Original Research Article

Sustainable soil utilization and agriculture production: recommendations towards achieving sustainability

ABSTRACT

The modern agricultural practices affect the environment namely nutrient cycle, soilerosion, carbon sequestration, and many other ecological patterns. Organic farming is influential practice tominimize the environmental and ecological impact of sustainable development. Usage of more organic matters inagricultural practices can reduce the adverse effects on the environment by keep saving its natural cycles onrecovery process and organic farming may enhance the food quality too. The organic farming may largely excludethe usage of chemical fertilizers, pesticides, growth hormones and feed additives of livestock activities. A combination of organic farming and new technologies is of utmost importance to reduce the limitations and challenges of organic farming. The innovative methods and new approaches making new trends toward sustainabilityfarming system and enhances the agricultural productivity, and quality of life of many farmers in an environmentally friendly way. Soil not only provide food and nutritional support but also performs many ecosystem functions and services. Soil is considered as a non-renewableresource, but it takes centuries to form one millimetre of soil.One of the most popular phrase in agriculture is the term “Soil Health”. The health of soil determines agricultural sustainability.‘Soil health’ has been threatened by various challenges such as soil fertility depletion/degradation, loss ofsoil organic carbon/ biodiversity, salinization, acidification, contamination, soil erosion &degradation.According to FAO “Soil management is sustainable if the supporting, provisioning, regulating, and cultural services provided bysoil are maintained or enhanced without significantly impairing either the soil functions that enable those services or biodiversity”.

Keywords: Sustainability, Organic farming,Soil health, Soil,Agriculture production, etc.

Introduction

Land productivity capacity or land quality is a comprehension, at the same time a precise concept in terms of agricultural activities (Dengiz and Saglam, 2012). Agricultural intensification and massive infrastructure development in the recent years without considering the variability of entire production system enhance the risk of soil erosion and fertility depletion (Singh *et al*., 2007).Soil is a component of the lithosphere and biosphere system. It is a vast natural resource on which the life supporting systems and socio-economic development depends. Organic matter is one of the most important constituents of soil, a good amount of organic carbon / matter in soil increase soil fertility. The core constraints in relation to land use include depletion of organic carbon, soil micronutrients and macronutrients, removal of top soil by erosion, change of physical properties and increased soil salinity (Kumar *et al*., 2017).

The term “soil health” originates in the observation that soil quality influences the health of animals and humans via the quality of crops (Warkentin, 1995).“Soil health, also referred to as soil quality, is defined as the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals and humans.” Indeed, the definition of Mader *et al*. (2002) that a fertile soil “provides essential nutrients for crop plant growth, supports a diverse and active biotic community, exhibits a typical soil structure, and allows for an undisturbed decomposition” went beyond the provision of yields. In line with this, the maintenance of “natural soil fertility” is at the heart of organic farming (Rusch, 1985).The concept of soil quality as introduced by Larson and Pierce (1991) and Doran and Parkin (1994) was heavily criticized in a series of papers (Letey*et al*., 2003; Sojka & Upchurch, 1999; Sojka *et al*., 2003) for being subjective and ill-defined. A particular recommendation was to speak of soil use rather than soil functions, so that the responsibility to maintain the quality of the soil can be clearly assigned to the user of the soil. In particular, it was claimed to raise awareness and enhance communication between various stakeholders regarding the importance of soil resources (Karlen *et al*., 2001).

Characteristics of a healthy soil

- **Good soil tilth:** Soil tilth refers to the overall physical character of the soil in the context of its suitability for crop production. Soil with good tilth is crumbly, well structured, dark with organic matter and has no large and hard clods.
- **Sufficient depth:** Sufficient depth refers to the extent of the soil profile through which roots are able to grow to find water and nutrients. A soil with a shallow depth as a result of a compaction layer or past erosion is more susceptible to damage in extreme weather, thus predisposing the crop to flooding, pathogen attack or drought stress.
- **Good water storage and good drainage:** During a heavy rain, a healthy soil will take in and store more water in medium and small pores, but will also drain water more rapidly from large pores. Thus, a healthy soil retains more water for plant uptake

during dry times, but will also allow air to rapidly move back in after rainfall, so that organisms can continue to thrive.

