residues, that is when spores from necrothrophic parasites die because their food has disappeared.

Table 5 presents some examples of crops not best suited to cultivation in sequence for phytosanitary reasons. However, the specific choice of crops to grow in the rotation depends on the history of bad pest or disease problems in farmer fields. Crop sequences for Eastern Europe and Central Asia are further discussed in *Annex 3.*

Weeds

Certain cover crops can themselves become weeds if they have persistent seed. For this reason, it is advisable to avoid using the same cover crop species every year.

Table 5. Less-than-ideal crop sequences

Main crop		Less-than-ideal subsequent crops
Wheat	+	Wheat, sorghum, sunflower
Barley	+	Barley, sunflower
Sorghum	+	Sorghum, sunflower
Oat	+	Oat, barley
Legumes	+	Legumes, rapeseed, sunflower (risk of *Sclerotinia*)
Cotton	+	Cotton, sunflower, sorghum (risk of higher density of rice stink bug *Oebalus pugnax*)
Sunflower	+	Sunflower, barley, cotton (risk of *Fusarium* head blight)
Rapeseed	+	Rapeseed, sunflower, pea, faba bean (risk of *Sclerotinia*), flax (sensitive to allelopathic compounds, risk of *Verticllium*)

Weed incidence can be reduced by seeding the next crop immediately or as soon as possible after harvest instead of leaving the land bare. In this improved fallow system, the (cover) crop is used for "remediation" purposes and does not need to be harvested. Improved fallows – as opposed to bare fallows – are very simple systems that simultaneously help avoid soil erosion, replenish soil fertility and save labour for weed control *(Section 6.2).*

Pests

There may be differences between the pest species occurring in Conservation Agriculture and in tillage-based systems, but not in the size of their populations. Tillage and/or the presence of crop residues directly affect species that spend one or more stages of their life cycle in the soil. However, these Conservation Agriculture practices also favour their **natural enemies,** and it is therefore rare to experience pest or disease outbreaks related to Conservation Agriculture.

Pests that were never a problem in tillage-based systems may appear in the no-till system. In general, Conservation Agriculture systems are at greater risk from the following insect pests:

- **Cutworm** larvae find a suitable habitat in crop residues for overwintering. Cutworms damage seedling plants by cutting them below their growing point, resulting in stand loss.
- **Grasshoppers** (most species) overwinter as eggs buried in the soil of an uncultivated field. Grasshopper incidence varies widely from year to year and seems to be regulated primarily by the weather and natural enemies.
- **Slugs** (*Deroceras* spp.). benefit from crop residues, which provide a source of food and habitat. However, slug populations thrive in the simultaneous occurrence of warm temperatures and high humidity – not a characteristic of the region.
- **Wireworms** (*Agrypnus variabilis*) in cotton and **false wireworms** (*Isopteron puctatissimus, Adelium brevicorne, Gonocephalum* sp., *Pterohelaeus* sp. and *Eleodes* spp.) in rapeseed, wheat, sorghum and sunflower are stand-reducing insects affected by tillage. Adults are attracted to fields with crop residue to deposit their eggs. However, the same habitat favours their natural predators: carabid beetles.

On the other hand, pests that were a problem in tillage-based systems may disappear with no-till:

- **Greenbug aphids** (*Schizaphis graminum*) – pests of wheat – do not respond well to the light reflection from straw in no-till and prefer to move to tilled fields with no residue cover.
- **Army cutworms** (*Euxoa auxiliaris*) – pests of wheat – prefer to lay eggs in bare fields and therefore are harmful in tilled fields.
- **Thrips** (*Thysanoptera*) – pests of cotton – are deterred by the mere presence of accumulated biomass (e.g. from a cover crop such as vetch or rye).
- **Hessian fly** (*Mayetiola destructor*) populations carry over in wheat, barley and cereal rye stubble and tend to be more of a problem in areas where continuous wheat is grown. Therefore, it is important to use diversified and sufficiently wide crop rotations.

In general, it is useful to grow flowering plants in field margins to increase populations of natural enemies and to reduce pest populations in adjacent field crops. For example, phacelia and buckwheat attract syrphid flies, which feed on aphids.

Diseases

Crop residues reduce the incidence of several splash-dispersed pathogens, for example:

- Pyrenophora triticirepenetis and *Puccinia* sp. in cereals.
- *Roselina* sp. in soybean.
- *Sclerotina sclerotiorum* in soybean and rapeseed.
- *Fusarium* sp. and *Helminthosporium* sp. in maize.

However, if contaminated residues from previous crops are not removed and if crop rotations are not sufficiently long, diseases may transfer (via raindrops) from the partially decomposed residues to the new germinating crop. This should nevertheless not justify burying crop residues with the plough. Ploughing in the crop residues distributes the infestation more uniformly and exposes more roots of the successive crop to the pathogen. It is recommended to remove only the infested crop residues from the field and to practise crop rotation as a prevention measure.

5.6 Nutrient management

With regard to nutrient management, **Conservation Agriculture systems share certain characteristics with tillage-based systems:**

- Crop nutrient needs are the same.
- A balanced nutrient and pH status is necessary to achieve good productivity.
- If soil analyses identify low values of certain elements, corrective fertilization and/or liming must be carried out in order to achieve at least medium, and with time, high levels of nutrients in the soil.

The difference between the two systems lies in the type and timing of application of nutrients. This section discusses strategies for nutrient management in Conservation Agriculture. Section 6 discusses strategies for the adequate selection of cover crops to help maintain and improve soil nutrients.

Liming

The critical percent base saturation[xii] in Conservation Agriculture is 40. Below this level, lime must be applied to raise it. It is important to note that Conservation Agriculture reduces the lime demand by 35-50 percent compared with tillage; however, local recommendations for lime application often refer exclusively to tillage-based systems and are thus an overestimate of the demand in Conservation Agriculture.

If lime is needed to neutralize soil acidity, it should be applied before the transition to Conservation Agriculture and – if possible – several months (one rainy season) before seeding to ensure longer reaction time. One lime application of approximately 1 tonne/ha every 2-3 years may be sufficient to regulate the acidity. Care must be taken not to apply more than 0.5-1 tonnes/ha (depending on soil texture and cation exchange capacity), otherwise there can be an overreaction at the soil surface, raising pH to above 7 (when micronutrients, especially manganese, become less available), or risking cementation problems on silty sands.

Gypsum application

Gypsum is broadcast in small quantities in order to: correct calcium deficiencies by supplying soluble calcium; reduce aluminium toxicity; and correct sulphur deficiency throughout the root zone. It may be applied with lime.

Nitrogen nutrition

Plants take up nitrogen in the inorganic form, as ammonium (NH_{4+}) and nitrate (NO_{3-}); they then convert it into amino acids. The availability of nitrogen for crops depends on the amount of inorganic nitrogen present in the soil, provided it is not immobilized by soil microorganisms.

During the first few years of Conservation Agriculture, nitrogen is often found in organic form (immobilized) and thus is not readily available to plants. In the initial years (when the mineralization process is slow), it is advisable to apply nitrogen in mineral form.

In this respect, it should be noted that urea rapidly converts to the ammonium form – especially in the presence of crop residues that release urease (a catalytic enzyme of the process). Ammonium is retained in the soil by soil organic matter (which is negatively charged). However, in aerobic conditions, temperature-sensitive soil bacteria convert it to the nitrite form (nitrification). This process is followed by further oxidation of the nitrites to nitrates. Nitrates, which are negatively charged, tend to be lost: by leaching in moist conditions; and by denitrification as greenhouse gases (N_2O and NO) in anaerobic and dry conditions. This is why it is recommended to always incorporate urea (to the side of the row of seeds) and not to top-dress it.

Over the years, increased biological activity will efficiently recycle plant nutrients and reduce the fertilizer requirement per unit of output.

In general, in Conservation Agriculture systems, nitrogen may not be readily available during the early part of the growing season. One reason for this is that crop residues left on the soil surface decompose more slowly than those incorporated in tillage-based systems because of the limited contact between the soil microbes and residues lying on the soil surface. This is true in the presence of both low and high C/N ratio residues. In addition, where larger quantities of crop residues with high C/N ratio remain in the field, some of the nitrogen is immobilized by the decomposition process. Therefore, in order to avoid lack of nitrogen for plant growth as a result of slow mineralization or immobilization processes:

- Allow time for organic matter to decompose before sowing, if appropriate.
- Apply N fertilizer at seeding. Always apply N fertilizer in bands to ensure more efficient use. In mechanized systems, direct drills place the fertilizer in a band underneath the seeds – a practice which also avoids seeds being damaged by the toxicity of the fertilizer.

Spring-seeded crops generally use soil nitrogen more efficiently than winter crops. Their requirement for nitrogen coincides with the normal period of soil nitrogen release, whereas winter crops require nitrogen in early spring (at vegetative regrowth) when the soil is still too cold to count on the microbial delivery of nitrogen.

Phosphorus nutrition

Phosphorus is usually highly immobile. In soil, the amount of total phosphorus actually available to crops is about 0.5-2.0 percent, and much of this variation depends on the soil fixation capacity (by aluminium, iron or calcium) and the level of SOM. Soils with a high clay content require increased P fertilization.

P fertilizer should be applied as a band near the seed row at seeding to help overcome problems of soil fixation capacity and phosphorus immobility. Phosphate should not be broadcast together with surface application of lime, since a surface pH close to 7 causes reduced phosphorus availability. Soils with pH values of 6-7.5 are ideal for phosphorus availability, while pH values of < 5.5 and 7.5-8.5 limit phosphorus availability to plants due to fixation.

Short-cycle crops have a higher phosphorus demand than long-cycle crops that have more time to extract it.

Potassium nutrition

The decomposition of crop residues at the soil surface slowly releases potassium in the surface soil layer, and crops develop superficial roots that absorb nutrients and mobilize them within the profile. However, this uptake can be affected by weather conditions. When surface soil layers become drier, root development in deeper portions of the soil profile increases. When this happens, the portion of the root system actively taking up nutrients can be below the zone of highest nutrient concentration and can inhibit root growth (and nutrient uptake) early in the season.

Banded K fertilizer should be applied below or to the side of the seed row at seeding to enhance early seedling growth.

6

Designing cropping systems for specific goals

Chapter 6

6. Designing cropping systems for specific goals

Management measures should be oriented towards maintaining and improving soil productivity while capitalizing on soil moisture. Cover crops, together with no-till, offer great potential for achieving this objective.

For selection of the most suitable cover crop system, farmers need to follow the steps below:

- **Step 1: Set goals for the farming system's specific needs** (see Section 6.1 for characteristics and potential of the various cover crops). In addition to improving the soil and controlling weeds, cover crops can provide many other benefits. However, cover crops are not do-it-all crops. Farmers need to establish priorities for the desired cover crop effects, including provision of nitrogen, addition of organic matter, improved soil structure, reduction of soil erosion, weed control and increased soil moisture.
- **Step 2: Identify when the cover crop can be grown in the crop rotation** *(see Annexes 1 and 2).* Field operations and labour needs for the production of the main crop take precedence over cover crop management: it is important to minimize potential conflicts. Once the opportunity for cover crop growth and termination is identified, species selection depends on the climatic and soil conditions during the growing window.
- **Step 3: Select cover crop species** (or mix) to meet the goals (Step 1) and requirements (Step 2). As Farmer Field School facilitators come close to selecting a particular cover crop system for trial, it essential to consult the farmers (see *Section 6.2* for a decision-making tool for farmers and facilitators/extension agents) *(Figure 27).*

If seeds of a particular crop or variety cannot be found in the country, it is possible to order them from other countries *(Box 10).*

Box 10. Purchasing seed material abroad

Documents needed for the transfer of seeds across borders:

- Quarantine import permit issued by the phytosanitary control body of the destination country (i.e. the country to which the seeds will be shipped).
- Phytosanitary certificate from the country of origin (i.e. the country from which the seeds will be imported) stating that the seeds are free of pests and diseases. The shipper/seed supplier often supplies this certificate.

Steps to obtain necessary documents (check with the Ministry of Agriculture in the destination country):

- Obtain the quarantine import permit, which could contain specific seed treatments required for entry.
- Send the import permit to the seed supplier in the country of origin, so that the supplier can carry out any specific seed treatments outlined therein; list the treatments in the phytosanitary certificate. Both documents should be included in the box of seeds to be shipped (originals may be required).
- Request that shipments be sent via a reputable carrier. Extra costs can be incurred if it becomes necessary to hire a separate courier to clear seeds through customs once they arrive in the destination country.

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Figure 27. Trials of main crop (left) and cover crop (right) varieties, Hisor, Tajikistan

6.1 Cover crops characteristics

This section provides a definition of cover crops *(see Box 11 at page 73)* and discusses their selection and management in relation to achieving specific goals: soil fertility management, soil structure improvement, weed management and phytosanitary management. Each goal generates benefits that are important for the farmers in the region to successfully adopt Conservation Agriculture. *Box A3.1 (Annex 3)* outlines the crop sequences required for each goal.

