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18

Future proofing agriculture systems

Circular sanitation economies for more resilient and sustainable food systems

TOILET BOARD COALITION

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Toilet Board Coalition Introductory letter

The Coronavirus disease (hereafter COVID-19) has brought the global economy and communities around the world to their knees, revealing weaknesses in systems wherever they appear. It also put tremendous pressure on businesses and supply chains across the globe with growing uncertainty, reduced demand and workforce disruption (Deloitte, 2020). Most importantly, the crisis has highlighted the need to strengthen the local economies, make them resilient enough to bounce back from surprises and setbacks, and to increase their capacity to serve the communities they correspond with - economically, socially and environmentally. In a world of broken supply chain networks and disrupted livelihoods, there are echoes everywhere of the need for resilient systems and demands for new innovations and visions to put in place systems which are future-proofed to the 'new normal'.

The sanitation economy plays a unique role in strengthening global food and agricultural systems by creating more local, closed and circular resource loops and therefore shortening supply chains. A sanitation economy approach promotes the conversion of waste and biosolids, or toilet resources (TBC's preferred term), that a community produces into compost, water or energy that is then used locally. Nutrients such as phosphorus and nitrogen can also be recovered from biosolids.

The Food and Agriculture Organization of the United Nations (FAO) and the Toilet Board Coalition (TBC) have collaborated on this piece of work to shine a light on the benefits and rationale for agricultural systems and the local and national contexts in which they operate to champion circular sanitation economies and the products coming from them. We highlight several sanitation economy businesses already partnering with the agricultural sector to demonstrate how this thinking and approach is currently being realised.

It is more apparent than ever that our global systems, in particular our food and resource systems, must operate in a new, more sustainable, and resilient manner. Business innovation in the sanitation economy can provide the agricultural sector with a reliable source of valuable resources that grow with the population whilst providing benefits for people, the planet and business.

Bérangère Magarinos-Ruchat, Founding Member
Toilet Board Coalition

Food and Agriculture Organization of the United Nations Introductory letter

Five years into Agenda 2030, and the world is not on track to achieve many of the SDGs such as SDG 2 on zero hunger and SDG 6 on water and sanitation for all. Global population trends indicate that the number of people going hungry is slowly increasing. There are nearly 60 million more undernourished people in 2020 than in 2014, when the prevalence was 8.6 percent – up by 10 million people between 2018 and 2019 (FAO, 2020a). Strengthening food systems is essential. COVID-19 has made the fight against poverty, inequality and food insecurity more urgent than ever.

Finding more sustainable ways of doing business is essential. Global demand for agricultural outputs is forecast to increase by 35 to 50 percent between 2012 and 2050 as a result of population and income growth. Meeting this demand will further strain the world's natural resources and cause more environmental and land degradation, water scarcity and biodiversity loss, which will be further exacerbated by climate change.

Today, open defecation is still an environmental and health issue, and it is a major barrier for sustainable development. A shift from linear to circular economies can help address this challenge, where recovered nutrients, water and energy from toilet resources (faeces or urine) are returned to food systems. This paper provides examples of companies implementing circular sanitation models to recover nutrients for agriculture, thereby creating new markets and more local supply chains.

The pandemic is a reminder that minimising disruptions to food systems is essential for global food security. However, many of agriculture's essential workers - such as smallholder farmers - are highly susceptible to unexpected shocks, often lacking access to basic services, such as safe and clean water and sanitation. At FAO, our commitment is to help countries plan across the rural, peri-urban, and urban landscapes and find innovative and integrated solutions to meet water, energy and food demand in support of and transform to more resilient food systems. Now is the time to re-think how the agriculture sector does business, and to take the next steps to achieve the 2030 Sustainable Development Agenda.

Sasha Koo-Oshima, Deputy Division Director of Land and Water
Food and Agriculture Organization of the United Nations

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Executive summary

The agriculture sector is at a pivotal moment and finding innovative solutions is essential to meeting water, energy and food demands. Addressing water scarcity in the agriculture sector requires innovative solutions that provide multiple environmental, social and economic benefits. At its broadest level, the One Water approach recognizes that water resources operate within a closed loop system. The water of today is the current cycling through of a system that has been in operation for millennia. The One Water approach to water resources management is based on the premise that all forms of water (rainwater, groundwater, surface water, brackish water, used water, fit-for-purpose reuse water) form a system that provides the most effective service when adopting a circular sanitation economy approach.

The global water community at large supports efforts in water-scarce countries and communities to go beyond conventional water resources and plan for nonconventional water resources to increase supply. The objective is to narrow the water demand/supply gap and to achieve Sustainable Development Goals (SDGs) including SDG 1, SDG 2, SDG 3, SDG 6, SDG 7, SDG 9, SDG 13 and SDG 14, calling collectively for achieving zero hunger and clean water and sanitation for all by the year 2030.

COVID-19 has shown the world that minimising food system disruptions is essential for food security, calling for innovative solutions such as circular sanitation economies that foster local markets, shorten supply chains and provide necessary products at affordable prices. The agriculture sector is already facing the impacts of climate change, erratic rainfall patterns and extreme events. Therefore, targeted investment for more sustainable water, energy and food systems is necessary. Circular sanitation models have the potential to enhance the resilience of farmers by capturing "waste" and converting it into renewable resources that are then returned to agricultural systems.

This paper focuses on discussing the entry points of circular sanitation economies for the agriculture sector and the role they can play to meet the expected increase in population, urbanisation and global food demand. The paper discusses the need for circular sanitation models and how they are currently being implemented. The business case section of the paper highlights the growing role of the private sector in implementing these models linked with the Water-Energy-Food nexus (WEF nexus), the opportunities and barriers to overcome. Finally, the paper ends with a call to action section for policy makers, governments, agriculture sector professionals and the private sector, as well as consumers at both local and national levels, to implement circular sanitation economies in order to achieve global food security.

Introduction

Circular approaches can help close the nutrient loop between the sanitation and agriculture sectors whilst addressing major global water, energy and food security issues.

