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ORIGINAL PAPER

Effect of Conservation Agriculture on soil biological properties

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INTRODUCTION

The rice-wheat (RW) cropping system is one of the world's largest agricultural production systems, covering an area of 26 million hectares spread over the Indo-Gangetic Plains (IGP) in South Asia and China. In South Asia, more than 85% of the RW system is practiced in the IGP. The sustainability of this important cropping system is at risk due to second-generation problems related to degradation of natural resources (soil health, air quality, and ground water depletion), and mono cropping (inadequate system diversity) under conventional tillage (farmer's practice/ 'business as usual') based management systems. Furthermore, this risk is intensified with in-situ burning of crop residues which hampered the soil biological activities and microbial diversity. To overcome formidable problems of the RW system in South Asia, conservation agriculture (CA) has emerged as an important alternative to conventional RW system. Higher yields of rice/maize were recorded with CA-based management practices over conventional management due to the improved soil quality indices (Choudhary *et al*., 2018). The activity and diversity of soil microbial populations are directly affected by management practices (as tillage, crop establishment, residue disposal, water and nutrient management), and soil environment. Microbial biomasses which are sensitive indicators of changes in soil organic matter, are influenced by agriculture management practices. Microbial enzymes are involved in soil nutrient cycling, and are used to evaluate soil quality (Choudhary *et al*., 2018).

Among soil microbes, fungi are critical components in soil system and are regarded as the primary decomposers in soils, as they secrete various enzymes that breakdown lignocelluloses (Choudhary *et al*., 2018). Plenty of data reported on fungal communities in different natural soil habitats but less is so far known about fungal communities in agricultural soils, and very limited in conservation agriculture practices (Wang *et al.,* 2016). An in-depth understanding of the fungal community in agricultural soils provides the path to study their roles in agro-ecosystems, which is not possible by traditional methods like culture-based methods and microscopic studies. With the advanced techniques of metagenomic analysis it is possible to decipher taxonomic and functional assemblages of natural indigenous communities, and their roles in the ecosystems.

INFLUENCE OF THREE KEY CA PRINCIPLES ON SOIL MICROBES

With global issues such as food security in a world with an exploding human population, arable land lost to urbanization forever available for agriculture, exhaustion of fossil fuels and natural resources, and climate change, we might be surprised to realize that the solution lies in something we walk on, and overlook, every day: our soils. There cannot be life without soil and agriculture. But traditional agriculture has left us with unhealthy soils depleted of nutrients, unable to naturally sustain crops, unless chemical fertilizers are applied—almost like a drug addict who cannot get through the day without a "chemical fix." Our soils are alive, but cannot function without their "chemical fix for the day." Just as a drug addict cannot be rehabilitated overnight, even more so, we cannot expect our soils to be rehabilitated in a matter of a few years after decades of chemical fertilizer abuse. Conventional intensive agriculture that resulted in declining crop yields, increased use of chemical fertilizers, increased crop disease due to monoculture, and soil erosion due to wind and rain have led farmers on the quest for alternative practices that would not leave arable land bare and unprotected after harvest, causing a loss of 24 billion tons of soil to erosion in 2011 alone. These increased environmental concerns led farmers to the realization that fertile, healthy soils are urgently needed to increase yield dramatically on all available arable land (Johansson *et al*. 2004). This resulted in farming practices aimed at increased and sustainable SOM, crop rotation, integrated pest management, and other ecological-oriented farming practices. The application of currently expanding knowledge led to CA by integrating three main principles, i.e., crop rotation (crop diversification) in combination with minimum soil disturbance (no-tillage) and permanent soil cover (mulching). Amendments applied to soil in terms of crop rotation, tillage, and residue management practices significantly impact soil biology, especially soil microbial diversity and activity (Govaerts *et al.* 2006)

a. Influence of Different Crops :

Crop diversification encourages high soil microbial activity and diversity, initiating synergistic associations with other organisms such as rhizobia and mycorrhiza. Different crops have different root structures, placing OM in different soil strata, thus fertilizing the soil. Due to the interaction between plant roots and microorganisms in the rhizosphere through the release of root exudates, soil quality, crop health, and yield are affected by initiating improved nutrient cycling, disease resistance, and plant growth stimulation (Sturz and Christie, 2003). Crop rotation and changes in planting dates might also contribute to disease control. Crop rotation with leguminous crops reduces the need for expensive nitrogen fertilizer. BNF can be enhanced by inoculating legume seeds with the appropriate *Rhizobium* strain for a specific legume.

b. Soil Disturbance:

