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Editorial

Towards New Soil Management Strategies for Improving Soil Quality and Ecosystem Services in Sustainable Agriculture: Editorial Overview

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Abstract: The major issues related to indiscriminate land use are overall related to topsoil depletion, groundwater contamination, plant disease outbreaks, air pollution and greenhouse gas emissions. Currently, global vision focused on the environmental impact and use of eco-friendly strategies are increasing. The design of new agroecosystems and food systems are fundamental to make more sustainability in soil management systems by improving the release of advanced ecosystems services for farmers. Sustainable agriculture utilizes natural renewable resources in the best way due to their intrinsic features by minimizing harmful impact on the agroecosystems. Farmers should sustain or even increase the soil organic matter (SOM) content overall in depleted, semiarid and arid soils. Nutrients recycled from agro-waste into the soil using residual biomass sources should be endorsed by diversified agriculture and governmental policies in which livestock and crop production are spatially integrated. Many good agricultural practices that growers may use to promote soil quality and soil health by minimizing water use and soil pollution on farms are yet available from past years. Exploration of the natural soil biodiversity and manipulation of soil microbiota by continuous amendment with compost, biochar and digestate represents a pre-requisite to develop more efficient microbial consortia useful for soils and crops. On the other hand, more attention is proven regarding the sustainable use of useful microorganisms employed as pure inoculants in rhizosphere. Among them, plant growth-promoting rhizobacteria and biological control agents cover the major groups of tailored inoculants in order to rationalize the internal recycling of nutrients and their energy recovery, or to improve the soil quality and plant health thanks to their diversified mechanisms of action and complex interactions between SOM, microbiota and plant roots in the rhizosphere.

Keywords: circular economy; microbial inoculant; microbiota; nutrient recycling; plant disease suppression; plant health; soil quality

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The worldwide population is increasing and cleaner agricultural productions to sustain the world population demand for food is needed. Overexploitation of crops has led to use of chemical fertilizers and pesticides, causing environmental contamination associated with human health risks. Agriculture has changed dramatically due to the need to increase food productivity, including development of new technologies, mechanization, increasing chemical use, specialization and government policies favoring maximizing production, reducing food prices and contamination by chemicals. Although these developments have had positive effects in reducing many risks in farming, they also have significant costs. These changes allowed very few farmers to actually produce more food at lower prices.

Land use is a determinant for cleaner agricultural productions depending on soil quality. The main issues related to indiscriminate land use are topsoil depletion, groundwater contamination, air pollution, greenhouse gas emissions, decline of family farms and neglect of the living and working conditions of farm laborers. The current global vision is more friendly with environmental issues, and increasing use of eco-friendly strategies are needed. Interest has emerged during the past four decades for the necessity to offer innovative alternatives by reducing higher costs. The main goal of sustainable agriculture is to meet society's food needs without compromising the ability of future generations to meet their own needs. Practitioners of sustainable agriculture try to integrate three main objectives into their work: healthy environment, economic profitability, and social and economic equity. People involved in the food system as growers, food processors, distributors, retailers, consumers and agro-waste managers can play a key role in ensuring a sustainable agricultural system. A variety of governmental policies, local legislation and good practices have contributed to address these challenges, but fewer common themes and principles weave through most definitions of sustainable agriculture. Agroecosystems and food systems are both essential to understanding sustainability. Agroecosystems are envisioned in the broadest sense; from individual fields, to farms, up to wider ecological niches. Food systems, which include agroecosystem designs and food consumption components, spread from farmers of a local community to the global population.

Sustainability studies of different types of agroecosystems have led to conclusions that systems surviving over time usually are highly resilient, adaptive and diverse. Resilience is a critical issue due to many factors such as climate change, pest populations and policies that are often highly unpredictable and rarely stable overtime. Adaptability is a key component of resilience, as it may not always be possible or desirable for an agroecosystem to gain the precise form and function it had before a disturbance, but it may be able to adjust itself and take a new form in the face of changing conditions. Diversity instead confers more adaptability since more variability existing within a food system, whether in terms of crop types and cultural knowledge, will allow major adaption to changes. Agroecosystems and food systems also require multi-pronged efforts in research, education and action. Not only researchers, but also farmers, laborers, retailers, consumers, policymakers and others who have a stake in our agricultural and food systems have crucial roles to play in moving toward greater agricultural sustainability. For example, the agriculture ability to adapt to climate change was not considered a critical issue until 20 years ago, but now it is receiving increasing attention. In addition, the details of what constitutes a sustainable agroecosystem may quickly change from one set of conditions to another with regard to soil type, climate, labor cost, etc. Therefore, it is more useful and pertinent to think of agriculture as a complex system ranging on a continuum from unsustainable to very sustainable, rather than fixed in a specific sustainable way. Agroecosystems cannot be sustainable for a longer time without the knowledge, technical competence and skilled labor needing to manage them effectively. Sustainable agriculture requires a diverse and adaptive basic knowledge utilizing formal, experimental science and on-the-ground local knowledge of farmers.