The Food and Agriculture Organization of the United Nations (FAO) and the Toilet Board Coalition (TBC) see opportunities coming from a circular sanitation economy for the agriculture sector. This paper aims to highlight how circular sanitation models recover nutrients, water and energy from toilet resources, thus creating more local supply chains for urban, peri-urban and rural areas.

Leaving no one behind and providing adequate and equitable sanitation for all by 2030 is a collective goal that lies at the heart of Sustainable Development Goal 6 (SDG 6). However, the world is far from reaching this common goal and innovative solutions are imperative to achieving this challenge for the water, energy and food sectors. Globally, over 2.2 billion people still lack access to drinking water, while 4.2 billion lack sanitation services and 3 billion lack basic hand-washing facilities (UN-Water, 2019).

In addition, 33 percent of the world's soils are already degraded; land degradation affects almost 2 billion hectares of land worldwide (FAO, 2019a) and more than 2 billion people live in countries experiencing high water stress (UN-Water, 2018). Meeting the expected increase in global food demand will largely depend on the availability and quality of land, water and soil resources as well as the access to affordable and readily-available nutrients such as phosphorus (P) and nitrogen (N) for agricultural production. Projections suggest that a growing population in an increasingly urbanised world, rising incomes and lifestyle changes will lead to an increase in demand for agricultural products by 35 to 50 percent between 2012 and 2050, exerting even more pressure on already scarce resources. With a circular approach in the realm of agriculture, the reliance on finite resources used in the production of synthetic fertilizers through mining can be reduced.

COVID-19 has put food systems in the spotlight where a minimal disruption to the value chain can heighten food insecurity. Therefore, carrying on business as usual is no longer an option and finding sustainable models is necessary. The availability of fresh, nutritious and diverse food, and access to safely-managed water resources is more important than ever.

The shift to a circular sanitation economy requires a unique collaboration between local and national governments, policy makers, agriculture sector workers, the private sector, and all stakeholders across relevant sectors and the value chain. Inadequately-treated human waste creates negative societal costs and, if treated properly and innovatively, waste becomes a precious resource. A circular sanitation economy can be both circular and smart, and can become a source of renewable energy, water, compost or animal feed and nutrients that are recoverable from wastewater for putting back into agriculture.

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1. Connecting sanitation with the Water-Energy-Food nexus and sustainable agriculture systems

1.1. The need for sustainable agriculture systems

A global transition to circular and regenerative food and agriculture systems is needed to develop resilient agri-food value chains, that use natural resources efficiently, sustainably and in a circular fashion.

Agriculture withdraws the largest share of the world's freshwater resources, and more than one quarter of the energy used globally is consumed onfor food production and supply (FAO, 2014). According to the United Nations Department of Economic and Social Affairs (UNDESA), by 2050 the global population will reach more than 9 billion people, requiring almost a 50 percent increase in food production than it did in 2012 (FAO, 2017a). Even with improvements in water efficiency and productivity, achieving the increased demand in food production will require additional water resources. If the world is to meet this demand, swift changes are needed.

Sustainable food systems focus on long-term solutions, based on five key principles for sustainability for food and agriculture (FAO, 2020b) as shown in Figure 1.

FIGURE 1
Five key principles of sustainable agriculture

Source: FAO, 2020b

The five principles focus on increasing productivity, protecting natural resources, inclusive economic growth, enhancing community resilience and adapting governance models to meet global challenges. A circular sanitation economy fits within this sustainable agriculture mode and can contribute to all five principles.

1.2. Water-Energy-Food nexus

The Water-Energy-Food nexus falls under FAO's vision of sustainable food and agriculture to achieve its mandate of eradicating hunger, reducing poverty and managing resources sustainably. A circular sanitation economy can support this approach.

The Water-Energy-Food nexus (WEF nexus) approach is an entry point for FAO's work on sustainable agriculture and food security. Circular sanitation economies can serve as an alternate pathway to meet global water, energy, food and nutrition security needs in service of (often marginalised) urban, peri-urban and rural areas. The WEF nexus describes the complex interactions between global resources systems and it can help identify needs across all sectors. Ideally, the WEF nexus can help identify and manage trade-offs and facilitate more cost-effective planning, decision-making, implementation, monitoring and evaluation of interventions.

The case studies in this paper show examples of circular sanitation systems operating under a WEF nexus approach. The companies implementing circular sanitation systems are implementing wastewater treatment systems where water, energy and nutrients recovered can be reinserted for productive uses into the system. Results of a feasibility study carried out by TBC and Ethical Tea Partnership (ETP) in tea production in Assam, India show the potential of a circular sanitation economy if it were to be applied fully (Box 1).

In agricultural areas and when marginal water is separately collected and managed as a local water supply, introducing a circular sanitation economy can be cost-effective. Overall, circular sanitation approaches appear to shorten supply chains, generate new revenue streams, make products more readily available and increase local resilience.

BOX 1

Sectoral investments in the tea production sector

To address inadequate sanitation, TBC and ETP (2018) carried out a feasibility study to assess the potential of implementing circular sanitation systems in tea production systems in Assam, India where 2.6 million tea plantation workers produce at least 1 billion litres of human excreta per year. The figure increases when adding household members to 12.5 million people residing on tea-farms, producing 6.6 billion litres of human excreta per year. If the circular sanitation economy model were successfully implemented, it could result in the following:

- ***Fuel:*** *250 000 tonnes of briquettes mixed with ash resulting in 1.5 billion MJ per 100 million* m^3 *of methane gas, resulting in 2.4 billion MJ of biogas per 280 million kWh of electricity;*
- ***Feed:*** *170 000 tonnes of black soldier larvae;*
- ***Fertilizer:*** *420 000 tonnes of compost, 3 100 tonnes of phosphorus, 3 300 tonnes of Potash, 4 600 tonnes of nitrogen;*
- ***Water:*** *14 billion litres of water (low-flush system - additional 12 billion litres of water).*

Source: TBC, 2018.

1.3. What is the circular sanitation economy and how is innovation is applied?

Circular sanitation business models with innovation can create positive value for agricultural communities while addressing current environmental and health issues associated with poorly managed sanitation.