Goal: soil fertility management

Most nutrient losses occur when there is no crop in the field. The soil is most exposed during two periods: from seeding until the crop has grown big enough to create a dense canopy; and after the harvest. The appropriate selection of cover crops can help replenish soil nutrients in two different ways:

- **Scavenging cover crops recycle nutrients** leached to the deeper soil layers and no longer available to crops. Selected cover crops should have an extensive root system that develops quickly after seeding and captures soil nutrients remaining after the harvest of the previous crop. *Table A2.2 (Annex 2)* provides examples of cover crops and their distinct nutrition needs.
  - **Nitrogen.** The best cover crops to use for nitrogen (nitrate) conservation are non-legumes. They should be planted as early as possible to maximize nitrogen uptake and prevent leaching.
  - **Phosphorus.** In general, legumes need phosphorus for nitrogen fixation, but are poor scavengers of phosphorus in the soil (taproot). However, as legumes acidify the soil, they tend to make phosphorus more available. Grassy species store and supply more phosphorus than legumes because they have a finer root system and more surface area. In mixed legume-grass systems, the legume cycles nitrogen to the grass and the grass cycles phosphorus to the legume.
  - **Calcium and potassium.** Calcium and potassium have a tendency to travel in the soil solution, and can be brought up from deeper soil layers by any deep-rooted cover crop.

Box 11. Cover crops

Cover crops are plants grown to improve soil fertility and/or control weeds. In general, cover crops should have the following characteristics/functions:

- Not compete (for nutrients, space and time) with market crops.
- Involve minimal or no cash costs (seed material). Cover crops cost the farmer nothing once the seeds have been purchased the first time. This implies that year after year farmers can produce their own seeds for future seedings. Preferably, cover crops should also save farmers money, leading to a reduction in the amount of money spent on chemical fertilizers and herbicides.
- Be easy to seed, establish and manage. Cover crops should not lead to an increase in the amount of work for farmers. When intercropped, cover crops should be able to shade out weeds and save on labour. In many cases, this reduction in labour can counterbalance the labour needed for seeding and cutting the cover crop.
- Provide physical soil protection (prevent/minimize soil erosion, water evaporation and high soil temperature) and good weed control. Cover crops should be able to grow rapidly under local conditions and cover weeds fast. This implies that cover crops should have no disease or pest problems that are serious enough to significantly diminish their growth.
- Produce a positive residual fertilizer effect on following market crops. The production of above- and below-ground biomass in situ recycles nutrients, feeds soil life, improves soil structure and, over time, accumulates SOM.
- Reduce pest and disease infestation. Some cover crop species can also be substituted for certain pesticides.

It is important to give cover crops the same respect as any other crop in the rotation and plant them in a timely manner. Cover crops may be sown as follows:

- Independently, in succession.
- In association with farmers' main crops (shade-tolerant cover crops):
  - At about the same time (intercropped).
  - Before the crop is harvested (relayed). In order to ensure adequate sunlight for the cover crop, seed before full canopy closure of the main crop, or just before the canopy starts to open again as the main crop starts to die. If possible, seed just before a soaking rain is forecast; alternatively, irrigate after seeding. Species with small seeds (e.g. clovers) do not need a lot of moisture to germinate, but larger-seeded species need several days of moist conditions to germinate.
  - As living mulches. Living mulches are cover crops that co-exist between the rows of the cash crop during the growing season; they continue to grow after the harvest of the main crop. The living mulch can be an annual or perennial plant established each year, or it can be an existing perennial grass or legume stand into which a crop is planted. Living mulch systems are dependent on adequate moisture for the cash crop. They should be chosen and managed to minimize competition with the main crop while maximizing competition with weeds. To avoid competition for water with the main crop (especially with spring crops), living mulches (especially cover crops that regrow during the warm season) should be adequately controlled (chemically or mechanically). Living mulches are viable for: vineyards, orchards and cereal-based systems (e.g. maize and small grains).

Depending on the intended goal of the cover crop system, cover crops are cut down after they have produced seeds (for food/feed, commercialization and/or future seedings) and are left on top of the soil. Alternatively, they are terminated earlier in the season before they set seeds.

Root systems stabilize the soil and reduce nutrient losses. In addition, some cover crop roots increase plant-available macronutrients, as is the case for phosphorus. Phosphorus is only slightly soluble (i.e. plant-usable), therefore it does not generally leach, but may not be easily available for uptake by plants. Cover crops such as buckwheat and lupins secrete acids that turn phosphorus into a more soluble form. Furthermore, at the end of the crop cycle, decaying roots contribute about 30 percent additional biomass compared with the tops, and slowly release approximately 40 percent as much nitrogen as the tops.

- **Cover crop roots intercept nutrients,** which are then held within the plants and are only released back into the active organic matter when the cover crop dies and decomposes. To make the recycled nutrients available to the following crop, once the cover crop cycle is complete or once the cover crop has been terminated, residues should be left on the soil and not removed. As the dead cover crop residues decompose, nutrients are released slowly to the soil allowing the plants that follow to make use of them gradually. The amount of nutrients effectively available for uptake by the immediately following crop is mainly related to the following:
  - The amount of **nutrients captured,** which in turn depends on the amount of nutrients available in the soil profile, and on biomass production and composition (species-specific). *Box 13* includes an estimation of the quantity of nitrogen content in the biomass of some cover crops.
  - The amount of **nutrients released** *(see Box 13 at page 76),* which in turn depends on the C/N ratio, and hence on the time of termination of the scavenging cover crop or mix *(Box 8).* Optimum termination time must balance the need to produce enough biomass with the need to keep the C/N ratio in the 20-30 range. Timely termination is especially important for grass cover crops.

It is important to note that when cover crops are used in soil fertility management, the main priority of the cover crops is not seed production.

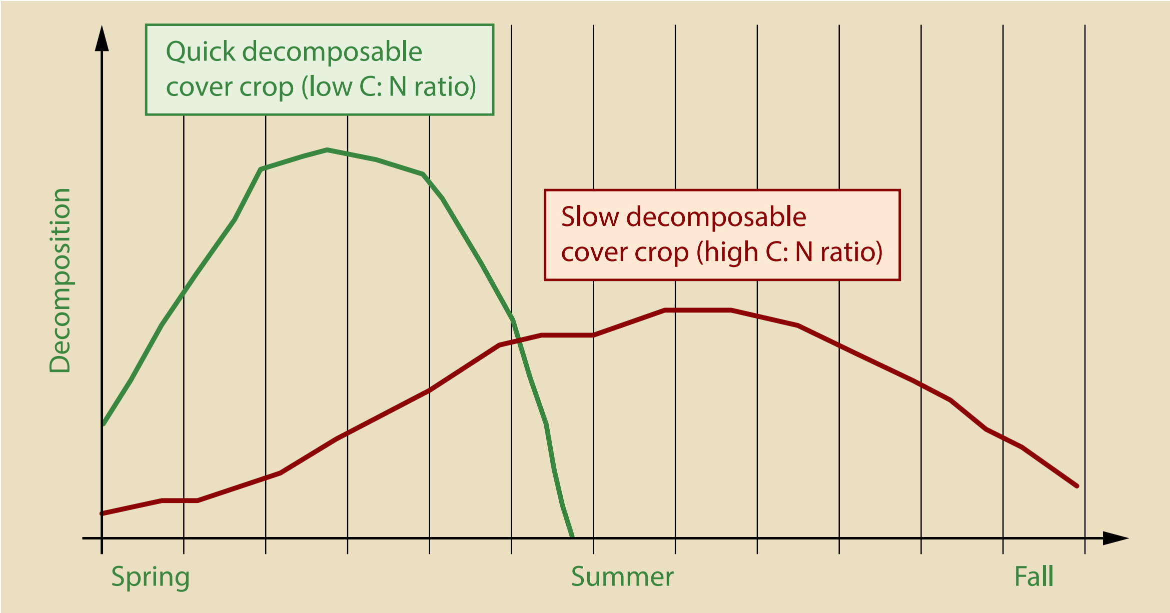
In fact, cover crops are used in replacement (partial or total) of mineral fertilizer inputs, and often need to be terminated before seed deposition.

When selecting cover crop species and planning for their management, both short- and long-term effects on soil and crop nutrition should be accounted for *(Figure 28).*

In the case of crop residues with high C/N ratio, N fertilizer should be applied at seeding to avoid initial lag in availability of nitrogen to the main crop.

In this system, cover crops allow the soil to grow in two directions:

- At **the surface,** due to the deposition and slow decomposition of organic matter. Keeping nutrients in an organic form is the most efficient way to keep them cycling in the soil (especially important for phosphorus).
- At **depth,** due to the passage of roots and soil macroorganisms able to break compacted layers.



Source: PennState Extension (2011)

Figure 28. Effect of ease of decomposition of crop residues on soil structure

Soil improvement is a long-term process that may not be immediately noticeable to farmers. Although organic matter benefits accrue slowly over decades, taking action now to improve soils makes good business sense and will help maintain productivity and reduce risks and costs in the future *(see Box 12 at page 75).*

The goal of **nitrogen nutrition** requires particular attention. Where access to mineral fertilizers is difficult, it is possible to supply the necessary nitrogen through the use of legume cover crops. Legume plants are capable of adding nitrogen to the soil through symbiotic biological N_2 fixation in the nodules formed by *Rhizobium* bacteria on their roots. The fixed nitrogen is almost immediately translocated into the stems and leaves of the growing legume (to form, for example, proteins or chlorophyll) and does not become available to the next crop until the legume decomposes.

It is important to note that in this system – for the purpose of nitrogen nutrition – the production and harvest of cover crop seeds is not the priority and is not always possible. In fact, to obtain maximum legume nitrogen, the legume cover crop should be killed in the early- to mid-blossom stage, and its residues returned to the soil. Subsequent crops can take advantage of this nitrogen.

Box 12. Organic matter – farmers "listen" with their eyes

In most cases, significant improvement in productivity through cover crops does not occur until the second cropping cycle. This means that it is not easy to convince farmers of the importance of organic matter.

Simple demonstrations (e.g. heavy application of animal manure on a small plot or showing how organic matter increases the water-holding capacity of soil) would help make farmers realize the value of organic matter for their fields and convince them of the importance of cover cropping.

It should also be noted that not all legume crops make the same percentage of fixed nitrogen available to the soil when the main crop needs it *(see Box 13 at page 76).* Therefore, in some cases, the use of fertilizer integration at the appropriate time of year (at exactly the time the crops are likely to run out of the nutrients supplied by cover crops) may still be advised to supplement soil nutrients.

Box 13. How much nitrogen is made available from a cover crop?

To find out if farmers might need more nitrogen than their cover crop will supply:

- **Step 1:** Calculate the amount of nitrogen in the cover crop. Laboratory analyses can determine the exact nitrogen content in the plant tissue. However, the height of the cover crop, the ground cover percentage and the average nitrogen content percentage of different cover crop types give a quick and rough guide to the actual nitrogen content of the cover crop stand:
  - At 100% ground cover and 15 cm height, most non-woody (i.e. herbaceous) legumes contain roughly 1 500-2 000 kg/ha of dry matter (each centimetre is conservatively considered to provide 100 kg of dry matter). For each additional centimetre, add 170 kg.
  - If the stand has less than 100% ground cover, multiply the dry matter content by the ground cover percentage.
  - Multiply biomass yield by the average percentage of nitrogen content reported in the table below.

Estimation of the quantity of nitrogen accumulating in the above-ground parts of different cover crops

Cover crops	% N contents in the above-ground parts		
	Before flowering	At flowering	Notes
Annual legumes	3.5–4	3–3.5	After flowering, N in the leaves decreases quickly as it accumulates in the growing seeds.
Perennial legumes	2.5–3	2–2.5	They have a significant number of thick, fibrous or woody stems.
Grasses and Brassica	1.5–2.5	1–2	Other covers (e.g. Brassica and buckwheat) are generally similar to, or slightly below, grasses in their N content.

Note: Use the higher end of the range for young(er) material

- **Step 2:** Estimate how much nitrogen will be available to the main crop in the current growing season. The amount of nitrogen in the cover crop (Step 1) by must be divided by 3.