Tillage alters not only a soil's chemical and physical characteristics but also the spatial integrity of the soil as a support matrix for soil microbial community function (Fig. 20.3). Although tillage was supposed to substitute "biological plowing" by earthworms, tillage kills earthworms—no wonder earthworms constitute a vital part of the health status assessment of soils converted to CA after withdrawal of intensive plowing. SOM in a no-tillage system is mainly decomposed by fungi. As mentioned in the section on Terrestrial Nematodes, CT drastically alters SOM decomposition by breaking up crop residues into smaller pieces and redistributing it throughout the plowed layer, establishing bacteria as primary decomposers of SOM. Not only does the redistribution of broken-up crop residues increase microbial colonization but also it enhances aeration. SOM is consequently oxidized when exposed to air by tillage. Combined with the removal of produced OM during harvesting, tillage results in less OM content, unless additional OM is returned to the soil as residues or compost (Atlas and Bartha 1993). Contrary to reduced (or no-) tillage (RT), CT accelerates nutrient cycling, consequently increasing nitrogen mineralization and soil carbon loss. Correct agricultural management practices can therefore be practiced to ensure effective nitrogen mineralization through minimum tillage, which minimizes soil erosion and compaction. Soil benefits are greater with continuous no-till compared to rotational tillage, i.e., 1 year no-till, tillage the next year. Pores left by microbial activity and plant roots are also disrupted by tillage. Although the detrimental consequences of bare fallow soil after tillage are well known, the effect of tillage on soilborne diseases is still unclear. It is known, however, that a healthy soil with high microbial diversity does have a positive impact on disease suppression. Zero tillage has exhibited great potential to facilitate integrated pest management and biological control (Govearts *et al*. 2006)

c. Residue Retention (Mulching):

Forests and plants protect the soil. Every year, 13 million ha of forest is cut down. When these virgin (undisturbed) lands are converted for agricultural (disturbed) use, SOM content decreases annually until stabilizing at a much-reduced concentration, influencing soil microbial functioning. Buildup of SOM through residue retention retains nutrients and increases microbial diversity and activity in soil. The quality and quantity of SOM entering the soil greatly influences soil microbial processes as already mentioned. Care should be taken when high-carbon plant material is applied as a residue; it should be composted or mixed with manure prior to soil application since high-carbon compounds (high C:N ratio) take longer to decompose by soil microbial communities than compounds with a lower carbon content (higher nitrogen content). Several long-term studies have shown that residue retention in combination with minimum soil disturbance created favorable conditions to promote ecological stability and develop antagonists and predators, contrary to the absence of residue retention which led to poor soil health

(Govaerts *et al.* 2006). It is also important to note that while surface mulch moderates soil moisture and temperature, favorable conditions are also created for microbial activity and biological diversity with increased amounts of beneficial insects under ground cover to assist in insect pest management (Kendall *et al.* 1995). Several studies have found more soil fauna (microorganisms, earthworms, nematodes) under no-till and residue-preservation management practices compared to treatments subjected to CT. Unfortunately, CA is also associated with an increase in weed incidence, and residue retention could stimulate plant parasitic nematodes and fungal diseases "preserved" in the stubble, or pests and other diseases stimulated by the increased moisture. Increased pests and diseases inevitably lead to increased use of pesticides and herbicides. Fortunately, weeds could frequently contribute to nutrient dynamics by supplying extra organic material.

CONCLUSION AND FUTURE RESEARCH THRUSTS

The relationship between the soil's physical, chemical, and biological properties is exceptionally complicated, and, depending on existing soil conditions, these relationships can be either positive or negative. Ecosystem functioning is greatly influenced by SOM availability, activity, and diversity of soil microbial communities, and the flow of nutrients (Elliott and Coleman 1988). Plants respond to and alter their environment through root exudates. Exudates are also used as a means of communication between neighbouring plants and rhizosphere microbial communities. Irrespective of the environments in which plants find themselves, they all rely on soil microbial communities for many crucial processes. Improved knowledge of the composition of different root exudates with regard to quality and quantity, according to plant species, environmental parameters, cropping systems, etc. is urgently needed to promote beneficial interactions in the rhizosphere. The beneficial impact of soil microorganisms, especially that of symbiotic rhizobia in soil health maintenance and crop yield increase, has been widely studied and recognized for long. On the other hand, the use of PGPR as biocontrol agents and biofertilizers to enhance plant growth has gained momentum in recent years. As a result of current advances in the development of commercial PGPR inoculants for sustainable agriculture, several PGPR, such as *P. fluorescens, P. putida*, *Bacillus subtilis*, and other *Bacillus* species with a wide scope for commercialization, have been identified (Nakkeeran *et al*. 2005). With this taken into consideration, it can only be advantageous to crops to "optimize" their microbial allies in the rhizosphere. This knowledge can be applied by several means to enhance the sustainability of agricultural systems by favoring beneficial soil microbial communities to increase plant health, while enhancing defenses against pathogens (Badri and Vivanco 2009). Although numerous techniques have been developed to provide valuable information regarding current soil activities and specific processes, few have been integrated to enhance our holistic understanding of ecosystem functions. Combining basic research/knowledge (i.e., ecology, molecular biology) with current knowledge of healthy ecosystems could lay the foundation for the development of microbe-based sustainable agriculture. By applying the correct agricultural practices as prescribed for CA, the soil ecosystem is granted the opportunity to nurture natural biological control measures during the buildup of soil cover and subsequent outbreaks of pests and diseases. This improved understanding will therefore be fundamental in the protection of our natural resources through the promotion of a balanced ecosystem that would inevitably lead to sustainable management of crop production and soil fertility through cropping systems that are resilient and sustainable.

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