Unlike today's predominantly linear take-make-dispose economy, a circular economy is based on recovering waste, keeping products and materials in use, and regenerating natural systems. Note that although this paper focuses on human waste, FAO works at a larger scale and the circular economy also applies to crop and livestock residues (FAO, 2017b).

The circular sanitation economy is one of three areas in the broader sanitation economy, a marketplace of innovative products and services, renewable resource flows, data and information that could transform future cities, communities and businesses. The idea behind this approach is that these systems are sustainable, cost-saving and revenue generating. The sanitation economy has three components:

- Toilet economy: toilet product and service innovation that provides toilets fit for purpose for all contexts and incomes;

- Circular sanitation economy: connects the biocycle, using multiple forms of biological waste, recovering nutrients and water, and creating value-adding products such as renewable energy, organic fertilizers, proteins and more;

- Smart sanitation economy: digitised sanitation systems which optimise data for operating efficiencies and maintenance, plus consumer use and health information insights.

BOX 2

WASTE & RDO Trust – production and application of co-compost for vegetable cultivation

Company name: WASTE & RDO Trust
System/technology: Circular economy of faecal sludge and solid waste for agriculture
Location: The Nilgiris District, Tamil Nadu, India
Sector: Water, sanitation, solid waste and agriculture
Agriculture use: Nutrient-rich co-compost
Beneficiaries: Smallholder farmers, low-income, non-sewered urban, peri-urban and rural populations

Summary and impact

Under the Securing Water For Food (SWFF) programme, WASTE & RDO Trust have linked sanitation and agriculture through the production and application of co-compost (mix of faecal sludge and organic solid waste) for vegetable cultivation by smallholder farmers in the Nilgiris. Two faecal sludge treatment plants have been established in Ketti and Adigarahatty Resource Recovery Parks (RRPs) in the Nilgiris since 2017.

Faecal sludge is collected from households by private entrepreneurs. It is transported to the closest RRP with a faecal sludge treatment plant with constructed wetlands. At the RRP, municipal solid waste is received and segregated in organic and non-organic solid waste. The dried form of faecal sludge gets mixed with organic solid waste for co-compost production. The co-compost is sold to female farmers, who use it for soil application. The addition of dry faecal sludge brings extra nutrient value in co-compost.

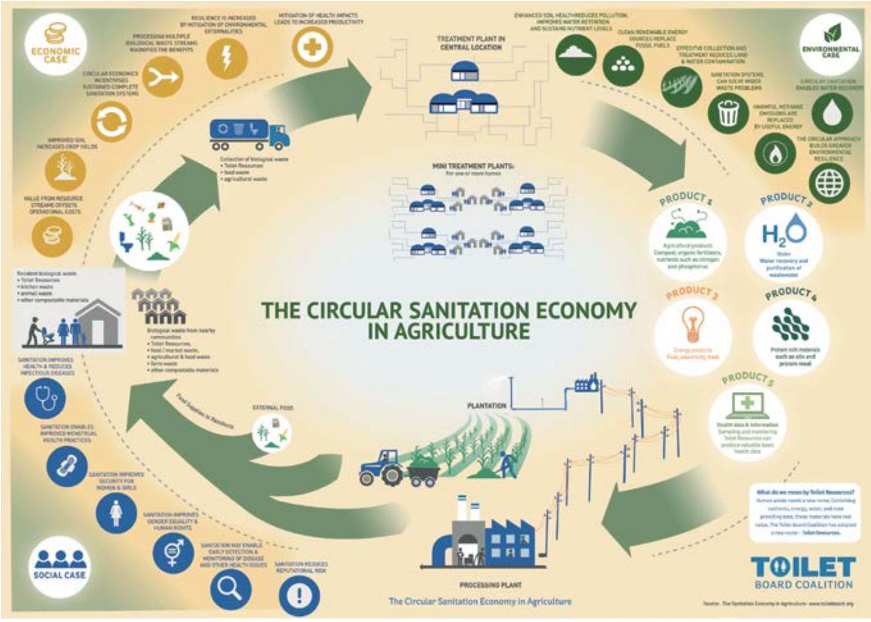
90 percent of the users are positive and confident to use co-compost (n=50), 100 percent of farmers reported increase in crop yield; approximately 70 percent of farmers felt the change in water usage after using co-compost; 98 percent of farmers saw increases in the survival rate of crops and 68 percent of farmers reported changes in family income. In Nilgiris, to date 1 134 tonnes of Greenhouse Gas (GHG) emissions are saved by utilising landfill waste to produce co-compost. Over 51 840 kg of nutrients from organic solid waste and faecal sludge are recycled, thus avoiding use of high-carbon-footprint chemical fertilizer. 350 740 kg of total organic carbon is added to the soil in the form of co-compost. This increases soil fertility and will eventually be captured through a carbon sequestration process.

The success of SWFF programme and co-compost innovation has provided a springboard for scaling model within India (Odisha, Rajasthan, Bihar and more) and internationally under the FINISH Mondial programme in Kenya, Uganda, Tanzania, Ethiopia and Bangladesh.

Source: WASTE & RDO Trust, 2020.

A characteristic of a circular sanitation economy is that it is not ‘business as usual’. As featured through a number of case studies featuring technologies in this paper, companies implementing these systems are using innovative approaches and new technologies and improving on existing technologies and combining them to generate greater value. A circular sanitation economy sees waste products as a valuable resource. For example, Box 2 illustrates production and application of co-compost for vegetable cultivation.

FIGURE 2
The circular sanitation economy in agriculture



Source: Toilet Board Coalition, 2018.