When **growing legumes,** it is important to consider the following:

- Sufficient *Rhizobium* bacteria must be present in the soil to give good root nodule formation, and hence N_2 fixation. If a legume has not been grown before, the proper inoculant should be added at seeding *(see Box 14 at page 77).*
- In the case of climbing legumes, standing stubble from the previous crop provides benefits: shelter (including from wind) to young seedlings; and physical support that helps increase plant height at harvest (thus reducing harvest losses).
- Hay production (in the case of complete removal of the above-ground parts) and bean production are not compatible with the use of legumes for fertilization purposes. Once

Box 14. *Rhizobium* inoculant types for leguminous species

Estimation of the quantity of nitrogen accumulating in the above-ground parts of different cover crops

Legumes	Rhizobium group and species
Alfalfa, yellow and white sweet clover	Alfalfa group (*Sinorhizobium meliloti*)
Cowpea, sunn hemp	Cowpea, peanut, and lespedeza group (*Bradyrhizobium* sp. [Vigna])
Kidney bean (*Phaseolus vulgaris*)	Dry and snap bean group (*Rhizobium leguminosarum biovar phaseoli*)
Lupin	Lupin group (*Bradyrhizobium* sp. [Lupinus])
Soybean	Soybean group (*Bradyrhizobium japonicum*)
Crimson clover, red clover, white clover	True clover group (*Rhizobium leguminosarum biovar trifoli*)
Field pea, winter pea, lentil, faba bean, common vetch, hairy vetch	Vetch/pea group (*Rhizobium leguminosarum biovar viceae*)

the legume stops actively growing, it halts the N_2-fixing symbiosis. In annual legumes, this occurs at flowering: no additional nitrogen gain occurs after that point, and a large portion of legume biomass nitrogen is transported into the seeds.

- Legume-grass (–broadleaf) cover crop mixes offer the following advantages:
  - Better weed suppression than legumes in pure stands.
  - Balancing of the C/N ratio over the crop rotation.

Mixtures can be an effective management tool to reduce leaching while improving the availability of nitrogen for the next crop. Nitrogen is mineralized more rapidly from mixtures than from pure grasses. For example, an autumn-seeded mixture can be adjusted to residual soil nitrogen levels. When nitrogen levels are high, a grass-dominated mixture is selected and when nitrogen levels are low, a legume-dominated mixture is chosen. *Table 6* provides information on "multi-service" crop mixes and on their management.

Goal: soil structure improvement

Cover crops can help relieve problems of soil compaction and poor drainage thanks to their roots: **active roots** hold soil particles together, create channels and produce exudates that

Table 6. Examples of cover crop mixes that provide multiple functions

Cover crop mixes	Purpose	Management	
Either of the following perennial legume crops: ▪ Alfalfa ▪ Sainfoin ▪ Birdsfoot trefoil (*Lotus corniculatus*)	Plant nutrition: N fertilizer	This system requires that the perennial legume is controlled (not killed) to avoid competition for water and space with the main cereal crop.	Grow a winter cereal in the living legume crop. After the harvest of the cereal crop, leave the legume to grow undisturbed and cut it later. After the first cut, if the legume continues to grow, cut it again and leave the residues on and for the soil. Never forget to feed the soil!
+ one winter cereal of choice: ▪ Wheat ▪ Oat ▪ Barley	Revenue		

Table 7. Cover crop mixes that provide biological soil tillage, soil protection and/or feed (for hay or for grazing before seeding the next crop)

Cover crop mixes	Purpose		Management	
Forage radish (*Raphanus sativus* var. *longipinnatus*)	Biological soil tillage:	Subsoiler (deep soil penetration)	Only one pass and little power is required.	Terminate the cover crops mix before seeding the main crop.
+ one or more of the following functional crops: ▪ Phacelia ▪ Annual ryegrass ▪ Niger (*Guizotia abyssinica*)		Rotary harrow (soil tillage for seedbed preparation)		
+ one or more of the following annual legume crops: ▪ Common vetch ▪ Clovers (*Trifolium* spp.) ▪ Peas (*Pisum* spp.) ▪ Faba bean ▪ Grass pea	Plant nutrition: N fertilizer			

facilitate the binding of aggregates; **decomposing roots** stimulate biological activity and the formation of soil aggregates. *Table 7* provides examples of structuring and decompacting crop mixes and their management. **The role of rooting systems** can be summarized as follows:

- Cover crops that produce fibrous, extensive root systems that hold soil together and manage to penetrate dense soils are important for soil structure improvement (e.g. grass species with extensive, fibrous root systems, such as oat, cereal rye and annual ryegrass).
- Plant species that produce large amounts of root biomass can help alleviate the effects of soil compaction (e.g. grass species, such as maize, sorghum and pearl millet).
- Deep-rooted plant species can help break through compacted layers in the soil and improve drainage in two ways:
  - Roots create channels through which water can move as the root systems decompose after death.
  - Decomposing roots add organic matter at depth, improving the soil structure and the water-holding capacity of the soil.

- Tap-rooted species penetrating subsoil layers create gateways for the roots of the succeeding crop, which can extract moisture from deeper depths than the same crop not following a deep-tap-rooted cover crop (e.g. species of the Brassica family with typically long and strong tap roots that can penetrate compacted soil layers).
- Cover crops that grow during the cold season are better suited to loosen hard layers in the soil, because roots can grow into those layers when they are softened by plentiful water (less likely in the summer).

Furthermore, cover crops (both living and not) can help maintain or improve soil structure thanks to their rainfall-buffering capacity and ability to protect from direct heat, thus avoiding soil erosion, compaction and crusting. Generally, soil protected by a superficial layer of organic matter improves the capture and use of rainfall through increased water absorption and infiltration and decreased evaporation from the soil surface. On poorly drained soils, living cover crops can help remove excess spring moisture. If the cover crop leaves behind too much residue, it should be moved out of the seed zone to dry out the soil while maintaining the benefits of mulch between the rows.

Finally, when cover crops die and decompose, **soil aggregation** is affected as follows:

- Crops with a **low C/N ratio** improve aggregate stability in the short term. Bacteria – that thrive on the residue – release large quantities of organic molecules (e.g. polysaccharides and other easily degradable organic substances) that act as glue and hold aggregates together. This effect lasts only as long as there is decomposable residue.
- Crops with a **high C/N ratio** improve aggregate stability more gradually. They have a slow release of polysaccharides, which improve soil structure more slowly but for a longer time than cover crops with a low C/N ratio.

It is important to note that **in Conservation Agriculture, the main use of cover crops is not seed production.** Cover crops are used in the replacement of mechanical soil tillage. However, soil structuring and seed production may be compatible.

Goal: weed and soil erosion management

Early crop establishment and a good dense crop stand help suppress the emergence of weeds and reduce the erosive forces of water and wind by means of their canopy, which intercepts rain and acts as a windbreak.To complement the contribution of residues produced by the main crop, the selected cover crops should have a high potential for biomass production.

Possible cover crops include:

- non-legumes (e.g. cereal rye, triticale, and buckwheat if a niche in the warm season is identified);
- high-biomass legumes (e.g. winter pea or hairy vetch, both of which would also provide nitrogen); and
- many of the species that are good nutrient scavengers.

It is key to choose species that rapidly cover the soil surface. *Tables 8 and 9* show the soil cover during the vegetative period provided by different species of, respectively, warm- and cold-season cover crops.

Table 8. Soil cover during the vegetative period of warm-season cover crops

	Day after emergence	Soil cover intensity													
		45	60	75	90	105	120	135	160	180	195	225	255	270	290
Cover crop species	Jack bean (*Canavalia ensifermis*)	▬	■	■	■	■	■	▬	▬	▬	—	—	—	—	—
	Sunnhemp (*Crotolaria juneea*)	—	—	▬	▬	▬	▬	▬	—	—	■				
	Pigeon pea (*Cajanus cajan*)	—	▬	▬	▬	■	■	▬	▬	▬	—	—	—	—	—
	Cowpea (*Vigna unguieulata*) var. Colorado	—	—	—	—	—	■								

Source: Florentín, 1999 (adapted)

Table 9. Soil cover during the vegetative period of cold-season cover crops

Day after emergence		Soil cover intensity						
		15	30	45	60	75	90	105
Cover crop species	Sunflower							
	Triticale							
	Oilseed radish							
	Hairy Vetch							
	Bitter White Lupine							
	Sweet White Lupine							
	Peas							

Source: Florentín, 1999 (adapted)

Once flattened, or once the cover crop's cycle has ended, the durability of the dead cover on the soil depends on the following factors:

- **Quantity of biomass produced** – different species of cover crops contribute different quantities of organic matter *(Table 10).*
- **Speed at which the residue decomposes** – which, in turn, depends on C/N composition *(see Box 8 at page 54)* and on microbial activity *(see Box 3 at page 14).*
- In order to keep the soil protected as long as possible without penalizing the nutrition of the subsequent crop, a combination of high above-ground biomass and moderate-to-high C/N ratio residues is desirable. The crop rotation would need to be devised to return crop residues with an average C/N ratio in the 25-30 range. A higher concentration of slowly decomposable crop residues alone will cause temporary soil nitrogen immobilization during the early stages of the decomposition process, whereas residues with a lower C/N ratio would improve nitrogen availability but would decompose too quickly to guarantee the necessary soil protection. This means that it may be beneficial to include a non-legume crop to provide structural carbohydrates that break down more slowly than legume residues alone. If the grass dominates the mixture and it is terminated late, the C/N ratio may be high and nitrogen can be tied up and not available to the following crop. To avoid this, nitrogen should be applied at seeding of the next crop. An example of high biomass (5 000-7 000 kg/ha of dry matter) producing legume-based cover crop mix: vetch + phacelia + niger; hairy vetch + triticale.

Table 10. Estimation of the quantity of dry matter produced by the above-ground parts of some cover crops

Cover crop types	Cover crop species	Dry matter (kg/ha)
Warm season:	Pigeon pea	9 200
	Jack bean	7 700
Cold season:	Oilseed radish	4 800
	White lupin	4 010
	Hairy vetch	2 900

Source: Derpsch and Florentín, 1992 (adapted)

- **Environmental conditions** – temperature, humidity, soil oxygenation and pH all affect microbial activity.

Whenever possible, seeding of the subsequent crop should follow soon after the termination of the cover crop.

Goal: pest and disease management

In pest and disease management, as in weed control, **prevention is key.** Farmers should diversify the crop rotation, opting for longer crop rotations and ensuring the inclusion of crops that favour natural enemies of the pest connected to each crop currently grown. Certain cover crops are good hosts for populations of beneficial insects. Generalist predators feed on many species and act as important biological control agents. When pests are scarce/absent, these predators subsist on nectar, pollen and alternative preys hosted by cover crops.

Some cover crops **host beneficial insects:**

- Various vetches, clovers and certain cruciferous crops can support high densities of predators of thrips and aphids, such as insidious flower bugs (*Orius insidiosus*), bigeyed bugs (*Geocoris* spp.) and various ladybirds (*Coleoptera coccinellidae*).
- Some covers can enhance a resident parasitic nematode[xiii] population if grown in succession with (before or after) another crop that hosts a plant-damaging nematode species. Crop succession should not favour resident parasitic nematodes. If the nematode community contains diverse species, no single species will dominate. Once a nematode species is established in a field, it is usually impossible to eliminate it. If a nematode pest species is absent from the soil, seeding a susceptible cover crop will not give rise to a problem. In a sound crop rotation, specific cover crop species should be matched with the particular nematode pest species. *Table A2.2 (Annex 2)* provides a list of cover crops with documented nematicidal properties against at least one nematode species. For example, cereal rye and sorghum are known to suppress rootknot nematodes and soil-borne diseases.

Other plant species are **sensitive to certain pests:**

- Sunflower and colza attract slugs. In the first years after conversion to Conservation Agriculture – as long as slug predators have not installed in the fields – it is recommended to avoid growing sensitive crops. Phacelia should be grown as a cover crop and/or in hedgerows to favour carabid beetles, which feed on slugs.
- Many legumes are excellent hosts for nematodes, and too short rotations cause the rapid increase of soil nematode populations.

Certain crops **suppress particular disease or pest organisms:**

- In potato-based crop rotations, oat, white lupin and field pea help reduce *Rhizoctonia solani* stem lesions, and sorghum helps reduce *Verticillium* wilt.
- Brassica varieties release biotoxic metabolic by-products active against bacteria, fungi, insects, nematodes and weeds.

6.2 Fitting cover crops in the cropping system

Farmers and extension workers have to "adjust" the cover crop to fit into the already-existing cropping system, rather than adjust the farming system to fit some way of growing a cover crop. Acceptance/adoption of elements of innovation are more easily achieved when farmers are not required to make a major effort to adapt. When devising an agronomic solution, it is essential to take into account farmers' culture and their reluctance to change. Farmers will often refuse to plant cover crops solely for agronomic reasons if the land can instead be planted with food/market crops. Cropping systems must ensure a balance of cash crops and soil-building cover crops.

When a new cover crop is introduced, the main crop must meet the following criteria:

- First, farmers know how to grow it.
- Second, either it is a cash crop, or it contributes to self-sufficiency in food production *(Figure 29).*

The cover crop is chosen based on one or more of the following criteria:

- It has a pivotal agronomic role (e.g. soil/crop nutrition, soil decompaction, soil buffering, weed/pest suppression).
- It is a low-cost production input.
- It provides food (diet diversification) or feed.
- It is a valuable output.