- **Sufficient supply, but not excess of nutrients:** An adequate and accessible supply of nutrients is necessary for optimal plant growth and for maintaining balanced cycling of nutrients within the system. An excess of nutrients can lead to leaching and potential ground water pollution, high nutrient runoff and greenhouse gas losses, as well as toxicity to plants and microbial communities.
- **Small population of pathogens and pests:** Plant pathogens and pests can cause diseases and damage to the crop. In a healthy soil, the population of these organisms is low or is less active. This could result from direct competition from other soil organisms for nutrients or habitat, etc. In addition, healthy plants are better able to defend against a variety of pests.
- **Large population of beneficial organisms:** Soil organisms help with cycling nutrients, decomposing organic matter, maintaining soil structure, biologically suppressing plant pests, etc. A healthy soil will have a large and diverse population of beneficial organisms to carry out these functions and thus help maintain a healthy soilstatus.
- **Low weed pressure:** Weeds compete with crops for water and nutrients that are essential for plant growth. Weeds can block sunlight, interfere with stand establishment and harvest and cultivation operations, and harbour disease causing pathogens and pests.
- **Free of potentially harmful chemicals and toxins:** Healthy soils are either devoid of excess amounts of harmful chemicals and toxins, or can detoxify or bind such chemicals. These processes make these harmful compounds unavailable for plant uptake, due to the soil’s richness in stable organic matter and diverse microbial communities.
- **Resistance and resilience to degradation:** A healthy, well aggregated soil, is resilient, full of diverse organisms and is more resistant to degradation from wind and rain erosion, excess rainfall, extreme drought, vehicle compaction, disease outbreak andother potentially damaging influences (Schindelbeck et al., 2020).

Principles for sustainable soil management

1. **Protect soil from physical, chemical and biological degradation, limit erosion and avoid deforestation.**

Maintain our current soil quality. Prevent soil loss, erosion, toxicity and compaction and eliminate deforestation:

- Keep soil covered.
- Avoid the unnecessary disturbance of soils; encourage conservation agriculture, no-till, and the proper drainage of soils.
- Choose geographically and agro-ecologically appropriate cropping systems, and encourage crop rotation.
- Employ established practices that control erosion and invest in the development of new approaches to prevent erosion.
- Limit the likelihood of soil contamination from all sources.
- Eliminate deforestation and allow our forests to naturally sequester carbon, while investing in reforestation.
- Discourage the cultivation of physically marginal soils.
- Establish sustainable grazing patterns to prevent overgrazing and potential desertification, and build buffers to prevent the expansion of deserts.
- Reduce the urbanization of agricultural land.

2. **Restore soils on degraded, stranded and marginal lands.**

Recover the stranded, idle, economic and environmental assets that are degraded and marginal lands:

- Conduct assessments of soil and land degradation.
- Understand to what level soils have degraded, examine the timeline involved and prepare appropriately for what it will take to bring the soil back to productivity.
- Rebuild soil structure, actively increase or maintain soil carbon and organic matter levels, and rebuild nutrient content and balance.
- Restore topsoil to historic depths.
- Encourage whole systems management at the global, national and local levels.

3. **Maintain soil-based ecosystem services, water availability and quality.**

Recognize and manage and sustain the ecosystem services and habitat that soil provides and contributes to:

- Manage soil and water in tandem.

- Use the appropriate balance of fertilizers at the right time of year, in the right amount while avoiding ecologically sensitive areas of the field.
- Encourage and protect beneficial microbial and biochemical activity in soil.
- Promote soil resilience as a gateway to climate resilient agriculture.
- Create buffers and riparian margins between agricultural land and water sources.
- Choose geographically appropriate and sustainable irrigation practices.
- Encourage ‘crop stability assessments’,‘environmental impact assessments’ and ‘high conservation value assessments,’ especially when consideringland use change.