BOX 3
Sanivation – treatment of faecal sludge and fuel and energy production

Company name: Sanivation
System/technology: Faecal sludge treatment facility
Location: Naivasha, Kenya
Sector: Sustainable cooking economy
Agriculture use: Fuel and energy
Beneficiaries: Local governments and industries, rural, urban and peri-urban populations

Summary and impact
Sanivation sells fuel made from community waste to local tea and flower gardens to use as part of their commercial operations.
Sanivation created a process in 2015 that mixed the toilet resources obtained from its container-based sanitation facilities with industrial waste from surrounding factories, such as sawdust from wood mills. The company is now also receiving faecal sludge from pit latrines and septic tanks to their faecal sludge treatment facility which operates in partnership with the local government. The sludge is heat-treated to inactivate any pathogens, and the sludge and biomass mixture is then put in a system that extrudes non-carbonized briquettes for commercial biomass boilers.
To date, Sanivation has treated 1 701 tonnes of waste; it has served 29 558 people with safely managed sanitation, and it has sold 2 218 tonnes of fuel. Sanivation employs 51 people, and it has an offset of 5 620 tonnes of CO_2eq from fuel displacing firewood.

Source: Sanivation, 2020.

Figure 2 details the innovative technologies and products for use by the agricultural sector that will simultaneously increase access to clean water, sanitation and hygiene.

A sanitation economy can provide products coming from waste in the form of water, energy, compost, animal feed, and nutrients. These products are suited to be inputs for the sectors facing constraint of essential resources such as water, nutrients and energy, like the agricultural sector. In addition, circular sanitation systems can help improve sanitary and hygiene conditions in marginalised areas that lack adequate sanitation systems. An entry point of a circular sanitation economy for the agriculture sector is summarised in the case study of a company called Sanivation in Box 3.

As previously discussed, inadequate sanitation has negative environmental, health and economic impacts and the business case lies in addressing these issues through circular sanitation models. According to a World Bank estimate, economic losses due to inadequate sanitation cost the global economy approximately USD 260 billion a year (World Bank, 2013). A lack of sanitation is linked with inequality and poverty, which calls for new business models.

BOX 4

Sanergy - toilet making and nutrient and energy recovery for agriculture

Company name: Sanergy
System/technology: Toilets and nutrient, water and energy recovery
Location: Nairobi, Kenya
Sector: Water, sanitation, agriculture and energy
Agriculture use: Fertilizer and animal feed industry
Beneficiaries: Large scale and smallholder farmers, restaurants, agricultural pack houses, low-income, non-sewered urban, and peri-urban populations.

Summary and impact

Sanergy hires local people to manufacture and distribute low-cost toilets for Nairobi's slums. Local residents pay a small amount for waste collection service.

Sanergy's model consists of four critical steps: building and distribution of high quality, low cost container-based sanitation units called Fresh Life, professional collection and removal of all sorts of organic waste (sanitation waste from the Fresh Life toilets, agricultural waste, and market/kitchen waste from restaurants, markets areas and agricultural pack houses), and its safe transportation to their large-scale recycling factory. Finally, the treatment and repurposing of the waste to agricultural inputs and energy for commercial and smallholder farms.

Since 2011, Sanergy has installed 3 145 toilets in Nairobi, which serve more than 100 000 people on a daily basis. The company safely removes 12 000 tonnes of waste annually and has created over 1 000 jobs throughout its full value-chain approach.

Source: Sanergy, 2020.

Circular sanitation economies are already under implementation in many settings around the globe, and this paper has showcased some of them. The experiences illustrating this paper provide a snapshot of the opportunities to be explored by other entrepreneurs globally if the right conditions are in place (e.g. government policies).

As highlighted by the Sanergy example in Box 4, circular sanitation economies have multiple benefits. The sanitation business model is in part driven by cost-reduction in management of infrastructure. For example: the recovery of phosphorus prevents damage to pipes and valves through unwanted precipitation. Another example is shown in Box 5, illustrating a biodigester system that produces fertilizers and fuel. Although companies operating in the circular sanitation economy have overcome many hurdles, there are still challenges to see some of the products accepted at a wider scale due to outdated thinking and policies around the reuse of this valuable resource.

BOX 5

ATEC* – biodigester system that produces fertilizers and fuel

Company name: ATEC*
System/Technology: Biodigesters
Location: Phnom Penh, Cambodia
Sector: Energy and fuel industry
Agriculture use: Fertillizers and fuel for cooking sources
Beneficiaries: Rural Cambodian families, smallholder farmers with two to three livestock, and around 1.5 hectare of rice and/or vegetables

Summary and impact

The ATEC* biodigester is a system which converts animal, green and kitchen waste into biogas and organic fertilizer, providing clean, off-grid energy and appropriate sanitation in flood-prone areas of Cambodia. The company produces energy to cover household cooking needs and has become a supplier of 20 tonnes of organic fertilizer for crops per year. The company's biodigester contributes to women's empowerment as it saves them 20 hours per week collecting and using wood.

In a smallholder farm with two to three livestock, on average, a biodigester system provides up to 1 500 litres of biogas daily, enough to cook three times a day, as well as 20 tonnes of high-quality organic fertilizer for 1.5 hectares of rice and vegetables increasing farm yield by up to 32 percent.

In summary, as of July 2020, ATEC* has sold 1 417 biodigesters, serving approximately 7 510 beneficiaries. The company's product has produced 13.5 billion litres of renewable biogas and 698 million kg of organic nutrient fertilizer; it has reduced greenhouse gas emissions (GHG) by 159 000 tonnes and helped conserve 7 644 tonnes of forest wood.

Source: ATEC, 2020.*

1.4. Urbanisation, the Water-Energy-Food nexus and circular sanitation systems

Cities are hotspots for biosolids due to the increasing number of humans living in urban settings and a growing global population. It is estimated that 55 percent of the world's population resides in urban areas. In developing countries, unplanned urbanisation comes with several challenges to sustainability. Waste management is a major problem for cities in developing countries, where it is often scattered and disposed of in unplanned settings. The developing world has some of the largest and most crowded slums worldwide. Due to unplanned urbanisation, these cities often lack infrastructure for the collection, transportation, treatment and disposal of waste.

COVID-19 has necessitated a transition towards greener and regenerative cities more essential than ever. As such, the potential for moving cities towards circular sanitation economies, in which products from recycled waste are used, constitutes an opportunity for advancing sustainability. The Water-Energy-Food nexus and circular sanitation systems can play a role in addressing the challenges that come with global urbanisation trends.