Sustainable agriculture seeks to utilize natural resources in the best way, where their intrinsic productive capacity is renewable while minimizing harmful impacts to the agroecosystems. Some ways that farmers have tried are, for instance, capitalizing on existing natural processes and resources, or designing new farming systems in order to incorporate crucial functions of natural ecosystems, or minimizing and eliminating hazardous residues from soil. Soil conservation for agricultural productivity means taking care of the depleted soil under intensive cropping systems and/or those placed in arid and semiarid areas of the Mediterranean basin, so that it can maintain its integrity as a complex and highly structured soil system composed of mineral particles, organic matter, air, water and living organisms. Farmers prioritize care and safety for soil because they recognize that healthy soil promotes crop productivity, crop quality and soil livestock.

Maintaining soil functioning means to sustain or even to increase the soil organic matter (SOM) input by more than 1% overall in arid and semiarid soil. SOM is a crucial source of macro-micronutrients for soil biota and crops; an active substrate for microbiota activity; and an excellent buffer against fluctuations in acidity, water content, salinity and contaminants. Furthermore, the build-up of SOM can help to mitigate the increase of atmospheric CO_2 and, therefore, global climate change. Another important function is inducing a better soil structure which leads to improved water penetration, less runoff, better drainage and increased stability, thereby reducing wind and water erosion. Moreover, SOM is a formidable source of beneficial microorganisms against soil-borne plant pathogens (archea, bacteria, actinomycetes, oomycetes, yeasts and filamentous fungi) affecting crop diseases. An unsustainable agroecosystem has been disconnected from the internal cycling of the key plant nutrients, such as nitrogen and phosphorus, due to a high reliance on chemical fertilizers. Phosphate minerals are currently mined, but global reserves are predicted to sustain food production for only another 50 to 100 years. Consequently, phosphate prices are predicted to significantly rise unless new sources are discovered or innovation in recovery of phosphates from agro-waste developed. Nutrients recycled into the soil from such renewable sources is facilitated by a diversified agriculture in which livestock and crop production are more spatially integrated among them. Only recycling organic carbon, nitrogen and phosphorus from agro-wastes (from the on-farm level to a regional scale) by improving efficiency in the use of both fertilizers and relying on organic nutrient sources (animal manure, agro-bioenergy co-products and agro-industrial wastes) will allow significant macronutrient inputs to be obtained. For these reasons, extensive mixed crop-livestock systems, particularly in developing countries, could significantly contribute to innovate agricultural sustainability and global food security.

There are many good agricultural practices that growers may use to promote soil quality and soil health by minimizing water use and soil pollution on farm. Consumers and retailers concerned with sustainability can look for "values-based foods", grown using methods promoting farmworker wellbeing that are environmentally friendly, or that strengthen the local economy. Researchers across the different interdisciplinary disciplines may combine biology, economics, engineering, chemistry, community development and many others into an effective framework. However, sustainable agriculture is more than a simple sum of good agricultural practices. It is instead an integrated and complex process of negotiation where "a push and pull" approach between the competing interests of individual farmers, or of people of a community, may help to solve problems about how we grow our food.

Modern agriculture is still strongly dependent on non-renewable energy sources, especially petroleum and its derivatives. The continued use of non-renewable energy sources cannot be sustained for a longer time. In sustainable agriculture, one of the main goals is to reduce the input of external energy and to substitute non-renewable energy sources with renewable ones (e.g., solar and wind power, biofuels from agricultural waste, biomass for thermal energy or, where economically feasible, animal or human labor). Organic amendments as compost, biochar and digestate coming from the different kinds of agro-wastes, that can be easily on-farm recycled, are profitable sources of SOM available at lower costs for growers than chemical fertilizers and pesticides.

Farmers aiming at a higher level of environmental sustainability might consider how chemical pesticides can be significantly reduced by bringing natural processes to bear on limiting pest populations. This might happen, for example, by planting hedgerows along field edges, or ground covers between rows, thereby providing habitat for insects and birds that prey on the pests, or planting more diverse blends of crops that confuse or deflect pests. Maintaining higher degrees of genetic diversity by conserving local crop varieties and animal breeds will also provide more plant genetic resources for breeding resistance against soil-borne diseases and pests.