4. **Enhance soil productivity according to its natural capacity.**

Ensure global food security through ‘sustainable intensification’, narrowing the ‘yield gap’ and replacing the nutrients we remove from the soil:

- Sustainably intensify productive agricultural systems.
- Employ an integrated approach to soil fertility management and replenish nutrients removed by the crop harvest.
- Maximize the organic cycle, utilizing organic and mineral fertilization as appropriate and apply the right balance of crop nutrients – both macro and micro.
- Make the appropriate crop selection for climate and soil type.
- Maintain crop residue cover.
- Manage the integration of livestock as a nutrient management tool.
- Reduce soil salinity and correct soil pH appropriately.
- Encourage the use of pyrolitic stoves among smallholders and the use of biochar.

5. **Develop extension services, knowledge systems, and promote innovation.**

Rebuild our global agricultural extension system to meet the demands of the twenty first century:

- Encourage increased investment in private sector and public extension services.
- Ensure that women and young people are specifically targeted by extension services.
- Provide hands-on training for farmers and agri-dealers.
- Encourage investment in innovation and the development of responsible and ecologically sustainable new technologies including improved farming practices, fertilizers, crop protection systems, seed varietals and species.

- Test, classify and map soils. Integrate existing data and provide specific fertility and management recommendations by crop and soil type.
- Create knowledge sharing platforms to promote best practices, make soil data widely accessible and develop long-term soil monitoring systems.
- Encourage appropriate mechanization while avoiding soil compaction.

6. **Communicate the importance of soil.**

   For the general public, farmers, policy makers, business and civil society:

- Advertise the importance of soils, economically, socially and environmentally.
- Promote knowledge sharing and partnership between government, business, academia and civil society that sets a minimum standard for soil awareness, management and protection.
- Provide training and advice for policy makers so that they can make informed decisions.
- Establish an agricultural curriculum in schools and encourage young people to explore advanced education and a career in agriculture.
- Take the pressure off soil to produce so much food by educating the value chain from consumer to farmer on how to reduce food waste (United Nation Global Compact,February, 2016).

Figure 1: Sustainable development goals of United Nation.

Why sustainable agriculture is important?

The world population is growing at a great pace. There are countries with a population expressed in billions of Asian countries, and in Europe and the Americas it is estimated that the population will soon find billions. This will certainly create a serious need for food in the future. One of the main objectives of industrial agriculture is to ensure that everyone has access to basic needs in the present and future years.

Industrial agriculture, on the one hand, uses more chemical input to meetthe increasing demand, on the other hand, agricultural and soil resources are polluted by chemical residues and production potential is reduced. In fact, this is a contradiction. At this point, the sustainable farming method protects both the soil and the environment and ensures the production and the long-term agricultural production. In summary, the benefits of sustainable agriculture are as follows:

- With sustainable agriculture method, it is possible to produce more than one product in small areas and high efficiency.
- An enterprise with sustainability will have a positive impact on the ecosystem. Efficient soils will have a habitat for animals, but will also contribute to agricultural production.
- The fertilization of the soil will ensure long-term use and increase of productivity.

- In addition to the benefits to agriculture, contributes to the creation of newareas of employment (Tuğrul, 2019).

Discussion of measures

1. Structural landscape elements/biodiversity refuges

Structural elements in agricultural fields include hedgerows, live fences, shelterbelts, ponds, nonproductive trees, flower strips, buffer strips, perennial wooden structures, or stone or terrace walls.Structural elements were also frequently linked to the prevention of wind and water erosion, as well as to preventing organic matter decline. To a lesser extent, positive effects of structural elements on water purification and retention and carbon sequestration were mentioned.