1.5. Transitioning from linear to circular sanitation models

The transition from linear sanitation models to circular sanitation models requires a shift from a take-make-dispose mindset towards a reduce-reuse-recycle one. The current global population's human waste - or toilet resources - amounts to 3.8 trillion litres of renewable resource per year (TBC, 2018).

In a world where 4.2 billion people live without safely-managed sanitation, reusing human excreta could potentially help lift people out of poverty. According to United Nations (UN) estimates, some countries experience a funding gap of 61 percent for achieving water and sanitation targets (UN, 2020). If these gaps were integrated with circular approaches, new sources of sustainable economic development could emerge.

Human excreta could potentially provide new reservoirs of renewable resources recovered by innovative companies with more cost-efficient, decentralised alternatives to the capital-intensive waste management systems of current linear models.

Human excreta can be a valuable resource under the principle of ensuring human health, soil health and food security. When the untreated human excreta get out into the environment, it becomes a breeding ground for parasites, pathogens, viruses and soil and water-borne diseases such as cholera, dysentery, *E. coli*, salmonella and soil-transmitted intestinal worms (helminthiases), posing high health risks to famers and consumers. To avoid the potential disease risks from human excreta, appropriate level of treatment technologies is essential to prevent the spread of contamination or inactive pathogens, viruses and steroids before applying as fertilizer to agricultural soils. Pathogens and viruses should not be present in treated waste (liquid or solid) to avoid the contamination of agricultural products, consumers, or be accidentally ingested by farmers during handling (Howard *et al.*, 2002).

Moreover, the treatment process can be also used to add value of waste product. Treated sewage sludge produces biosolids that are suitable for controlled application on croplands. For example, composting of biosolids can be utilised as a method further promote its usefulness and effectiveness for crop growth. The circular sanitation economy models can make productive use of wastewater and biosolids that contain valuable water, nutrients and energy, to safely boost agriculture while reducing and capturing greenhouse gas emissions.

1.6. Soils and nutrient recovery for agriculture

Circular sanitation approaches where human excreta are returned to the soil as nutrients can become a reliable resource for agriculture.

Healthy soils are the basis for sustainable food production, which, according to FAO, can increase food production by 58 percent (FAO, 2015). Healthy soils are composed of adequate amounts of nutrients including nitrogen (N) and phosphorus (P) needed for plant growth. For example, adequate P levels in soils are linked with increased water-use efficiency and crop yields. Healthy soils also require carbon (C) for building soil structure - which is important for retaining water in times of flood and drought, and also for avoiding run-off into water bodies. FAO also notes that healthy soils have a rich biodiversity, as soil organisms have vital roles in soils health and may be important for the continued capacity of soils to produce crops (FAO, 2021).

However, unsustainable agricultural practices such as monocropping, synthetic fertilizers, chemical pesticides and mechanical tillage, among others, are degrading soils. According to a report by the Soil Association (2020), "from plant breeding to soil structure, the abundant use of nitrogen fertilizers has been the lynchpin of agricultural intensification. This has created ecological imbalances and changed the nature of farming itself." According to FAO, a third of the world's soils are now moderately to highly degraded . This results in micronutrient depletion where a shortage of any of the nutrients required for plant growth limits crop yield (FAO, 2015).

The depletion of micronutrients in soils has resulted in an increase in demand for nutrients globally. According to FAO estimates, world consumption of the three main fertilizer nutrients, N, P expressed as phosphate (P_2O_5), and potassium expressed as potash (K_2O) was estimated at 186.67 million tonnes (N, P_2O_5 and K_2O) in 2016, up by 1.4 percent over 2015 consumption levels. The demand for N, P_2O_5, and K_2O is forecast to grow annually on average by 1.5, 2.2, and 2.4 percent respectively from 2015 to 2020 (FAO, 2017c).

The increasing trends in intensification of fertilizer nutrient demand can be observed in Table 1. When these figures were estimated, the global pandemic was not part of the equation. It is yet to be seen what the impacts of COVID-19 are on fertilizer nutrient demand.

TABLE 1
Global nutrient fertilizer demand (thousand tonnes) and Compound Annual Growth Rate (CAGR) for 2015-2020

Nutrient type	2015	2016	2017	2018	2019	2020	CAGR (%)
N	110 027	111 575	113 607	115 376	117 116	118 763	1.54
P_2O_5	41 151	41 945	43 195	44 120	45 013	45 858	2.19
K_2O	32 838	33 149	34 048	34 894	35 978	37 042	2.44

Source: FAO, 2017c.

Organic carbon

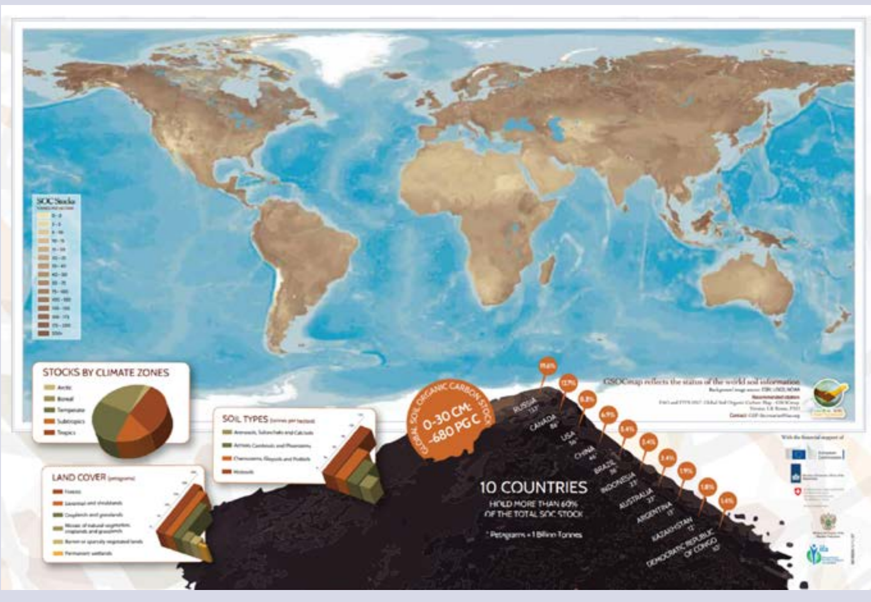
Globally, soil organic carbon stocks are estimated at an average of 1 500 PgC in the first meter of soil, although their distribution is spatially and temporally variable (Figure 3).

