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REVIEW

Plant disease dynamics *vis-a-vis* conservation agriculture

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Conservation agriculture (CA) based on the principle of minimal mechanical disturbance of soil and permanent soil cover coupled with efficient crop rotations is the new paradigm of farming and adopted in more than 180 million hectares throughout the world. Any major shift in farming practices such as reduced tillage or no tillage have a profound impact on the microenvironment on which the crop is grown. Again, retention of crop residues alters the local environment by affecting soil temperature and moisture, which provides soil borne microorganisms with a favourable habitat. Under this system, some disease increases in incidence and severity whereas some others decrease.The present review summarizes the consequences of CA practices on the soil- and residue-borne pathogens including soil antagonists.

Key words: Conservation agriculture, disease dynamics, antagonists, soil health

INTRODUCTION

Farming has possibly had the greatest visible impact on our planet of any human behavior. Considering the vast areas under cultivation of crops, farming has a profound impact on the landscape. For decades, it was a common practice to till the soil repeatedly by the famers because they believed that clean fields are required for maximum yields. This results in widespread erosion of top soil by wind and water which threatens the productivity. So, tillage based agriculture intensification had a negative effect on the quality of the natural resources like soil, water, biodiversity and associated microorganisms. The degradation of the natural resources which in turn reduces yield and productivity as well as decline in sustainability. As such agriculture contributes 30% of the total greenhouse gas emission of CO_2, N_2O and CH_4. Further, the effect of climate change is more pronounced in degraded agriculture. To overcome this, FAO has stressed on sustainable agriculture production to achieve the productive as well as remunerative agriculture which also enhance the natural resource base and environmental stability (Kassam *et al*., 2018). In this aspect Conservation agriculture (CA) may provide an alternative production system and also enhance the resilience of climate change. Conservation Agriculture (CA) is a farming system that can prevent losses of arable land while regenerating degraded lands. It promotes maintenance of a permanent soil cover, minimum soil disturbance, and diversification of plant species. It enhances biodiversity and natural biological processes above and below the ground surface, which contribute to increased water and nutrient use efficiency and to improved and sustained crop production.

CA principles are universally applicable to all agricultural landscapes and land uses with locally adapted practices. Soil interventions such as mechanical soil disturbance are reduced to an absolute minimum or avoided, and external inputs such as agrochemicals and plant nutrients of mineral or organic origin are applied optimally and in ways and quantities that do not interfere with, or disrupt, the biological processes. CA facilitates good agronomy, such as timely operations, and improves overall land husbandry for rainfed and irrigated production. Complemented by other known good practices, including the use of quality seeds, and integrated pest, nutrient, weed and water management, etc., CA is a base for

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sustainable agricultural production intensification. It opens increased options for integration of production sectors, such as crop-livestock integration and the integration of trees and pastures into agricultural landscapes. On a global scale, no-till management has increased more than 230% during the last 10 years, being 180.4 million ha in 2015.The CA area is mostly at South and North America, Australia, however, the area is continuously increasing in Asia (Table 1). In this review, the impact of conservation agriculture on different soil-, residue- borne pathogens including some air borne pathogens has been presented.

Conservation agriculture and Plant Diseases

Keeping the crop residues under no tillage conditions may have an impact on the incidence and severity of the soil and residue borne pathogens. Changing the tillage practice can lead to changes in the physical and chemical properties of soil which in turn is likely to influence theoccurrence of plant diseases (Singh *et al.,* 2004). Key factors in the occurrence of plant diseases include the survival and activity levels of pathogens, host susceptibility, and the population of other soil microorganisms. Reduced tillage can favour pathogens by lowering soil temperatures, increasing soil moisture, changing root growth, changing nutrient uptake, and changing the population of plant pathogen vectors.

development. A good quality soil physical environment is an important indicator for root health under conservation tillage in humid climates. The decomposition of riceplant residues may release phytotoxins and stimulate toxin producing microorganisms,thereby predisposing plants more to pathogen attack. The advent of conservation tillage presents a need for a greater understanding of plant disease and disease interactions in temperate and tropical humid agriculture, where excessive crop residues, continuous moist soil conditions and soil compaction are potential constraints.

Conservation tillage tends to concentrate plant debris and consequently microbial biomass in the top 5 to 15 cm of soil, and thus promotes survival of pathogens. However, disease-causing microbes make up only a proportion of the rhizophoral population. Relatively high soil microbial activity can lead to competition effects that may ameliorate pathogen activity and survival, and counteract a high pathogen inoculum pressure. Microbial antagonism in the root zone can lead to the formation of disease-suppressive soils. This phenomenon, which is important for the adoption of conservation tillage in humid climates, can be influenced by soil and crop management practices, especially crop rotation.

However, relatively high soil microbial activity can lead to competition effects thatmay affect pathogen activity and survival and thus reduce harmful pathogen inoculumpressures. This microbial antagonism in the root zone can be beneficial for farmers byleading to the formation of disease suppressive soils. Thus, on the one hand leaving plant debris on the surface or partially buried may allow pathogens to survive to the next crop, but it may also make conditions more

Table 1: Area of arable crop land under CA by continent in 2015-16

Continent	Area (M ha)	Percent of Global land	Percent of arable land
South America	69.9	38.7	63.2
North America incl. Canada	63.8	35.0	28.1
Australia & NZ	22.67	12.6	45.9
Asia	13.93	7.7	4.1
Russia & Ukraine	5.70	3.2	3.7
Europe	3.56	2.0	5.0
Africa	1.51	0.8	1.1
Global Total	180.44	100	12.5

Adopted from Kassam *et al.*(2018)

Soil densification and reduction in macroporosity can aggravate abiotic root disease. Changes in soil aeration and permeability status can alter the quantitative and qualitative differences between soil rhizophoral populations and survival and distribution of pathogen inoculum. Further-more, anaerobic soil conditions can result in root-pathogen interactions leading to plant disease favourable for the biological control of plant pathogens.