If the cover crop produces food, it can be grown like any other equally valued food crop. If the cover crop does not produce food, it must satisfy one or more of the following criteria:

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Figure 29. Field of maturing wheat under Conservation Agriculture, Armenia

- It is grown on land that has no opportunity cost[xiv] for the purpose of rehabilitating it or producing additional biomass (e.g. jack bean, which withstands very poor soils and can be used to rehabilitate degraded lands)
- It can be grown as an improved fallow – if the soil is very poor when the fallow starts, farmers must use hardy species (e.g. jack bean and sunn hemp).
- It can be grown in succession after the harvest of the main crop:
  - in short windows of warm weather (e.g. buckwheat – which is unsurpassed in the production of biomass to smother and suppress weeds – millet, sorghum and cowpea); or
  - as a late autumn crop (e.g. cereal rye – which can be grown as a stand-alone crop or in mix with hairy vetch, and harvested in late spring).

Note that **early seeding,** whenever appropriate, is a strategy to extend the growing window. Some crops are more suited than others to early seeding. In general, winter annuals should be seeded at least six weeks before a killing frost (usually from late September to early October). For example, clovers need to be established in late summer, while wheat and cereal rye can be planted later, although that reduces their N scavenging; rapeseed, on the other hand, is suited to late autumn seeding.

- It can be grown together with another food or market crop with a compatible cycle:
  - **intercropped** with the main crop and then left to grow after the main crop is harvested; or
  - **relayed** into the main crop (shade-tolerant crops can be intercropped into the established crop and will then continue to grow after the harvest of the first crop).

In **relay cropping,** small grains requiring a relatively superficial seedbed can be broadcast into an established cereal crop. Examples of crops suited to **broadcast seeding** include clovers and alfalfa; both can be sown into cereal crops (e.g. winter wheat or cereal rye) in the spring. When direct seeding into an “aggressive” cereal (e.g. triticale or barley), apply the seed early – at the beginning of tillering.

The **direct seeding** of a legume crop into a forage grass stand (i.e. killing the forage just before seeding) may have negative outcomes: poor germination due to reduced seedbed soil moisture; “aggressiveness” of the cereal crop; or microbial nitrogen immobilization. For this reason, time should be allowed between seeding and forage termination.

Prior to seeding, it is important to reduce competition by grazing short, hay cutting/mowing short and/or applying herbicides. The grass regrowth should be well controlled by periodically grazing or mowing the grass crops to favour growth of the newly established seedlings. During the autumn, ensure that perennial weeds are killed.

When **frost seeding** into a forage grass stand, seed should be applied when the stand is not actively growing and while the soil has a tendency to freeze for several weeks: overnight frosts followed by daytime thaws result in the seed becoming buried at a shallow seeding depth. At vegetative regrowth, the stand should be grazed or mowed periodically to prevent the grass crop from crowding out the new seedlings. It is important to monitor grazing height to avoid damage to new seedlings and prevent overgrazing (i.e. grazing too short).

Decision-making tool for the identification of suitable cover-crop-based systems

This seven-step tool allows to assist in the selection of most appropriate options (economically viable and environmentally sustainable) to meet farmers' needs. The cover crop systems recommended by the decision tool should be further adapted to the context-specific social, economic, environmental and climatic conditions.

Step 1. Identify farmers' needs and priorities

Farmers should start by identifying the most important factors limiting the productivity and sustainability of their production system and deciding which goals they aim to achieve *(Section 6.1).*

As well as considering desirable characteristics, farmers should also be aware of characteristics they do not want. Trade-offs may need to be made between goals. To make a sound economic assessment of the alternatives, farmers should consider the cost and availability of seed and water, as well as the number and types of field operations required throughout the crop rotation for the various cropping systems. In particular, cover crop use must be balanced against the economy of irrigation to produce the residue or against the value of the residue: for example, on the one hand, the main crop may produce insufficient residue for soil cover, but on the other, establishing cover crops would compete for water needed by the subsequent main crop. Nevertheless, in a medium-term perspective, producers growing low-residue crops on soils subject to erosion may wish to introduce high-residue crops in the rotation (e.g. with minimum irrigation input).

Box 15 provides a checklist to help farmers assess appropriateness and feasibility for growing cover crops.

Box 15. Are cover crop systems suited to all farmers?

The following questions are to be discussed with the farmers, who should respond in an atmosphere of trust and confidence:

- What percentage of farmers in the area still fallow land? For how many years at a time? Do farmers plant or harvest anything together with the natural vegetation on their fallowed land?
- What is the average size of the plot(s) belonging to each household? How many households have larger holdings (i.e. family farms) and how much land do they have?
- Do farmers have any preferences as to how they want to solve the soil degradation problem, and if so, what are the options? Have they tried some techniques already? What were the results? Why?
- Can farmers be sure they will be able to continue cultivating the land they have improved?
- What agricultural activities are carried out by women? What rights do they have related to crop or animal selection and use? How do women's priorities for the agricultural system differ from those of men? For example, do women want to plant different crops from men?

- If farmers do not include soil health among the three most important problems, and if they express little interest in working on soil health, go to Step 2. (Cover crops are not always the most appropriate solution for some farmers.)
- If farmers identify soil health as a major problem and show a strong interest in solving this problem, go to Step 4.

Step 2. Take into account the farmer's interest

Farmers must be able to consider the possibility of not working in soil health.

- If the decision is not to work in soil health, go to Step 3.
- If the extension officer or trainer who is using this tool is convinced that soil health is a major problem in the area and success in tackling it is definitely possible, go to Step 4.

Step 3. Acknowledge the end

This is the end of the programme's work in cover crops. In the future, something may change to make cover crops more attractive to farmers, but for now, cover crops will not be part of the cropping system.

Step 4. Verify the presence of a successful system nearby

It is important to identify any successful cover-crop-based system and to gauge farmers' awareness and interest.

- If such a system exists, ask the following questions:
  - Do smallholder farmers show an interest in the system?
  - Are they already practising or adopting it?
  - Are they adopting it in the absence of subsidies or of a programme promoting it?

  If the answer is affirmative to most of these questions, go to Step 5.

- If such a system exists, establish the farmers' level of interest:
  - If farmers are aware of it, but they are not adopting it, interview them: Have farmers already attempted to use natural means of improving soil health? What methods did they adopt? Did any of them involve cover crops that fertilize/structure/decompact the soil? What do farmers feel about using plants to address agronomic issues? Do people use animal manure and if so, how much per hectare? Do they use compost, and if so, how much per hectare?
  - If farmers are using it, interview them also. Take care to analyse the system's economics and its pros and cons (both according to the farmers and according to your own analysis). If the costs of the system exceed the benefits, go to Step 6. If the benefits outweigh the costs, go to Step 5.

- If there is no such system, go to Step 7.

Step 5. Organize field trials

There should be three or four trials for each technology tested. Trials must be carried out in small uniform plots either separated from cropped fields or, for rapid feedback on how the cover crops fit into the current cropping system, right in the cropped fields.It is important to test different seeding dates (especially in the case of intercropping and relay cropping) under optimal soil and weather conditions. The trial crop must be treated with as much care as any other crop.

Precise records must be kept of the costs – including all labour costs – and benefits compared with the system currently adopted by farmers. It is important to ascertain whether the cropping system tested fits the available equipment and labour.

- If the experiments are successful, ensure that farmers of both sexes can see the results of the experiments and in particular note that:
  - cover crops may well also be food crops;
  - after the cover crop residues have been applied to the soil, main crops grow healthier and are more productive.

- If the experiments fail, go to Step 6.

Step 6. Identify potential cover crops

If the farmers still do not seem interested, it is essential to find out why.

- If the farmers' objections are justified, go to Step 3.
- If farmers seem excited about the new possibility, if they want to learn more about the experiments, encourage them to test and experiment with the system on a small scale on a plot measuring between 10 m × 10 m and 25 m × 25 m.
  - If farmers understand the potential of cover crop systems, yet are reluctant to adopt them, go to Step 2.
  - If farmers would like to learn more about cover crop systems, collect the following information:
    - What are the dominant crops? Are other plants typically intercropped with these dominant crops?
    - Do farmers use crop rotation? What is the rotation, including the management and the seasons for each crop?

      Feed this information into *Table 11.* In the first row, write the name of the main crops (those currently grown and those that farmers are willing to test). Refer to *Table 5 (Section 5)* and *Annex 3* for suggestions on crop sequencing. Fill in all available information (i.e. water and length of growth) in the next rows, and colour the cells of the months in which the crops are going to occupy the field. *Annex 1* provides reference characteristics for the most important field crops in the region.

    - What are farmers' priorities and needs? For what cover crops is there a good market or potential market?

Table 11. Growing cycle of the main crops in rotation

	Crops	Crop Requirements		Growing Season											
		Water (mm)	Length of crop growth (days)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Crop Sequence															

- How will the cover crop be seeded? How will it be controlled/terminated?
- Are the necessary equipment and labour available?

  Identify a preliminary list of cover crops based on agronomic needs and commercial potential *(see Annex 2)* and feed this information into *Table 12* (colour the cells of the months in which the crops are going to occupy the field).

- Compare *Table 11* and *Table 12* to narrow down the choice of cover crops to those that fit in the available growing window and then go to Step 7.

Table 12. Growing cycle of cover crop candidates to be potentially included in the rotation

	Crops	Crop Requirements		Growing Season												Goal
		Water (mm)	Length of crop growth (days)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Legume																
Broadleaf																
Grass																

Step 7. Select and test

- Put together a cropping system of potential interest *(see Annex 3 for examples)* and then go to Step 5.

7

Recommendations for adoption and promotion of Conservation Agriculture

Chapter 7

7. Recommendations for adoption and promotion of Conservation Agriculture

Conservation Agriculture is knowledge intensive and represents a paradigm shift in farming. For this reason, the promotion process must be accompanied by a clear communication strategy.

7.1 A whole new system of production

Any effort to promote Conservation Agriculture should emphasize the importance of an intensive (in space) and diversified (in time) crop rotation in support of no-till. Changing the crop rotation implies – as a prerequisite – a change in the mentality of farmers. Farmers must begin to regard crops as functional agronomic inputs, as a (partial) replacement for chemical fertilizers and herbicides. This means that farmers need to become familiar with a whole new system of production. They need to change their mentality and acquire technological capabilities in line with the following recommendations:

- **Prioritize the development of an effective system for handling crop residues.** On-farm management must focus on learning how to transform crop residues from a nuisance into allies that will provide opportunities to reduce production risks, increase crop productivity and ensure agricultural sustainability.
- **Custom design crop residue management systems for successful no-till production** taking account of the following considerations:
  - Chopped crop residues must be distributed uniformly to ensure that there is no interference with the seeding operation, the crop's stand establishment and its uniformity of development.
  - Standing crop residues are important to optimize water availability, which is a major limiting factor for crop production in the region. Snow trapped in standing stubble and retained in the soil profile as melt water for the following spring is a precious resource.

- **Test on-site seeding dates for different crops** in order to identify the optimum match for each agro-ecology and for each crop succession. Where appropriate, involve research institutes in the early stages of the promotion process in order to obtain this information, which is essential to provide clear and specific guidelines for farmers.

New market linkages must be established so that farmers can have access to different seed material and find a niche in the market to sell unconventional/niche crops. Sustainability is easier to achieve when fully integrated in the market and market driven. The **extension service can play a determinant role in favouring linkages with national and international markets.**

To increase the chances of farmers adopting the recommended practices, their priorities must be seriously considered. The involvement of passionate and committed leading pioneer farmers is crucial to ensure the participation of the majority of farmers in the community and to catalyze the promotion process. While some farmers may be open to change with a desire to test alternative agronomic management practices, many farmers are averse to risk and are reluctant to change; this must be taken into account when devising agronomic solutions. It is believed that the acceptance/adoption of innovative practices is more easily achieved when the adaptation effort by the end users (i.e. farmers) is not excessive. Therefore, a conservative approach should be adopted when devising improved cropping systems. The crop rotation scheme should be agreed on in a participatory manner between farmers and extension specialists, and it should not require farmers to adjust their farming system to manage to grow new crops or implement new practices.

A final consideration concerns the often limited general crop and land management capacity of many farmers in the region. **Conservation Agriculture should be implemented along with other sound agronomic management practices** *(Table 13).*

Farmer Field Schools are an example of knowledge extension approaches useful to favour the adoption of Conservation Agriculture.