Soil organic carbon is the main component of soil organic matter. As an indicator for soil health, organic carbon is important for its contributions to food production, mitigation and adaptation to climate change, and the achievement of SDGs (FAO, 2017d).

A high organic matter content provides nutrients to plants and improves water availability, both of which enhance soil fertility and ultimately improve food productivity. Moreover, organic carbon improves soil structural stability by promoting aggregate formation which, together with porosity, ensure sufficient aeration and water infiltration to support plant growth. While plant growth and surface mulches can help protect the soil surface, a stable, well-aggregated soil structure that resists surface sealing and continues to infiltrate water during intense rainfall events will decrease the potential for downstream flooding. Porosity determines the capacity of the soil to retain water and controls transmission of water through the soil. With an optimal amount of organic carbon, the water filtration capacity of soils further supports the supply of clean water (FAO, 2017d).

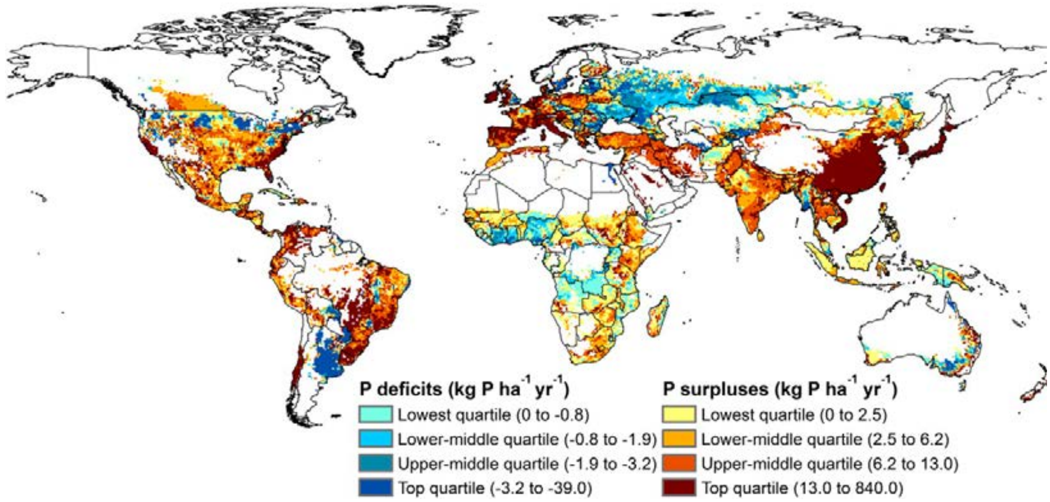
Soil organic matter is critical for the stabilization of soil structure, retention and release of plant nutrients and maintenance of water-holding capacity, thus making it a key indicator not only for agricultural productivity, but also environmental resilience (FAO, 2017d).

FIGURE 3
Global soil organic carbon map



Source: FAO, 2017e.

FIGURE 4
Phosphorus concentration worldwide



Source: MacDonald et al., 2011 and FAO, 2019a.

According to 2020 estimates by the United States Geological Survey (USGS), projections indicate that world consumption of P_2O_5 alone will increase to 50 million tonnes in 2023 from 47 million tonnes in 2019. Africa, India, and South America account for about 75 percent of the projected growth, making it a critical issue for food security (USGS, 2020).

Wastewater contains important nutrients – such as N and P – and water that can be returned to agriculture systems if managed properly.

1.7. Global distribution of phosphorus

An essential component to life on Earth, phosphorous (P) is a finite resource, which cannot be replaced nor created. Agriculture is extremely reliant on P, and potential shortages of it could heavily affect food systems, as there are no substitutes for it in agriculture.

The USGS's Mineral commodity summaries 2020 states that no current imminent shortages of phosphorus rock exists (USGS, 2020). However, most phosphorus rock reserves and production are concentrated primarily in the following countries (listed in production order starting with the largest producer): China, Morocco and Western Sahara, the United States, Jordan and Russia (USGS, 2020). Therefore, various countries across the world are heavily dependent on P production, supply and exports from these select countries. The phosphate price trend can be forecast to show a slow, long-term increase as the demand for fertilizers is increasing. Higher costs for producing phosphate could make the fertilizer more expensive; on the other hand, as conditions worsen, farmers will need to use more fertilizer to produce the same crop volume. This in turn indicates a rise in food prices in the future (INN, 2019).

According to a report by the Hague Centre for Strategic Studies (HCSS), in 2011, China, the US and Morocco and Western Sahara accounted for over two-thirds of global production. Morocco is the world's largest exporter, accounting for approximately one-third of total exports (HCSS, 2012). In conclusion, supply disruptions might not be due to rock reserves but could exist in the form of insufficient supply and import dependence.

Figure 4 shows that global P is not distributed equally across the world, leading to imbalance where some parts of the world experience P deficits or surpluses. In addition, not all phosphorus rock has been explored or exploited.

Lessons learned from the COVID-19 pandemic call for more reliance on local sources of supply to reduce the risk of disruptions in food systems. Circular sanitation economies can play a role in meeting nutrient demand from treatment of sewage sludge, also known as biosolids, to recover nutrient P, for example.

1.8. Recovering phosphorus from human excreta

Urine and faeces constitute a large portion of phosphorus derived from biosolids. Urine contains all the essential plant nutrients directly required in agriculture. Humans exert an estimated 3 million tonnes of P annually. According to Jansen (2016), 50 to 60 percent of the P in the toilet resources is in urine. Harder *et al.* (2019) estimate that N, P, and K make up 5 to 7 percent of human faeces.