Research confirms that structural elements form important soil biodiversity reservoirs (Barthel et al. 2013) and are crucial for habitat connectivity and for the preservation of species that are incompatible with agriculture (Grass et al.2019; Savić et al. 2021). Linear elements such as hedgerows, or flower strips can reduce soil erosion (Marshall and Moonen 2002), contribute to soil sediment and nutrient interception (Garratt et al. 2017), and thus benefit water quality (Tamburini et al. 2020). They can also significantly increase organic matter content and carbon stock in adjacent fields (Van Vooren et al. 2017; Wojewoda and Russel 2003). Structural landscape elements are important for the intrinsic and functional diversity of agricultural landscapes (Van Den Berge et al. 2018; Grass et al. 2019) and therefore contribute directly and indirectly to soilmultifunctionality.

While crop yield has been found to be more stable and more resilient to extreme events on fields with structural elements (Redhead et al. 2020), the overall yield is significantly reduced in close proximity to hedgerows and only slightly increased at farther distances (Raatz et al. 2019;Van Vooren et al. 2017).

Thus, improved funding schemes for structural elements may improve the adoption of this measure. It could easily be integrated into existing farming schemes, requiring only slight changes to management, such as respecting protective distances to structural elements when applying pesticides and fertilizers. Improved knowledge transfer about the longterm beneficial effects of diversely structured landscapes for yield stability and resilience might also foster a more positive attitude of farmers toward structural elements.

2. Organic fertilizer

This measure refers to an increased use of organic fertilizer or the addition of organic amendments. This includes the incorporation of straw and other crop residues, green manure, farmyard manure, solid dung, compost, sewage sludge, fermentation residues, horn manure and horn silica, or biochar. While some stakeholders recommended using mineral fertilizer as an additional option, others recommended completely avoiding mineral fertilizers.Organic fertilizers were considered to contribute to the improvement and maintenance of soilhealth, enabling good crop performance.

The use of organic fertilizer/adding diverse organic amendments to the soil has beneficial effects on soils, including improved biological functions, increased organic carbon, improved soil aggregate stability, more balanced release ofN fertilizers, decreased nitrate leaching, pest and pathogensuppression, and improved crop yields; especially when regularly applied over long periods (Bailey and Lazarovits 2003; Crystal-Ornelas et al. 2021; Diacono and Montemurro2011; Vida et al. 2020).Additionally, farmers also often lack knowledge of and experience with biobased fertilizers, e.g., regarding the timing of N availability to meet crop demands (Tur-Car-dona et al. 2018; Sanchez et al. 2004).Tur-Cardona et al. (2018) found that farmers are more likely to choose organic fertilizers when they are clearly cheaper than mineral fertilizers. With the drastic increase of the energy prices since early 2022, organic fertilizers may become more attractive to farmers. However, solid forms of fertilizers and fertilizers that ensure a fast release of nutrients are typically preferred by farmers. While unprocessed manure is mostly cost-free for them, processed organic fertilizers (e.g., digestates) come in a more convenient form (e.g., pellets, less odorous) andwithout uncertainties regarding their nutrient content.

The expected positive effect on soil quality and associated co-benefits may function as a driver for implementations of this measure. The decision to increase organic fertilizer use may motivate specialized crop farms to switch to a mixedsystem that includes livestock, resulting in a completeredesign of the farming system (Wezel et al. 2014). More research is needed, e.g., on the linkage between organic input and pests, diseases, and weeds (Hijbeek et al. 2019), to reduce farmer uncertainty regarding the effects of organicamendments.

3. Diversified crop rotation

Specific recommendations were to alternate leafy and cereal crops, winter and summer crops, and humus-decreasing and humus-enhancing crops; integrate catch crops, legumes, and deep-rooting crops; not grow corn directly after corn; and integrate rotational fallow land, rotational grazing, or planted set-aside areas for soil regeneration.Multiple benefits were associated with diversified crop rotations, such as increased biodiversity in agricultural landscapes and a reduction in pest pressure. This would reduce pesticide use and the associated risks of soil contamination and lead to more resilient crops. Furthermore, this measure was often linked to erosion control. Finally, diversified rotations also come with diversified root systems. This was considered to improve soil structure, increase fertility, reduce the risk of compaction and contribute to carbon sequestration and soilorganic matter preservation.