Table 13. Good agronomic management practices

Agronomic practices	Specific practices	Preconditions
Conservation Agriculture	→ Optimization of the growing season (seeding dates adjusted for intercropping and relay cropping systems) → Crop associations (seeding dates and crop combinations) tested	← Seeding dates tested ← Adapted small-mechanization options available ← Crop associations and seeding dates (for the purpose of nutrition of the main crop) tested
Contour farming	–	–
Hedgerows/windbreaks	–	–
Controlled grazing	→ Grazing interval restrictions, and/or supplementary feeding	← Fodder available
Diversification of crop rotations	→ Optimization of the growing season (seeding dates adjusted for intercropping and relay cropping systems)	← Quality seed material of adapted crop varieties tested and available ← Seeding dates tested ← Adapted small-mechanization options available (seed drill, combine harvester)
Intensification of crop rotations	–	–
Improved (more intensive and efficient) plant nutrition	→ Optimization of the growing season (seeding dates adjusted for intercropping and relay cropping systems) → Crop associations (seeding dates and crop combinations) tested	← Mineral fertilizers available ← Crop associations and seeding dates (for the purpose of nutrition of the main crop) tested
Integrated pest management (IPM)	→ Farmers' awareness of the importance and the modalities of IPM (e.g. biological control, beneficial insects)	← Pesticides available ← Improved seed material of grass, legume and broadleaf crops available ← Adapted small-mechanization options available (sprayer)

7.2 Farmer Field School – an example of knowledge extension

Why

Farmer Field Schools are an adult education and training programme originally developed by FAO in response to the need to support farmers to better and sustainably manage their production systems.

What

Farmer Field School is a non-formal, learner-centred applied adult educational and training process. It comprises a group of 20-30 farmers who get together to study a particular topic over a full crop season. The whole learning process is field based and seeks to empower farmers to solve their field problems actively by fostering participation, interaction and joint decision making.

Farmers learn how to organize themselves and their communities by carrying out various activities related to a selected farming technology and constantly observing the technology performance in the field. In most cases, communities provide a study site with a sheltered area where farmers have follow-up discussions on the specific practices that have been experimented and monitored, comparing their experiences.

The Farmer Field School curriculum follows the natural cycle (seed to seed) of the crop or technology selected. Regular meetings – weekly (most annual crops and livestock), biweekly (some long-term crops) or monthly (most perennial crops) – are held, timed to compromise between learning cycles based on crop management timing and farmer schedules.

See *Box 16* for further details of the Farmer Field School adult learning process.

How

Training of trainers is a cost-effective way to introduce new approaches requiring new skills to trainers, facilitators and institutions. It leads to a common vision and common methodology for moving into new areas of extension and education while promoting exploration, discovery and adaptation in local ecological, social, economic and historical contexts. The vision inherent in Farmer Field School is that trainers work alongside farmers as advisors and facilitators, encouraging independence, analysis and organization.

The facilitator is a technically competent person who leads group members through hands-on exercises and may be an extension agent or an Farmer Field School graduate. In any case, facilitators are not teachers: they offer guidance where necessary, and once farmers are clear on which strategies to adopt the extension worker takes a back seat.

Box 16. Adult learning principles

The Farmer Field School learning process is a learner-centred approach that relates to broad underlying principles of participation and adult non-formal education.

With its participative approach to collective inquiry, the Farmer Field School learning process aims to initiate community action to solve local problems. It applies a four-stage learning cycle based on:

1. acquiring concrete experience;
2. observing and reflecting;
3. generalizing and conceptualizing; and
4. experimenting actively – not only is this the last step in the cycle, it also represents the starting point of a new learning cycle.

This approach empowers participants, imparting the analytical skills to investigate problems in farming practice. Participants:

- gain new understandings and new explanations of the issue at hand;
- learn how to learn; and
- learn how to create new possibilities for action.

As an adult learning process, Farmer Field School is a process of self-directed inquiry that is activated by the learners themselves to create change (e.g. in their skills, behaviour, knowledge level or attitudes) and which puts the trainer in the role of facilitator. The fundamental principle of this approach lies in placing the learners in control of their own learning. Principles of adult learning:

- People more readily internalize and implement ideas relevant to their needs and problems.
- Acceptance of new practices is filtered through experience. At the same time, each person's experiences, ideas, feelings and attitudes are a rich source of material for problem-solving.
- Learning is a cooperative process. People enjoy working by themselves, but also working together. Group dynamics and team-building exercises encourage them to learn as a group.
- Learning is sometimes painful. Change often means giving up old, comfortable ways of thinking. It can be difficult to share ideas openly, to put one's ideas under the scrutiny of a group, and to confront other people. Experience makes this easier.

8

Appendices

Chapter 8

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Glossary

i	**Mineralization of organic matter:**	Biological oxidation to carbon dioxide and water with liberation of the mineral nutrients.
ii	**Water stable aggregates:**	Aggregates that can resist air-drying and quick submersion in water before siev ing.
iii	**Ageing:**	Deposition of polysaccharides and other organic cementing agents by microbial activity.
iv	**Cation exchange capacity:**	Estimate of the soil's nutrient reserve. Soil exchange sites are the negative sites on the clay particles that hold cation nutrients.It is reported in millequivalents per 100 g of soil (meq/100 g), i.e. the millequivalents of cations adsorbed per 100 g of oven dry soil.
v	**Mycorrhizae:**	Symbiotic association between a fungus and the roots of a vascular plant. In mutualistic associations, the fungus colonizes the host plant's roots to get relatively constant and direct access to carbohydrates. In return, the plant gains the benefits of the mycelium's higher absorptive capacity for water and mineral nutrients.
vi	**Pest:**	Any species, strain or biotype of plant, animal or pathogenic agent, injurious to plants or plant products (FAO, 1995 – definition subject to formal amendment of the International Plant Protection Convention [IPPC]).
vii	**Crop residues:**	Any biomass left in the field after the principal economic components of the crop have been harvested.
viii	**Intensive crop rotation:**	Crop rotation characterized by high species density in space and in time that produces large amounts of crop residues and maintains the soil surface permanently covered to "close the window" between the wet and the dry season.
ix	**Spray drift:**	Tiny droplets of sprayed agrochemicals (herbicides or pesticides) carried by the wind to any non-targeted area.

x	**Pesticides:**	Insecticides, fungicides, herbicides, disinfectants and any substance or mixture of substances intended for preventing, destroying or controlling any pest, including vectors of human or animal disease, unwanted species of plants or animals causing harm during or otherwise interfering with the production, processing, storage, transport or marketing of food, agricultural commodities, wood and wood products or animal feedstuffs, or substances which may be administered to animals for the control of insects, arachnids or other pests in or on their bodies. The term includes substances intended for use as a plant growth regulator, defoliant, desiccant or agent for thinning fruit or preventing the premature fall of fruit, and substances applied to crops either before or after harvest to protect the commodity from deterioration during storage and transport (FAO, 2005).
xi	**Allelopathy:**	Chemical inhibition of one species by another. The phytotoxic/inhibitory chemical is released into the environment where it affects the development and growth of the neighbouring and following plants (depressing their yields).
xii	**Percent base saturation:**	Number of basic cations held on the soil exchange sites in comparison to the total number of sites. When base saturation is 100 percent, the highest pH is near 7.6. Therefore, a favourable base saturation is obtained if the soil pH is maintained near neutral.
xiii	**Nematodes:**	Roundworms that interact directly and indirectly with plants. Some species are plant parasites: they feed on roots and plants, and also introduce disease through feeding wounds. Damage to the crop from plant-parasitic nematodes causes a breakdown of plant tissue. However, most nematodes are not plant parasites, but feed on and interact with many soil-borne microorganisms.
xiv	**Opportunity cost:**	The "cost" of not taking advantage of an "opportunity" to do something else with the land. Cover crops grown on land that has no opportunity cost occupy land that cannot be used for producing a market or a subsistence crop.

Annex 1. Characteristics of the main field crops in Eastern Europe and Central Asia

Limited water availability and a short growing season are the major regional limitations to crop production. Because of the arid climate, crop production relies heavily on irrigation. Due to lack of seeds of pulses and oilseed crops, farmers widely practise cereal monocropping. However, cereal yields are typically low, mostly because of the low yield potential of the varieties grown and the poor production practices.

Major irrigated crops: cotton, cereals (mainly wheat) and fodder crops (e.g. alfalfa).

Main rainfed crops: cereals (wheat, barley, cereal rye), grain and fodder legumes (pea, chickpea, lentil, beans, vetch), and oilseed crops.

Table A1.1 summarizes the characteristics of most important field crops.

Table A1.1 Characteristics of main field crops

Crops		Crop requirements			Growing season											
		Water (mm)	Irrigated (I) / Rainfed (R)	Length of crop growth (approx. no. of days)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Wheat:	*Triticum aestivum*	350-400	I / R													
Winter				230-270					]				[			
Spring				95-130				[			]					
Barley:	*Hordeum vulgare*	450-650	I / R													
Winter				200-230				]					[			
Spring				60-90				[		]						
Maize	*Zea mays*	600-800	I	80-135			[			]						
Cotton	*Gossypium hirsutum*	500-1 300	I	120-140			[				]					
Sunflower	*Helianthus annus*	600-1 000	I / R	120-130			[				]					
Sugarbeet	*Beta vulgaris*	550-750	I	140-200				[						]		
Potato	*Solanum tuberosum*	500-700	I	90-180				[					]			

Annex 2. Characteristics of cover crops suitable for Eastern Europe and Central Asia

Table A2.1 provides a synoptic description of the main potentially suitable cover crops in the region. *Table A2.2* presents the major cover crops grouped according to their specific features.

Table A2.1 Characteristics of main cover crops

Crops			Crop requirements		Growing season				Crop management				Crop roles						
														Agronomic benefits					
			Irrigated (I) / Rainfed (R) / Rainfed drought resistant (R*)	Length of crop growth (days)	Winter	Spring	Summer	Autumn	Place in the rotation	Info/Tips	Seeding	Termination	Main uses	Quick establishment (x)	Weeds suppression (WS)/ allelopathy (A)	Plant nutrition: N fixing (N) / scavenger (S)	Soil loosening (x) / subsoiling (*)	Soil structuring (x)	Pest control
Legume	Red clover	*Trifolium pratense*	I		➞	➞]…	[early spring to June (establish before mid-summer]	➞	• As intercrop with small grains. • In mix, e.g. red clover + hairy vetch + oat. • As relay crop with winter cereals, e.g. broadcast into winter wheat, barley or spelt (seeded the previous autumn) while the ground is frozen (late winter/early spring), it grows underneath the cereal until harvest, and afterwards it grows strongly. The top growth dies over winter (biomass input), but the following spring there is another flush of biomass before it is terminated at flowering.	• Slow growing in the seeding year and benefits from a nurse crop (e.g. buckwheat, oat); grows rapidly the 2nd year. • Short-lived perennial (2 years). • Shade tolerant.	• Rate: 10 kg/ha (row)	• When the first flowers are seen	• Feed • Biomass (especially in mix with grasses)			N	x	x	• Insectary crop (habitat). • Host for clover root curculio (*Sitona hispidula*), a pest also for alfalfa.
					[late winter/early spring ➞	➞	➞]…												
	White clover	*Trifolium repens*	I		➞…	[February / early spring ➞	➞	➞	• As intercrop with small grains (+ red clover).	• Slow growing in the seeding year and benefits from a nurse crop (e.g. buckwheat, oat); grows rapidly the 2nd year. • Short-lived perennial (2 years). • Anti-erosion. • Shade tolerant. • Traffic tolerant.			• Feed • Biomass (especially in mix with grasses)			N		x	• Insectary crop (habitat)
					➞	➞…	[September ➞	➞	• As living mulch for cotton.										
	Sweet clover	*Melilotus albus*	R			[➞	➞	➞]…	• Pure stand. • In mix, e.g. oat. • As intercrop with, e.g. maize. • After maize harvest, the clover grows to about 2 m in height, and can be grazed (with the maize stalks). The next spring, what is left of the sweet clover is cut down and maize is planted again	• Short-lived perennial (2 years). • Shade tolerant. • Fairly permanent/invasive – use only where farmers value raising cattle.	• Rate: 10-25 kg/ha		• Feed	x		N	x*	x	
	Common vetch	*Vicia sativa*	I			[➞	➞]		• Pure stand. • In mix, e.g. vetch + cereals (e.g. oat, wheat or barley); • vetch + phacelia + niger.		• Rate: 100-150 kg/ha (pure stand); 20-70 kg/ha (in mixtures). • Depth: 3-5 cm.		• Feed	x	WS	N			