Phosphorus can be recovered from biosolids, which are nutrient-rich organic materials resulting from the treatment of wastewater. The recovery of phosphorus usually involves the separation of phosphates from harmful substances. Recovering phosphorus from biosolids can contribute to a local supply of this nutrient. The case study in Box 6 shows how a private company, Liquid Gold, in South Africa is implementing a circular sanitation economy through the design of public urinals for females and males, and by collecting waste from urinals, which is then treated and reinserted back to agricultural systems.

BOX 6

Liquid Gold: building of urinals and nutrient recovery

Company name: Liquid Gold
System/technology: Nutrient recovery
Location: Johannesburg, South Africa
Sector: Energy and fuel industry
Agriculture use: Fertilizers and soil health
Beneficiaries: Farmers and rural households

Summary and impact

Liquid Gold designs both male and female urinals, including a model of public urinals made out of containers. The urine is then treated and sold to farmers or agriculture industries across South Africa. The pit latrine is a sanitation technology used by the majority of the people in Southern Africa. The current trend of usage shows adaptation of more improved designs.

The urinals are sometimes used to reduce the number of toilets required at a school, which typically reduces the cost per child served. The urinals for girls and women have been used with success in some countries and are easy for young children to use, are cheaper and faster to build than toilets and reduce unpleasant smells for younger children.

Annually, the company treats 150 000 litres of water per urinal, it collects 95 000 to 120 000 litres of urine per urinal and it keeps 75 to 80 percent of N and P out of the wastewater treatment plant or local waterways. Each unit saves 370 kg of CO_2 per year. In addition, urinals are up to 80 percent more hygienic due to no-touch technologies with no transfer of bacteria, especially for young girls and women. It is a source of employment since one micro-entrepreneur creates - for every 100 units - four permanent jobs, especially for women.

Source: Liquid Gold, 2020.

2. Lessons learned

2.1. Enabling policy environment

Transitioning to circular economy requires engagement from governments, cities, innovators, farmers, learning institutions and more, which can come together to identify and grasp the opportunities inherent in moving away from today's linear take-make-waste economy. The current world economy has led businesses to diversify their operations globally. Many multinational companies operate in a variety of countries worldwide. This presents an opportunity for implementing circular sanitation economies, promoting best practices, and making agreements with governments and local stakeholders to implement them at scale.

Businesses do not operate in isolation, and they often require support mechanisms such as policies and market incentives to be successful. Other external forces, such as the economic landscape of the operating region, societal habits, cultural values and taboos, policies and executing bodies, market structure and response, and technological advancements can largely influence business strategies. Additional factors such as safety, political stability or a global pandemic can influence the market.

TABLE 2
Opportunities and enabling factors in different areas

Areas	Enabling factors/opportunities
Economy	Local/national investment in business opportunities for a circular sanitation economy; Development of indicators that allow measurement of the impacts of a circular sanitation economy; Creation of employment opportunities linked with a circular sanitation economy; Financing programmes tailored to support a circular sanitation economy.
Society	Agreements with universities and research institutions to include circular sanitation economies in their curricula; Creation of a circular sanitation economy knowledge hub; Implementation of an advocacy campaign to discuss the benefits of a circular sanitation economy.
Policy	Coherence between main national climate (e.g. Nationally Determined Contributions, National Adaptation Plans) and sustainability strategies/policies with local circular sanitation economy city planning; Recognition of circular economies at national and local levels, e.g. city planners and/or policy makers; Integration of circular sanitation models with recycling, water management, agriculture and other relevant policies; Implementation of policies that align with international guidance of circular sanitation products testing and safety; Facilitation and encouragement of manufacture and sale of products made from human waste by provision of scientific guidance, safety instructions and their promotion at a local and national level.
Market	Implementation of incentives such as tax credits or design of optimal technologies or models for circular sanitation companies; Engagement with private sector stakeholders to engage/incentivise them to implement a circular sanitation economy business.
Technology, innovations and science	Government national and local level purchase of technology and innovations to be used by national/locally-owned/managed businesses (e.g. wastewater treatment plants); Provision of "financial support" by national and local administrations to purchase available technology and innovations for a circular sanitation economy for local businesses; Engagement of circular sanitation stakeholders/community for on-going communications and updates.

The transition to a circular economy is showcased more and more in policies. For example, part of the European Green Deal is a new circular economy action plan for a cleaner and more competitive Europe. At the hearth of the European Green Deal is also the Farm to Fork Strategy, aiming to make food systems fair, healthy and environmentally friendly (EU, 2020). These circular and green economies embrace waste and residues as essential to green growth and part of developing a circular economy that is resource-efficient and where nothing is wasted. FAO's new Green Cities Initiative also includes in its focus areas better food and water waste management as well as circular economy (FAO, 2020e).

Table 2 shows potential opportunities and enabling factors, based on the literature review carried out and company case studies presented. It can be observed that a country could optimise the implementation of a circular sanitation economy by aligning national policies and strategies with major international agreements, such as the Paris Agreement, highlighted in the "Policy" section of Table 2. A circular sanitation economy can be part of climate change adaptation and mitigation strategy in the agricultural sector.

In addition, countries should ensure co-ordinated action between various sectors to create an enabling environment for a circular sanitation economy. Often, a circular sanitation economy will come from market incentives making the reuse of materials affordable and feasible for businesses – these have to be implemented with specific sectoral perspectives.

2.2. Stakeholder mapping

Realising optimal policies and opportunities in a circular economy requires participation and alignment between stakeholders at various levels of the agricultural value-chain. The stakeholder mapping goes from "farm to fork to farm" at all levels of an economy, including national and local governments, the private sector, policy makers, and international organisations, among others. The stakeholder map shows that the interactions between stakeholders are dynamic, and everyone in society has a role to play.