Many studies confirm the positive effects of diverse crop rotations on soil biodiversity, microbial activity, soil structure, and aggregation, and consequently, on long-term fertility, habitat quality, erosion risk mitigation, and water retention (Ayalew et al. 2021; D’Acunto et al. 2018; Kay 1990; Kollas et al. 2015; Munkholm et al. 2013; Tiemann et al. 2015). However, effects depend on the specific management. For example, increases in carbon sequestration depend on crop choices, site-specific factors, and management (FAO and ITPS 2021; Scheffler and Wiegmann 2019). For beneficial effects on soil microbial communities and reduced pesticide use, rotations of 5 or more crops, including different crops and cultivation types such as winter and summer cereals, roots and tubers, legumes, or set-aside, have beenrecommended (Andert et al. 2016; Tiemann et al. 2015).

Overall, implementing more diversified crop rotations would require substantial systemic changes for most farms in Germany. To motivate the implementation of this measure by German farmers, Andert et al. (2016) recommend providing more detailed information on the advantages of crop diversity, as well as a better design of financial and political incentives, rather than using command and controlmeasures.

4. Permanent soil cover

This can be achieved through catch crops, undersown crops, mulching (e.g., with crop residues), and optimization of the crop rotation (minimizing the time between harvest and sowing of the succeeding crop). More specific recommendations for catch crops were the use of seed mixtures and optimized seeding time to minimize the risk of crop failure due to pests, diseases, or weather extremes (e.g., dry periods). Furthermore, avoiding row crops (e.g., substituting corn with alfalfa or clover grass in biogas production) or performing mulch sowing for row crops, as well as perennial crops or dense sowing (e.g., choosing more dense cereals over winter wheat), was recommended. Possible economic disadvantages were mentioned for some of these management options, but also the possibility of reduced herbicide demand due to the weed suppressing function of soil cover. Continuous soil cover was mostly linked to the prevention of erosion.

Soil cover is a key factor in reducing the risk of wind and water erosion (Deumlich et al. 2006). In the universal soil loss equation (USLE), soil cover management is represented by the C-factor, which is the only factor that farmers can control (Auerswald et al. 2021). Cover crops are particularly favourable, since they provide soil cover during winter when soils would otherwise be barren. However, they come with additional costs for farmers (e.g., seeds, additional management) and their implementation may require changes to the established crop rotations (Sattler & Nagel 2010). In this regard, farmers may lack specific knowledge (Werner et al. 2017). Furthermore, continuous vegetation cover increases the overall water demand and reduces groundwater recharge(Lischeid and Natkhin 2011).Efficient soil cover can also be achieved by undersown crops (i.e., sowing a cover crop into the main crop after its establishment), while yields may be unaffected or even increase (Bergkvist et al. 2011; Johnson et al. 2021). Providing soil cover through mulching with crop residues (e.g., wheat straw) is a common practice in conservation tillage systems. Depending on the quantity and quality of residues, mulching can increase soil fertility, reduce fertilizer need, increase soil organic matter, and contribute to sustaining stable soil ecosystems (Kollas et al. 2015; Tiemann et al. 2015). However, mulching may also add to the persistence of residue-borne pathogens (Koivunen et al. 2018). This problem is likely to worsen with ongoing climate change (Fareed MohamedWahdan et al. 2020).