Crops		Crop requirements: Irrigated (I) / Rainfed (R) / Rainfed drought resistant (R*)	Crop requirements: Length of crop growth (days)	Growing season: Winter	Growing season: Spring	Growing season: Summer	Growing season: Autumn	Crop management: Place in the rotation	Crop management: Info/Tips	Crop management: Seeding	Crop management: Termination	Crop roles: Main uses	Agronomic benefits: Quick establishment (x)	Agronomic benefits: Weeds suppression (WS)/ allelopathy (A)	Agronomic benefits: Plant nutrition: N fixing (N) / scavenger (S)	Agronomic benefits: Soil loosening (x) / subsoiling (*)	Agronomic benefits: Soil structuring (x)	Pest control
Legume	Hairy vetch / woollypod vetch *Vicia villosa*	R*		➞ (frost killed in some areas)	May]		[early September / 30–45 days before frost ➞	• Pure stand in succession with, e.g. winter wheat, cotton. • In mix with cereals, e.g. 60% hairy vetch + 40% wheat or cereal rye, the nurse crop provides quick cover and captures snow that helps protect the young vetch seedlings in the winter. • As relay crop in, e.g. maize, soybean.	• Shade tolerant. • Slow to establish, grows slowly in autumn, matures in late spring. • If the nurse crop winter kills (e.g. oat), there will be a pure hairy vetch stand left in the spring. • If the nurse crop survives the winter, the vetch climbs up into the small grains in the spring. • If the goal is to terminate the cover crops at about the same stage of maturity prior to seed production, the nurse crop has to resume growth at the same time as the vetch (e.g. triticale, wheat); cereal rye is not suited, as it will mature prior to hairy vetch flowering.	• Rate: 25-50 kg/ha (row); 30-35 kg/ha (broadcast). • Depth: 3-5 cm.	• 10 days before next crop.	• Feed • Biomass		WS	N; S	x		• Hard seed can become a weed in wheat.
				➞	germination, vegetative growth in early spring ➞		[very late autumn (when it will be too cold and it will not germinate) ➞											
	Faba bean / broad bean *Vicia faba minor; Vicia faba maior; Vicia faba equina*	I	80-100		[April ➞	]		• As intercrop with, e.g. maize		• Rate: 100-200 kg/ha. • Depth: 3-5 cm.		• Food • Feed			N	x		
				➞	➞]		[➞	• Pure stand										
	Field pea *Pisum sativum*	П		➞ frost killed mulch]			[early September ➞	• As intercrop, e.g. with cereals. • In mixture with, e.g. Brassica.	• Poor competition ability against weeds. • Not shade tolerant (do not sow into row crops). • In spring it can be grown for pods production or for mulch production (and terminated after flowering for early summer cash crop seeding).	• Rate: 55-90 kg/ha.		• Food • Feed • Biomass			N			
		П / Б			[➞ early spring (the same time as oat)	➞]		• In successions. • In mixture with, e.g. pea + barley; pea + oat; pea + triticale.										
	Jack bean *Canavalia ensiformis*	R*	60–90–110 (depending on the variety: short vs tall)		[➞	➞]		• As improved fallow. • In hedgerows. • In orchards.	• Bushy type (not the climbing type).	• Rate: 55 kg/ha.		• Food • Feed • Biomass	x	WS	N	x	x	• Poisonous roots keep away mole rats.

Crops		Crop requirements		Growing season				Crop management				Crop roles						
													Agronomic benefits					
		Irrigated (I) / Rainfed (R) / Rainfed drought resistant (R*)	Length of crop growth (days)	Winter	Spring	Summer	Autumn	Place in the rotation	Info/Tips	Seeding	Termination	Main uses	Quick establishment (x)	Weeds suppression (WS)/ allelopathy (A)	Plant nutrition: N fixing (N) / scavenger (S)	Soil loosening (x) / subsoiling (*)	Soil structuring (x)	Pest control
Legume	Cowpea *Vigna unguiculata*	R*			[➞	➞]		• As relay crop in winter cereals, e.g. frost seeded into wheat. • In orchards.	• Photoperiod responsive.			• Food • Feed • Biomass		WSA	N	x	x	
				➞ frost killed mulch]			[late summer ➞	• In mixes.										
	Mung bean *Vigna radiata*	R	90-120		[May ➞	➞]		• As intercrop, e.g. with wheat	• Photoperiod responsive	• Rate: 20-30 kg/ha broadcast. • Depth: 3-5 cm.		• Food • Feed			N	x	x	
	Rice bean *Vigna umbellata*	R	120-150		[➞	➞]		• As relay crop with maize, broadcast 1-2 months before maize harvest, it continues to grow afterwards. • In orchards.				• Food • Feed • Biomass	x	WS	N	x		
	Moth bean *Vigna aconitifolia*	I	90-120		[May ➞	➞]			• Photoperiod responsive (short day).	• Rate: 35-40 kg/ha.		• Food • Feed			N	x	x	
	White lupin *Lupinus albus*	R		➞	➞]		[➞	• In succession, e.g. with cotton. • In orchards.		• Rate: 150 kg/ha.		• Food • Feed • Biomass			N; S (Phospho-rus)			• Rotate lupins to avoid anthracnose
	Fenugreek *Trigonella foenum-graecum*	I / R			[➞	➞]		• Pure stand. • In mix with, e.g. oat.		• Rate: 15-20 kg/ha. • Can germinate in cold soils.		• Feed • Biomass			N	x	x	• Breaks some pest cycles in maize.

Crops		Crop requirements		Growing season				Crop management				Crop roles						
													Agronomic benefits					
		Irrigated (I) / Rainfed (R) / Rainfed drought resistant (R*)	Length of crop growth (days)	Winter	Spring	Summer	Autumn	Place in the rotation	Info/Tips	Seeding	Termination	Main uses	Quick establishment (x)	Weeds suppression (WS)/ allelopathy (A)	Plant nutrition: N fixing (N) / scavenger (S)	Soil loosening (x) / subsoiling (*)	Soil structuring (x)	Pest control
Legume	Grass pea / chickling vetch *Lathyrus sativus*	R*			[➞	➞]		• In succession, e.g. with winter cereals (e.g. wheat, cereal rye).				• Food • Feed			N	x		
Legume	Winter pea *Lathyrus hirsutus*	R		➞	➞]		[early/mid-September ➞	• In succession. • As intercrop with a nurse crop, e.g. cereal rye, annual ryegrass, oat, radishes or turnip (Brassica rapa var. rapa). • As relay crop, maize may be planted into live winter pea, allowing it to continue to grow, and then spraying and killing the pea within 1 month of maize emergence.				• Feed • Biomass			N	x		
Legume	Chickpea	R	100		[➞	➞]						• Food			N			
Legume	Sulla / Italian sainfoin *Hedysarum coronarium*	R*		➞	➞]...	[➞	➞	• Pure stand. • As relay crop with cereals (broadcast).	• Short-lived perennial.	• Rate: 20-25 kg/ha. • Depth: 0.5 cm.		• Feed			N	x		
Legume	Sainfoin *Onobrychis viciifolia*	I / R	60-70	➞]…	[April ➞	➞	➞	• In mix with, e.g. white clover. • As relay crop with cereals (broadcast).		• Rate: 40-60 kg/ha.		• Feed			N	x*	x	
Legume	Alfalfa; lucerne *Medicago sativa*	I / R	60-70	➞]…	[April ➞	➞	➞	• As pure stand. • In mix with a companion grass, e.g. ryegrass, oat, spring barley, spring triticale. • As relay crop (broadcast) in early spring in winter cereals, e.g. winter wheat.	• As pure stand, quicker establishment, higher drought tolerance due to greater root growth, but good weed control needed. • With a companion crop to minimize weed competition at establishment and soil erosion; • harvest the grain at boot stage (not recommended to harvest companion crops for grain: competition).	• Rate: 10-25 kg/ha. • Depth: 0.5-1.5 cm.	• Harvest from floral bud stage to 50% flowering and at least 4 weeks before frost (as the top growth develops at the expense of the roots) – about 70 days after seeding or 60 days after emergence for 2-3 cuttings.	• Feed (highest quality forage, especially as pure stand).			N	x*	x	• Do not follow after red clover to avoid carry-over of clover root curculio (*Sitona hispidula*).

Crops			Crop requirements		Growing season				Crop management				Crop roles						
														Agronomic benefits					
			Irrigated (I) / Rainfed (R) / Rainfed drought resistant (R*)	Length of crop growth (days)	Winter	Spring	Summer	Autumn	Place in the rotation	Info/Tips	Seeding	Termination	Main uses	Quick establishment (x)	Weeds suppression (WS)/ allelopathy (A)	Plant nutrition: N fixing (N) / scavenger (S)	Soil loosening (x) / subsoiling (*)	Soil structuring (x)	Pest control
Legume	Black medic	*Medicago lupulina*				[April ➞	➞	➞	• As living mulch under the crop canopy, e.g. flax.	• Low-growing, self-seeding: • it regenerates under a growing crop that allows light to penetrate. After the crop is harvested, the black medic continues to grow and set seed until the first killing frost.			• Feed		WS	N			
Legume	Annual medic	*Medicago littoralis*	R			[➞	➞	➞]		• Low-growing, self-seeding. • Not winter hardy. • Grows more rapidly than Medicago sativa.			• Feed • Biomass	x	WS	N	x	x	
Legume	Sunn hemp	*Crotalaria juncea*	R*	80-100	➞ frost killed mulch]		[➞	(tolerates light frost)	• As intercrop with maize. • In succession, e.g. after wheat (in wheat-maize rotations).	• Photoperiod- responsive – because it flowers in response to short days, seed production in the region is expected to be minimal, and domestic price of seed high.			• Feed • Fibre • Biomass	x	WS	N	x	x	• Anti-sedentary endoparasitic nematodes.
Broadleaf	Radish	*Raphanus sativus*								• Does not establish quickly in low-N systems.						S	x*		
Broadleaf	Forage radish	*Raphanus sativus var. longipinnatus*	R		➞ frost killed mulch]		[late summer ➞	➞	• In succession, from cereal harvest to early autumn to allow for early autumn planting.	• Rate: 5-9 kg/ha (drilled). • Establish early to achieve sufficient plant size to withstand winter conditions.									
Broadleaf	Oilseed radish	*Raphanus sativus var. oleiformis*	R	60-100	➞	➞]		[➞	• In succession, e.g. with cotton.	• Rate: 5-15 kg/ha (row); 10-22 kg/ha (broadcast). • Depth: 0.5-2 cm.									• Anti-slugs
					➞ frost killed mulch]		[30 days before frost ➞	➞											
Broadleaf	Niger	*Guizotia Abyssinica*	R*	Short cycle	➞ frost killed mulch]				• In succession, from cereal harvest to autumn.	• Rate: 6-8 kg/ha.			• Feed				x*	x	

Crops		Crop requirements		Growing season				Crop management				Crop roles						
													Agronomic benefits					
		Irrigated (I) / Rainfed (R) / Rainfed drought resistant (R*)	Length of crop growth (days)	Winter	Spring	Summer	Autumn	Place in the rotation	Info/Tips	Seeding	Termination	Main uses	Quick establishment (x)	Weeds suppression (WS)/ allelopathy (A)	Plant nutrition: N fixing (N) / scavenger (S)	Soil loosening (x) / subsoiling (*)	Soil structuring (x)	Pest control
Broadleaf	Phacelia *Phacelia tanacetifolia*	R			[May ➞	➞ autumn]		• In hedgerows. • In mix, e.g. phacelia (8 kg/ha) + buckwheat (40 kg/ha); • phacelia (5 kg/ha) + lupin (150 kg/ha).	• Rate: 8-10 kg/ha (row). • Depth: 1-1.5 cm.			• Biomass	x	WS	forms my-corrhizae	x		• Insectary crop (e.g. pollinators, carabid beetles that feed on slugs, Aphelinidae that feed on aphids).
				➞ frost killed mulch]		[30 days before frost ➞	➞											
	Wild sunflower *Tithonia diversifolia*							• In hedgerows, green stems (not woody stems), leaves and flowers can be removed after flowering and distributed over the filed; woody stems for firewood.				• Feed • Biomass (firewood, fertilization)						
	Rapeseed *Brassica napus*	I	70-95		[April ➞	August]		• In mix with crops that have very different root types, e.g. rapeseed + oat + turnip (*Brassica rapa* var. *rapa*).							S			
				➞	➞]		[➞											
	Mustards *Brassica juncea; Brassica hirta; Brassica alba; Brassica negra*	I	70-95				frost tolerant	• In mix with, e.g. other Brassica or mustards + small grains or clover. • Brassica, as relay crop in the previous crop (before harvest).	• Rate: 14 kg/ha. • Early seeding to maximize biomass production and nutrient scavenging in the autumn.				x	WS	S	x*		• Anti-bacteria, fungi, insect pests, nematodes.
	Buckwheat *Fagopyrum esculentum Moench / Fagopyrum sagittatum Gilib*	R / I	40-90		[April / June ➞	➞]		• In short windows in the warm season. • In hedgerows. • In orchards and vineyards.	• Photoperiod responsive (short day). • Rate: 40-60 kg/ha.		• If grown for biomass production, it can be cut after approximately 40 days / at flowering.	• Food • Weed/pest management	x	WS when thickly planted	S (Phos-phorus, Calcium)	x		• Insectary crop (food and habitat).
	Flax *Linum usitatissimum*				[April ➞	June]						• Food • Fibre						