TABLE 3
Stakeholder map: sanitation solutions for sustainable agriculture

STAKEHOLDER	FUNCTION	NEED	IMPACT
Governments (e.g. central, state, local)	Enabler, implementer	Regulation and policy	Enabled policy environment, incentivising businesses to invest in a circular sanitation economy
International organisations and business coalitions (e.g. FAO, WHO, TBC)	Facilitators, collaborators, incubators and knowledge managers	Forming networks, knowledge and resource sharing, call for action, advocacy, demonstration of need, guide policy and standards	Proactive business coalitions interested in investing in the WEF nexus, informed and aware of the environments, shared resources, contacts
Private sector (e.g. local businesses and corporations)	Actor, knowledge generator, investor	Financing, research and development, and innovative models	Implementation of circular sanitation solutions resulting in the complete use of the toilet resources, strengthened local economies and reduced dependency on scarce nutrients
Waste treatment and recycling (e.g. treatment plants, innovation labs, etc.)	Processors, quality control, and producers	Converting waste (toilet) resources and extracting essential nutrients to produce fertilizers	Upcycled products and ensured safety, full use of toilet resources, nutrient extraction and reuse, water management, use of technology for achieving sustainable development goals
Fertilizer industries (e.g. Manufacturers)	Producer, collaborator, and distributor	Using naturally recovered nutrients to produce fertilizers	Production of fertilizers, increased food production and security, local economic empowerment, enhanced environmental impacts
Local labour (e.g. Transportation companies, waste-pickers, on-site workers, etc.)	Intermediaries, and distributors.	Strengthening supply chains and minimising disruptions	Shortened supply chains, shock-resilient systems, smooth processes, community involvement and integration
Farmers (Smallholder farmers, farmer unions, etc.)	Beneficiaries, customers, and farming business managers	Validators, implementers, buyers of supplies	Enhanced soil health, use of natural nutrients, ease and self-sufficiency and increased availability of fertilizers, better crop growth and yields, sustainable agriculture practices and enhanced food security
Scientists and innovators	Provider of knowledge, facts, research and evidence about public health and nutrients	Consulting authentic research, the need for fact-finding and creating a culture of data reliability in businesses and organisations	Better and informed decision-making, scope for new innovations and business models based on the new evidence, combatting fake news and misinformation, high awareness and know-how about public health, pathogens and nutrients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3. Call to action

The role of the government and private sector to enable the environment to implement and scale these solutions:

The circular sanitation economy models and technologies have been created and validated at various scales, but the benefits have not yet been fully attained by the private and public sectors. Based on the literature reviewed and case studies analysed, the following recommendations can help develop and implement a circular sanitation economy at country and local levels. These recommendations take into account global international processes and link them with climate change and unexpected events such as the COVID-19 pandemic. In addition, it is often the case that gaps in implementation of policies are derived from insufficient funding, which is included in these recommendations.

1. Integration of circular sanitation economy policies, laws and incentives within the agricultural food value chain: farm-to-fork-to-farm approach.

It requires tailor-made policies throughout the value chain from farm to end consumer and back to the farm to make food systems more resilient. For example, farmers can be incentivised to adopt a circular sanitation economy by integrating the concept into agricultural policies and ensuring it is implemented through extension services and amongst smallholder farmers through local capacity development. Targeted policies can be developed for packaging, distribution and/or retailer level to implement a circular sanitation economy. Such policies include the European Green Deal and its Farm to Fork Strategy, as well as FAO's work for a sustainable and circular bioeconomy.

2. Create market incentives to finance investments of scale for successful sanitation business models and de-risk the sanitation sector as a whole.

The incentives can target both the businesses and consumers. For the businesses, market incentives can come from local and national government policies using targeted price incentives and/or tax breaks that promote the reuse of materials, whereas ensuring affordable prices for consumers can incentivise local sustainable consumption.

3. Coherence with the Paris Agreement with national implementation of circular sanitation economies.

Ensure coherent action on the implementation of incentives for a local circular sanitation economy with national climate objectives (e.g. Nationally Determined Contributions, National Adaptation Plans) linked with the major climate global agenda – the Paris Agreement of the United Nations Framework Convention on Climate Change.

4. Enabling a policy environment.

Assess local and national laws and policies on reuse and recycling of materials and identify gaps in these laws and policies to overcome barriers for their implementation.

5. Mapping, creating, and supporting innovation ecosystems around sanitation.

Encourage sanitation innovations and build infrastructure to sustain them and integrate these stakeholders into action plans. Make platforms available to promote stakeholder discussion for co-ordinated action between the private sector, local government administrations and national government to work on a coherent action plan to implement a circular sanitation economy and champion international standards that would enable the sale and use of Toilet Resource Products. Facilitate a greater consultation with the scientific community to ensure safe practices and to reassure society.

6. Develop local and national communications strategies to overcome consumer perceptions around the "yuck" factor of Toilet Resource Products.

The objective is to make people aware of the benefits of creating more locally sourced value chains, including on the following: COVID-19 and the need to implement more local circular sustainable systems; current phosphorus rock extraction is not a long-term sustainable solution; recycling nutrients from toilet resources is safe and it creates more sustainable, local and circular systems; to meet increase in food demand, food systems need to shift towards more resilient solutions – business as usual is not an option anymore.

7. Promote good practices for more resilient food systems globally.

Scale up the business models that have been developed and tested with the support of international organisations and other multi-stakeholder regional and global platforms to incentivise the adoption of worldwide circular sanitation economies that have made a positive impact in food systems as a global solution.

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Future proofing agriculture systems

Circular sanitation economies for more resilient and sustainable food systems

The Food and Agriculture Organization of the United Nations (FAO) and the Toilet Board Coalition (TBC) have collaborated on this piece of work to shine a light on the benefits and rationale for agricultural systems, and the local and national contexts in which they operate, to champion circular sanitation economies and the products coming from them.

This paper focuses on discussing the entry points of circular sanitation economies for the agriculture sector and the role they can play to meet the expected increase in population, urbanisation and global food demand. The paper discusses the need for circular sanitation models and how they are currently being implemented. The business case section of the paper highlights the growing role of the private sector in implementing these models linked with the Water-Energy-Food (WEF nexus), the opportunities and barriers to overcome. Finally, the paper ends with a call to action section for policy makers, governments, agriculture sector professionals and the private sector, as well as consumers at both local and national levels, to implement circular sanitation economies in order to achieve global food security.

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