Interestingly, soil microbiota plays a crucial role in modification of the nutrient recycling, soil formation and soil evolution. These effects can be achieved by contribution of soil microbiota which facilitates mineralization of SOM and releases nutrients. Many soil organisms can contribute to natural transformation of nutrients by recycling them for purposes related to energy requirement in metabolism. Besides these processes, soil microbiota contributes to soil structure formation and build-up of soil aggregates which may contribute to formation of topsoil layer of the whole soil profile. An important feature of these functions is the interaction between different kinds of microorganisms which can vary in abundance, richness magnitude and taxonomic diversity. The complex interaction between soil biota varies along the space and during the time by upscaling to larger space-temporal scales often brings another layer of complexity. A continued exploration of the natural soil biodiversity with the subsequent manipulation of the rhizosphere microbiota by continuous organic amendment application in soil with compost, biochar, digestate, etc. represents a prerequisite to develop more efficient microbial inoculants for crops. In this regard, a framework based on the extensive survey of soil biota and soil processes in agricultural grasslands and arable land or specific natural conservation areas has been constructed. Ecosystem services were specified with ecological requirements in terms of soil biota and soil processes related to particular land use.

Recently, scientists have addressed their researches toward tailored microbial inoculants, so called "ecofriendly microorganisms", which are microorganisms that offer advantages without causing environmental issues and human risks. These microorganisms have a secondary metabolism, secreting more useful substances for humans. These substances are chemical compounds which we can use for more benefit in soil quality. Therefore, we can think of microorganisms as true "living biorefineries" producing a wide array of chemical compounds with beneficial effects on our lives that should be usefully employed in agriculture. The study of the chemical compounds secreted by beneficial microorganisms and their impact on plants or plant pathogens are fundamental topics. The future is exciting in this sense; as an interesting challenge, the discovery of new microbial strains and new isolates today is characterized by omics approaches (e.g., high-throughput amplicon sequencing with Illumina and Ion Torrent platforms) with potential taxonomic resolution up to genus/species level to be applied for designing novel organic farming systems under the light of microbiome-assisted strategies. The compounds produced by these useful microorganisms can be portioned in antibiotics against multidrug resistant soil bacteria, antifungals against plant pathogenic fungi and bacteria causing crop diseases, and crop promoters with biostimulation effects on productivity and quality. Therefore, many microbial inoculants (tailored microbial consortia) can be considered as eco-friendly and attractive alternatives to further soil applications by partly replacing mineral fertilizers and chemical pesticides. In this framework, beneficial microorganisms can help farmers to improve agricultural production worldwide by opening new research fields to study beneficial microorganisms and their mechanisms of action by which they can improve sustainability of new cropping systems. Thus, these newer researches have turned toward this group of microorganisms in recent years. However, it is very important firstly to know the interactions that occur between plants, soils and microorganisms. In this framework, we can find plant growth-promoting rhizobacteria (PGPR) which are a group of bacteria that colonize roots by enhancing plant growth and producing plant hormones, secondary metabolites, factors for controlling diseases, and inductors of systemic resistance through changing physicochemical interactions between PGPR and plants. Many PGPRs have been studied in the last few decades, belonging to the genera *Azospirillum*, *Bacillus*, *Pseudomonas*, *Rhizobium*, white-rot fungi (*Acremonium*, *Pleurotus*, *Trametes*, etc.) and arbuscular mycorrhizae fungi (*Glomus*, etc.). This beneficial microbiota efficiently works by increasing photosynthesis, producing bioactive substances such as phytohormones and enzymes, controlling soil-borne diseases by specific suppression mechanisms, and accelerating breakdown of the lignin-cellulosic fraction in soil. Another strategy that has been successfully applied during the last few years has involved biological control agents (BCAs), whose suitable agrochemical formulations are available commercially to control diseases in agricultural and horticultural crops. The soil is naturally very rich in fungi and bacteria by acting as effective BCAs (*Bacillus*, *Fusarium*, *Gliocladium*, *Pseudomonas*, *Streptomyces*, *Trichoderma*) for suppressive soil (or suppressive-induced soil) that can reduce incidence and severity of more soil-borne diseases even under the co-presence of virulent pathogens, susceptible host plants and favorable climatic conditions for developing diseases. However, the soil layer that actively interacts with the plant roots, the rhizosphere, is a site of intense microbial activity. Therefore, the rhizosphere is the key layer in soil habitat where the interactions between plants and microorganisms play a crucial role in plant growth. Research has shown that applying effective microbial inoculants to the soil or plant ecosystem can improve soil quality, soil health, plant growth, crop yield and quality of production.

In conclusion, under a general viewpoint of plant protection and sustainable land use both in intensive cropping systems and depleted, arid, semiarid and marginal soils, there is an increasing need to establish more biological indicators for soil quality and new ecosystem services based on sustainable management of tailored soil microbiota and new cropping systems. Only by designing biologically-integrated agroecosystems to rationalize the internal recycling of nutrients and energy input-output balance in soil systems, and to improve plant disease suppression at the same time using agricultural wastes for improving soil quality and plant health, will it be possible to maintain an economically viable production system with fewer potentially hazardous interventions under the perspective of a modern circular economy system.

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