Crops			Crop requirements: Irrigated (I) / Rainfed (R) / Rainfed drought resistant (R*)	Crop requirements: Length of crop growth (days)	Growing season: Winter	Growing season: Spring	Growing season: Summer	Growing season: Autumn	Crop management: Place in the rotation	Crop management: Info/Tips	Crop management: Seeding	Crop management: Termination	Crop roles: Main uses	Agronomic benefits: Quick establishment (x)	Agronomic benefits: Weeds suppression (WS)/ allelopathy (A)	Agronomic benefits: Plant nutrition: N fixing (N) / scavenger (S)	Agronomic benefits: Soil loosening (x) / subsoiling (*)	Agronomic benefits: Soil structuring (x)	Pest control
Broadleaf	Safflower	*Carthamus tinctorius*	I / R	100-120		[April ➞	August]				• Rate: 15 kg/ha.		• Food (oil)		Against late-emerging weeds (grassy) only.				
Broadleaf	Amaranth	*Amaranthus* sp.	I / R	90-100		[➞	➞]						• Food (grain and leaves) • Biomass	-					
Grass	Sorghum	*Sorghum bicolor*	I 450-650	250-300		[April ➞	August]				• Rate: 10 kg/ha.		• Food • Feed • Biomass	x			*	x	
Grass	Sorghum Sudan grass	*Sorghum bicolor x S. bicolor var. sudanese*			➞ frost killed mulch]	[➞	➞					• Leaves hard residues – chop well to increase decomposition. • Should be mowed twice – once in early summer to maximize root growth and once in late summer.	• Feed • Biomass	x	WSA	S	*	x	• Nematode suppressor, e.g. anti-soybean cyst nematodes.
Grass	Spelt	*Triticum spelta*	I / R		➞	➞]	[	➞					• Food • Feed						
Grass	Cereal rye	*Secale cereale*	R*	260	➞	➞ resumes growth earlier in spring (May)]	[September / 10-15 cm before frost ➞	grows longer in autumn than other grains ➞	• In succession, e.g. after maize, cotton or late-maturing soybean. • As intercrop, e.g. with hairy vetch. • In mix, ryegrass + clover mix for beneficial insect habitat. • Windbreak within vegetables or fruit crops. • As relay crop, • e.g. into silking maize or *Brassica*.	• Shade tolerant	• Rate: 70-140 kg/ha (row); 100-180 kg/ha (broadcast). • Depth: 3-5 cm.	• Cut as it finishes its vegetative growth and switches over to reproductive growth) / 10 days before next crop. • May be hard to kill – volunteers are particularly undesirable in small grains (e.g. wheat or barley). Special care must be taken if they are following in the rotation.	• Food • Feed • Biomass	x	WSA (broadleaf)	S (nitrogen)	x	x	• Non-host for soil-borne diseases/ nematodes (rootknot); • Anti-soybean cyst nematodes. • Attracts armyworms (*Spodoptera* spp.); • Not suitable where cutworms and wire worms are a problem ahead of grass crops (e.g. maize, sorghum, pearl millet).

Crops			Crop requirements		Growing season				Crop management				Crop roles						
														Agronomic benefits					
			Irrigated (I) / Rainfed (R) / Rainfed drought resistant (R*)	Length of crop growth (days)	Winter	Spring	Summer	Autumn	Place in the rotation	Info/Tips	Seeding	Termination	Main uses	Quick establishment (x)	Weeds suppression (WS)/ allelopathy (A)	Plant nutrition: N fixing (N) / scavenger (S)	Soil loosening (x) / subsoiling (*)	Soil structuring (x)	Pest control
Grass	Annual ryegrass	*Lolium multiflorum*	R				[late summer / 45-60 days before frost ➞	frost killed]	• As intercrop.	• Not productive if water is short in late summer: not suited for warm-season intercropping systems (e.g. with barley).	• Rate: 20-25 kg/ha (row); 30-35 kg/ha (broadcast). • Depth: 1-1.5 cm.		• Feed • Biomass	x	WS	S			
Grass	Triticale	*Triticosecale*					[September / November ➞			• Anticipated cycle compared with wheat.	• Rate: 130 kg/ha.	• Termination: 10 days before next crop or earlier if water is a concern (especially in rotation with maize). • May be hard to kill.	• Feed: in mixes with legumes; chopped (1.5-2.5 cm) for silage. • Biomass			S (nitrogen)			
Grass	Oat	*Avena sativa*	I / R 300	40-60	➞ frost killed mulch]		[late August / 40-60 days before frost ➞	➞	• As autumn nurse crop, intercrop at a low seeding rate with an overwintering legume (e.g. oat + hairy vetch) or with crops that have very different root types (e.g. oat + Raphanus sativus var. oleiformis). The oat provides soil cover between the nursed crop until the latter dominates. • In succession, e.g. with cotton, or after summer legumes as a N catch. • As relay crop, broadcast before harvest of the previous crop (e.g. into soybean, at leaf-yellowing or early leaf-drop stage) and with little residue present.	• Next crop should not be sensitive to oat allelopathic compounds, e.g. wait 3 weeks before wheat.	• Rate: 70-110 kg/ha (row); 110-155 kg/ha (broadcast). • Depth: 2-3 cm for quick germination, shallow seeding in moist soil (or just before rains).	• Let it winter kill or send in cattle for some autumn grazing. • If not winter killed, terminate it (e.g. roll it) at dough stage or later.	• Feed • Biomass	x	WSA	S	x	x	
Grass	Oat	*Avena sativa*	I / R	120-150		[April ➞	August]												
Grass	Black oat	*Avena strigosa*	R		➞]		[September ➞	➞		• Diploid oat.	• Rate: 50-80 kg/ha. • Rate: 20-25 kg/ha.		• Food						
Grass	Proso millet	*Panicum miliaceum*	R*	60-90		[➞	]						• Food						
Grass	Morap	*Setaria italica*	R*	Short cycle		[May/June ➞	]		• In succession, from cereal harvest to autumn. • In mix, e.g. with clover.			• Winter kills.	• Feed • Biomass			S			

Table A2.2 Specific features of main cover crops

			Cover crop species
Cover crop characteristics	Goal	Deep root system (decompaction)	Sorghum, annual ryegrass, oilseed radish, forage radish, sweet clover, cereal rye, oat, faba bean, winter pea
		Fibrous root system (anti-erosion)	Cereal rye, annual ryegrass, oat, wheat, barley
		Nutrients scavenging (soil/plant nutrition)	Oilseed radish, forage radish, turnip (*Brassica rapa* var. *rapa*), annual ryegrass, cereal rye, oat, wheat, sorghum, buckwheat, sweet clover, winter pea, cowpea, red clover, hairy vetch, alfalfa
		Low c/n (fast nutrients cycling)	Winter pea, red clover, sweet clover, hairy vetch, alfalfa, soybean
		High c/n (persistent soil cover)	Sorghum, cereal rye, annual ryegrass, triticale, oat, wheat, spelt, barley
		Light feeders	Spring barley, flax, buckwheat, soybeans
		Medium feeders	Spring wheat, oat, rye, winter barley
		High feeders	Maize, sunflower, rapeseed, winter wheat, spelt
		Weed suppression	Hairy vetch, triticale, annual ryegrass, cereal rye, oat, buckwheat
		Release of allelopathic compounds (weed and disease control)	Cereal rye, oilseed radish, forage radish, Brassica, oat, barley, buckwheat, sorghum, sunflower
		Attraction of beneficial insects (pest control)	Buckwheat, phacelia, sweet clover, red clover
		High-residue production	Maize, triticale, barley + hairy vetch, wheat, sorghum
		Forage	Oat, radishes, turnip, cereal rye, annual ryegrass, sorghum, barley, pea
		Nurse crops	Oat, cereal rye, buckwheat
	Habitat	Tolerance to wet soils	Sweet clover, red clover, annual ryegrass, cereal rye, wheat, oat
		Tolerance to cold	Cereal rye, wheat, spelt, triticale, sweet clover, winter pea, mustards
		Tolerance to heat and drought	Cowpea, hairy vetch, mung beans, sweet clover, sorghum Sudan grass, buckwheat, barley, triticale, cereal rye, teff
		Nematicidal properties	Cereal rye, sorghum Sudan grass, hairy indigo (*Indigofera hirsuta*), *Crotolaria spectabilis*, sunn hemp, rapeseed, radishes
		Susceptibility to / attraction of pests or diseases	Annual ryegrass, cereal rye, hairy vetch, wheat, oat
	Management	Good to start Conservation Agriculture with	Oilseed radish, forage radish, turnip, sorghum, triticale
		Ease of establishment	Sorghum, oat, cereal rye, annual ryegrass, wheat, barley, oilseed radish, radish
		Winter killed mulch (crops that need to establish well before a killing frost in order to have put on enough biomass and root mass to protect and hold the soil in place until spring)	Pea, radish, oat
		Suitability to broadcast seeding	Sweet clover, red clover, cereal rye, annual rye, oilseed radish, forage radish, turnip
		Low management	Oilseed radish, forage radish, turnip, oat, cowpea
		High management	Annual ryegrass, cereal rye

Annex 3. Cover-crop-based successions and rotations suitable for Eastern Europe and Central Asia

Warm season cover crops are grown approximately from May to early September. As with any other crop, moisture is needed to establish a cover crop. Soil moisture availability and use is especially critical from June to August.

As a crop intensification strategy, summer annuals suitable for double cropping need to be quick-growing (e.g. buckwheat, millet, sorghum and cowpea). These can be grown in succession with early planted crops.

Gaps in the cold season occur after harvesting a major summer crop. To extend the window when these gaps are too short, cover crops can be relayed in the main crop.

Relay cropping is especially useful for cover crops that are killed by cold: before they are winter killed, cover crops need to have produced sufficient biomass and root mass to protect and hold the soil in place until the following spring. This residue makes for excellent mulch that it is easy to plant into in the spring.

If the cover crop does not naturally winter kill, it will remain alive through winter and resume growth in spring. In this case, farmers should have a method for controlling (but not necessarily killing) the crop before it competes with the next main crop.

Considerations on crop sequences for different purposes/goals are presented in *Box A3.1.* Some examples of suitable crop successions and rotations are provided in *Table A3.1* and *Table A3.2,* respectively.

Box A3.1 Crop sequencing in cover-crop-based systems

The first rule is to avoid leaving the soil bare. If the growing season is too short, relay the second crop into the main one, or grow a cover crop for mulch production purposes (this does not necessarily need to complete its growing cycle and produce seed).

For **soil fertility management** and **soil health improvement,** alternate between:

- shallow-rooted crops and deep-rooted crops;
- crops with high-root biomass (e.g. cereal rye) and low-root biomass;
- crops that are high moisture users and crops that require less moisture;
- allelopathic crops and non-allelopathic crops;
- heavy feeding crops and medium or light feeders;
- nitrogen-fixing/scavenging crops and high nitrogen-demanding crops;
- legumes and grasses – grasses following legumes help to accumulate SOM, recycle nutrients and reduce soil compaction;
- legumes and Brassica – Brassica following legumes help to recycle nutrients, reduce compaction, and promote weed and disease suppression.

For **weed management** and **phytosanitary management:**

- weed suppressing crops should precede slow-growing crops, which are more susceptible to weed competition;
- low residue crops may not follow another low residue crop;
- plants that with allelopathic weed germination inhibitors should be included in the rotation – a balanced rotation is important to prevent build-up of natural chemical toxins that inhibit the growth of other crops.

Table A3.1 Examples of crop successions in cover-crop-based systems

Suitable previous crops	Main crop	Suitable subsequent crops	Goal
Legume, oilseed or forage radish, turnip (not rye – voluntary rye is difficult to prevent in wheat)	Cereal (winter species) (e.g. winter wheat, cereal rye, annual ryegrass)	Winter pea	Nitrogen
		Red clover, sweet clover, hairy vetch	Nitrogen
		Turnip, radishes, annual ryegrass	Soil decompaction
		Turnip, radishes	Recapturing leached nutrients
		Cereal rye, annual ryegrass, sorghum Sudan grass, oat, teff	Biomass, feed
		Buckwheat, cowpea,	Short window rainfed
		Cereal rye, buckwheat, rapeseed, radishes	Weed control and disease suppression
Winter pea, hairy vetch, oilseed or tillage radishes, red or sweet clover, radishes	Maize	Winter cereal	Nitrogen
Radishes, cereal rye	Pulse	Winter cereal, flax	Biomass, phytosanitary
Buckwheat	Legumes (high biomass species) (e.g. hairy vetch, winter pea)	Maize, flax	Nitrogen

Table A3.2 Examples of cover-crop-based crop rotations suitable for Eastern Europe and Central Asia