However, implementing the different soil cover management options also requires systemic change. For cover crops, rotations may need to be adapted, while for the integration of undersown crops, compatible crops must be selected and specialized machinery, such as for combined harvesting and sowing, may be required (Sattler and Nagel 2010). Where water is a limiting factor, mulching may be preferable to continuous vegetation cover. In this case, diversified crop rotations may be necessary to avoid increased pest pressure (Buhre et al. 2009). Alternatively, farmers may considerswitching to conservation tillage systems.

5. Conservation tillage

Conservation tillage practices refer to management where mulch seeding, strip-till, or direct seeding replace conventional plowing to minimize mechanical disturbances of the soil. These practices were considered to improve the soils' carrying capacity; increase carbon sequestration; lower water losses; increase biological activity; prevent erosion, compaction, and capping; and reduce -NO_3^- losses. Opinions differed on how to manage the increased weed pressure associated with plowless systems.

Conservation tillage measures can increase soil carrying capacity and reduce soil compaction, though effects differ depending on soil properties and types of management (Mirzavand and Moradi-Talebbeigi 2021; Pöhlitz et al. 2018). On the other hand, switching from conventional tillage to conservation tillage may also increase compaction, e.g., when crop rotations do not include deep-rooting crops and when the conditions for bioturbation by earthworms are unfavourable (Schlüter et al. 2018). For the whole soil profile, Dimassi et al. (2014) report a net decrease in the soil organic carbon stock in reduced tillage systems under wet and warm conditions. Even where an increase in carbon stock is achieved, the climate benefits may be offset by higher -N_2O emissions (Guenet et al. 2021; Mei et al. 2018). Conservation tillage practices have also been found to reduce soil erosion (Seitz et al. 2018). Obstacles to implementation mostly arise from trade-offs with weed pressure. As mechanical weed control through plowing is no longer applied, conservation tillage practices typically result in increased herbicide use and the combination of conservation tillage and use of broad-spectrum herbicides reduces labourrequirements and working costs (Mal et al. 2015), while effects on soil biodiversity can be positive or negative for different invertebrate, microbial, and fungal taxa (Chávez-Ortiz et al. 2022; Froslev et al.2022; van Capelle et al. 2012; Zaller et al. 2014).

Conservation tillage practices require specialized machinery and potentially different timing of farming operations, but they can easily be implemented without major systemic changes if broad-spectrum herbicides are used for weed control. For increased herbicide use to be avoided, successful application of conservation tillage requires a high standard of management, including thorough crop choice and rotations tailored to local soil and climatic conditions (Peigné et al. 2007), indicating substantial systemic change. Nabel et al. (2021) suggest that the use of broad-spectrum herbicide can be avoided in mulch seeding and that tillage couldbe used as a measure for pest control if all other options fail. In this case, they recommend immediately applying organic amendments to offset the carbon losses caused by the tillageand allow for a quick fauna restoration.

Summary

The world population is expected to grow from 7.7 billion today to 9 billion by 2050, and, at the same time, agricultural land is being lost to expanding urban areas and climate change. The World Bank estimates that food production will have to increase by 70% by 2050 to make up the difference.Sustainable agriculture is an important piece of the puzzle of how to feed more people and reduce climate change. Shifting food and fiber production to a sustainable system helps attain both objectives. Sustainable agriculture practices are intended to protect the environment, expand Earth's natural resources, and maintain and improve soil fertility.For a planet bedevilled with droughts and challenges in energy demand, a change from conventional industrial food systems to sustainable agriculture can be quite promising, in the long run. While contemporary agriculture produces a lot of agricultural jobs and generates massive amounts of output within a harvest season, it comes with several devastating problems that require sustainable farming practices to remedy the mess.

Conclusion

Many of the measures address more than one threat or function, and most of the measures have multiple benefits. However, the measures require varying degrees of systemic change in the farm system to be implemented, even more so since the measures should ideally be implemented in combination. Diversification is one of the key principles behind more sustainable soil management. Our findings support the common evidence that a diversification of approaches and cropping systems is the preferable way to maintain and restore soil health and to meet future challenges of foodsecurity and climate change.

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