		Goal	SEASONS													
			Spring		Summer		Autumn		Winter	Spring		Summer	Autumn	Winter	Spring	
CROP ROTATIONS	1.	Rainfed – valleys	[WHEAT / BARLEY ➞		➞]	[BUCKWHEAT in valleys, where the growing season is longer / - ➞	➞]	[CEREAL RYE + HAIRY VETCH + FIELD PEA (N nutrition, weed control))	➞ the pea will frost kill, the hairy vetch will climb the rye to access the light	➞]	[RAPESEED / FLAX	➞]	[WINTER PEA ➞	➞ (frost killed)	➞ return residue]	
	2.	Rainfed					[HAIRY VETCH (for winter survival, establish early in autumn before hard frost) ➞		➞	➞ terminate early in the season and return residue (soil water replenishment)]	[MAIZE relayed in hairy vetch ➞	➞]	[CEREAL RYE + FIELD PEA ➞	➞ the pea will frost kill	➞ return residue]	
	3.	Rainfed	[FORAGE RADISH / FORAGE RADISH + PHACELIA + SULLA + VETCH + BUCKWHEAT ➞		➞]		[WHEAT / BARLEY / BARLEY + HAIRY VETCH ➞		➞	➞]	[FLAX	➞]	[TRITICALE	➞	➞]	[PULSE (e.g. mung bean, phaseolus, chickpea, lentil) ➞]
	4.	Irrigated	[COWPEA / FIELD PEA (soil coverage) ➞		➞ harvest and return residues (mulch)]		[CEREAL RYE (weed control) ➞		➞	➞ terminate and return residue (N nutrition)]	[COTTON ➞	➞]	[HAIRY VETCH (pest control, N nutrition) ➞	➞	➞ grow as long as possible (max N fixation), terminate and return residue]	[BUCKWHEAT]
	5.	Irrigated									[SOYBEAN / QUINOA ➞	➞ early/mid-September]	[OAT + FORAGE RADISH + FIELD PEA in early autumn➞	➞ frost killed	➞ return residue]	[MAIZE]
	6.	Irrigated – double cropping	[OAT + FIELD PEA ➞		➞ terminate (e.g. mow) after flowering for early summer seeding (N nutrition)]	[SOYBEAN ➞] [CEREAL RYE relayed in soybean ➞	➞		➞	➞ terminate and return residue (N nutrition)]	[MAIZE ➞	➞]	[HAIRY VETCH late autumn ➞	➞	➞ it germinates and starts growing]	
	7.	Irrigated – living mulch	[OAT ➞		➞]		[WHITE CLOVER (thrips pest control, N nutrition) ➞		➞	➞] [COTTON strip-till the rows and leave the cover crop growing between the strips / in raised bed systems: relay the cotton 4 weeks after band application of herbicide on cover crop ➞		➞]	[WHEAT ➞	➞	➞	
	8.	Irrigated – intercropping, double cropping and living mulch	[RAPESEED + FIELD PEA ➞		➞]		[CEREAL RYE ➞		➞	➞harvest]	[GRASS PEA ➞	➞]	[WHEAT ➞	➞	➞]	RED CLOVER relayed in regrowing wheat in early spring ➞]
	9.	N nutrition	ALFALFA / SAINFOIN early harvest, or partial suppression (with herbicide) after harvest] ➞]	[MAIZE ➞	➞]		[HAIRY VETCH + OAT (the oat provide quick cover and captures snow that helps protect the young vetch seedlings in the winter) ➞		➞ the oat will frost kill, and in spring there will be a pure stand of hairy vetch	➞ terminate and return residue (N nutrition)	[SAFFLOWER	➞]	[FORAGE RADISH (N scavenger) ➞	➞ frost killed]	[WHEAT]	

Annex 4. FAO Environmental and Social Management Guidelines – Environment and Social Standard 5 (E&SS5): Pest and Pesticide Management

Introduction

1. E&SS5 defines pesticides as any substance, or mixture of substances of chemical or biological ingredients intended for repelling, destroying or controlling any pest[1], or regulating plant growth.
2. E&SS5 recognizes that pesticides can contribute to effective crop and food protection during production and in storage. Pesticides are also used in forestry, livestock production and aquaculture to control pests and diseases. At the same time, pesticides are designed to be toxic to living organisms, are intentionally dispersed in the environment and are applied to food crops.
3. It recognizes that exposure to pesticides poses risks to the people who use them, to others nearby, to consumers of food and to the environment. Risks are often elevated by overuse or misuse. Many countries also lack effective regulatory control thereby compounding problems.
4. E&SS5 follows the guidance on the life-cycle management of pesticides as provided by the International Code of Conduct on Pesticide Management[2] and its supporting technical guidelines, which are drawn up by an FAO/WHO expert panel and expand on specific articles.

Objectives

The primary objective is to promote sustainable agriculture through integrated pest management (IPM), reducing reliance on pesticides and avoiding adverse impacts from pesticide use on the health and safety of farming communities, consumers and the environment during and after the project life cycle. Pesticides can be part of that, provided their use is managed carefully.

Scope of application

5. The applicability of E&SS5 is determined during environment and social screening and applies to any FAO-supported activity that provides or facilitates the use or disposal of pesticides in any quantities.
6. Include the application of subsidies, voucher schemes or incentives for the provision of pesticides as well as direct provision of pesticides, and the indirect provision as treatments on seeds and other planting materials.

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[1] A pest is defined as any species, strain or biotype of plant, animal or pathogenic agent injurious to plants and plant products, materials or environments and includes vectors of parasites or pathogens of human and animal disease and animals causing a public health nuisance.

[2] The International Code of Conduct on Pesticide Management. FAO/WHO, 2014. http://www.fao.org/fileadmin/templates/agphome/documents/Pests_Pesticides/Code/CODE_2014Sep_ENG.pdf

7. E&SS5 applies to FAO activities that in an indirect manner may increase pesticide use, such as establishment of irrigation schemes and crop intensification. E&SS5 should also be triggered by any activities that require pesticides to be used or handled in projects, even if the pesticides were not supplied through the project.

Requirements:

General

8. FAO promotes IPM as a pillar of sustainable agriculture. IPM means the careful consideration of all available pest control techniques and subsequent integration of appropriate measures that discourage the development of pest populations and keep pesticides and other interventions to levels that are economically justified and reduce or minimize risks to human and animal health and/or the environment.IPM emphasizes the growth of a healthy crop with the least possible disruption to agro-ecosystems and encourages natural pest control mechanisms.

Pest Management Plan

9. If provision or use of large volumes of pesticides is foreseen, a Pest Management Plan (PMP) needs to be prepared to demonstrate how IPM will be promoted to reduce reliance on pesticides, and what measures are taken to minimize risks of pesticide use. Such a PMP needs to be an integral part of the Environment and Social Commitment Plan.

Selection of pesticides

10. If after considering available IPM approaches, pesticide use is deemed to be justified, careful and informed consideration should be given to the selection of pesticide products. Factors to be taken into account include hazards and risks to users, selectiveness and risks to non-target species, persistence in the environment, efficacy and likelihood of development or presence of resistance by the target organism. Minimum environment and social analysis is needed.
11. FAO does not maintain a list of permitted or non-permitted pesticides because many locally specific conditions govern which pesticides may be used. However, in line with the provisions of the FAO/WHO International Code of Conduct on Pesticide Management and relevant multilateral environmental agreements that include pesticides, the following list of criteria will need to be met in order for a pesticide to be considered for use in an FAO project:

    a. The product should be registered in the country of use, or specifically permitted by the relevant national authority if no registration exists. Use of any pesticide should comply with all the registration requirements including the crop and pest combination for which it is intended.
    b. Users should be able to manage the product within margins of acceptable risk. FAO will not supply pesticides that meet the criteria that define highly hazardous pesti-

cides (HHPs).[3] Pesticides that fall in WHO Hazard Class 2 or GHS Acute Toxicity Category 3 can only be provided if less hazardous alternatives are not available and it can be demonstrated that users adhere to the necessary precautionary measures.[4]

c. Preference should be given to products that are less hazardous, more selective and less persistent, and to application methods that are less hazardous, better targeted and requiring less pesticides.
d. Any international procurement of pesticides must abide with the provisions of the Rotterdam Convention on the Prior Informed Consent (PIC) Procedure for Certain Hazardous Chemicals and Pesticides in International Trade.[5]

Supply of pesticides by FAO

12. FAO applies the following requirements to all pesticides that are being supplied directly by FAO and to pesticides supplied by others within the framework of FAO projects:

a. Proceeded by a thorough risk assessment, which should lead to adequate measures to reduce health and environmental risks to acceptable levels.
b. Quantities provided should be based on an accurate assessment of actual needs. Pesticides should not be provided as fixed components of input packages of projects, credit schemes or emergency assistance.
c. Pesticides should be packaged and labelled in accordance with FAO standards. Labels should be in the national language. The remaining shelf-life should be sufficient to permit use of all pesticides before the expiry date and within the scope of the project (i.e. no expired pesticides remain unused after the project).

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3 The criteria for HHPs are listed by WHO and FAO as follows:
- Pesticide formulations that meet the criteria of <b>classes Ia or Ib of the WHO Recommended Classification of Pesticides by Hazard (www.who.int/ipcs/publications/pesticides_hazard/en/index.html);\;or
- Pesticide active ingredients and their formulations that meet the criteria of carcinogenicity Categories 1A and 1B of the Globally Harmonized System on Classification and Labelling of Chemicals (GHS); or
- Pesticide active ingredients and their formulations that meet the criteria of mutagenicity Categories 1A and 1B of the Globally Harmonized System on Classification and Labelling of Chemicals (GHS); or
- Pesticide active ingredients and their formulations that meet the criteria of reproductive toxicity Categories 1A and 1B of the Globally Harmonized System on Classification and Labelling of Chemicals (GHS); or
- Pesticide active ingredients listed by the Stockholm Convention (www.chm.pops.int) in its Annexes A and B, and those meeting all the criteria in paragraph 1 of Annex D of the Convention; or
- Pesticide active ingredients and formulations listed by the Rotterdam Convention (www.pic.int) in its Annex III; or
- Pesticides listed under the Montreal Protocol (www.ozone.unep.org/Ratification_status/montreal_protocol.shtml); or
- Pesticide active ingredients and formulations that have shown a high incidence of severe or irreversible adverse effects on human health or the environment.

4 The hazard classification concerns the formulated product. Formulations with a low concentration of active ingredient are less hazardous than formulations with a high concentration of the same active ingredient. The WHO Recommended Classification of Pesticides by Hazard and Guidelines to Classification (http://www.who.int/ipcs/publications/pesticides_hazard/en/) classifies technical products based on acute oral and dermal toxicity. It includes a conversion table that allows determination of the hazard class for the pesticide formulation under consideration. Towards 2008, this list will be replaced by the Globally Harmonized System of Classification and Labelling of Chemicals (GHS), which in addition to acute toxicity also takes into consideration chronic health risks and environmental risks (http://www.unece.org/trans/danger/publi/ghs/ghs_welcome_e.html). The term "pesticide formulation" means the combination of various ingredients designed to render the product useful and effective for the purpose claimed; the form of pesticide as purchased by users. The term "active ingredient" means the biologically active part of the pesticide.

5 http://www.pic.int/Implementation/Pesticides

d. Appropriate application equipment[6] and personal protective equipment offering adequate protection from the specific pesticides must be used. If available, it needs to be provided by the project.
e. Users of the pesticides must have been trained to ensure they are capable of handling the supplied pesticides in a proper and responsible manner.
f. Proper storage of pesticides in accordance with FAO guidelines should be ensured for all supplies.
g. Empty pesticide containers should be triple rinsed, punctured and disposed of in an environmentally sound manner in compliance with FAO guidance.[7]

13. If pesticides are to be purchased for seed treatment (seed storage chemical or seed treatment), the following additional conditions must be met:

a. The treatment of seeds must be done in an appropriately equipped facility that ensures full containment of the pesticides.
b. Users of seed treatment equipment should be provided with suitable application equipment and instructed on calibration, use and cleaning of the equipment.
c. Treated seeds must be dyed using an unusual and unpalatable colour to discourage consumption.
d. All packages containing treated seeds must be clearly marked "Not for human or animal consumption" and with the skull and crossbones symbol for poison.
e. Those handling treated seeds during distribution or use in the field should be informed that the seeds are treated with pesticides which can have toxic effects on their health, the health of others and on the environment. They should be instructed to wear gloves, dust masks and clothes that fully cover their body. Gloves and dust masks must be provided if these are not available.
f. Packaging from treated seeds should not be reused for any purpose.

Disposal

14. Projects dealing with the disposal[8] of obsolete pesticides, pesticide-contaminated soil and materials should follow the guidance in the FAO Environmental Management Toolkit for obsolete pesticides.
15. Such disposal projects reduce risk by eliminating hazardous waste problems, but also create risk through the handling and movement of hazardous waste. Suitable risk evaluation, management and mitigation measures provided by the Toolkit must be applied in all such activities.

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6 http://www.fao.org/agriculture/crops/thematic-sitemap/theme/pests/code/list-guide-new/en/

7 Guidelines on management options for empty pesticide containers. FAO/WHO, 2008. http://www.fao.org/agriculture/crops/core-themes/theme/pests/pm/code/list-guide/en/]

8 http://www.fao.org/agriculture/crops/obsolete-pesticides/resources0/en/

Responsibility

16. Whenever pesticides are provided by FAO, it should be established in advance which institution, and which person(s) within that institution, will be responsible and liable for the proper storage, transport, distribution and use of the products concerned in compliance with the requirements of E&SS5.
17. Procurement of pesticides by FAO is subject to an internal clearance procedure as provided by the ESS Manual. The same applies to the contents of Pest Management Plans.

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