High Disease Incidence under CA

Residue retention and the associated increased humidity at the soil surface favour the survival of pathogens until the following crop is planted. Surface crop residues infected with gray leaf spot (*Cercosporazeae-maydis*) provide an early-stage inoculum for the next maize crop resulting in acute infection (Thierfelder*et al.*, 2014), tan spot (*Pyrenophora tritici-repentis*) (Bhatal and Loughman, 2001) and crown rot (*Fusarium pseudograminearum*) (Burgess *et al.,* 2001) in cereals, sclerotinia (*Sclerotinia sclerotiorum*) in legumes (Simpfendorfer*et al.,* 2004) and blackleg (*Leptosphaeria maculans*) in *Brassica* oilseeds (West *et al.,* 2001).

Several species of *Pythium*, the root infecting pathogen are favoured by reduced tillage. *Pythium* spp. produce long lasting resting spores which can grow saprophytically. It produces motile spores which swims through the water in the soil, hence its greater activity in moist soil is observed. The reduced tillage conserves moisture in the soil as well as evaporation from the soil is much less due to presence of plant residues which is conducive for *Pythium* spp.. The root infecting pathogen, *Rhizoctonia* which survives in the infected root and stem bases is also more under CA as it is favoured by undisturbed soil.

Another study conducted at Uttarkhand by Joshi *et al.* (2004) on the impact of tillage practices on rice and wheat diseases. The observations are: i) no significant difference on the severity of foiar blight (*C.sativus*) between zero tillage and conventional tillage, ii) slightly higher disease seveity due to bacterial leaf blight in zero tilled fields, iii) no significant difference in disease index for sheath blight of rice and iv) a higher mean root lesion severity on rice in zero tillage fields.

Low Disease Incidence under CA

Some wheat pathogens are partially or completely controlled by reduced tillage. These include *Bipolaris sorokiniana, Fusarium graminearum,F. culmorum* and *F. avenaceum* due to increase in soil moisture, disruption of spore movement from straw to crop by large amount of straw.

Sharma *et al.* (2004) studied in detail on rice and wheat disease under rice-wheat cropping system. They recorded no significant variationin the occurence and type of microbial flora between the resource conservation and conventional tillage. The adoption of reduced tillage and surface seeding of wheat does not have any impact on *Bipolaris sorokiniana* and *Pyrenophora tritici-repentis*. Further, the disease severity in rice due to *Rhizoctonia solani* and *Cochliobolus miyabeanus* depends on the location, date of sowing and variety irrespective of the cultivation practices.

An extensive study was conducted at Madagascan highlands on effect of conservation agriculture in limiting rice blast disease as well as yield performance. The rice crop was planted every second year following oat (*Avena sativa*) after common bean (*Phaseolus vulgaris*), with both conventional tillage and no tillage. For each cropping system, two levels of fertilization were used: (i) organic and (ii) organic + mineral fertilization. The level of blast epidemic was measured on two different cultivars over a 5 year period. Disease severity was significantly lower in the no tillage cropping system than in the conventional tillage system. Mineral fertilization increased the level of blast. A significant interaction between cropping system and fertilization indicated that the impact of fertilization differed with the cropping system. When the level of blast was low, yield was higher in the conventional cropping system but as soon as blast level increased, yield was better in the no tillage cropping system. The presence of a soil cover has been shown to change soil nitrate and ammonium content (Xu *et al*., 2001) and the degradation of crop residues left on the soil in the no tillage cropping system and exported in the conventional tillage system may be a source of silicon. Silicon has been shown to have a high impact on plant–pathogen interactions and a silicon input improves rice tolerance against blast (Seebold *et al*., 2000).

At Uttar Banga Krishi Viswavidyalaya, extensive studies have been conducted on the dynamics of rice and wheat diseases in conservation agriculture system followed continuously for five years. The most important disease of rice (sheath blight caused by *Rhizoctonia solani*) and wheat (spot blotch caused by *Bipolaris sorokiniana*) in different crop varieties were estimated both under CA and Conventional system. Both the diseases were high in the initial year of cultivation irrespective of the varieties under CA system than conventional tillage, however, there were no significant differences were recorded from third year onwards, even in some variety the disease incidence was lower than conventional system (Chowdhury *et al.,* 2017). The survival of the pathogen in the soil and crop residue was also same in both the systems. The antagonistic population of *Trichoderma* and *Psuedomonas* fluorescence and dehydrogenase enzymes in soil were higher under CA when analyzed after five years of practice (unpublished data).

CA and Antagonistic Microflora

Changes in soil carbon allocation, mixing intensity, and soil moisture and temperature conditions affect the distribution and living conditions of microbial communities in soil. In suppressive soils, disease incidence or severity remains low regardless of the presence of the pathogen, the host plant, and favourable environmental conditions for disease development (Alabouvette *et al.,* 2006). One form of soil suppressiveness is fungistasis, defined as the attribute of the soil that restricts the germination and growth of fungi (Garbeva*et al.,* 2004). In theory, soil-resident microorganisms mediate suppressiveness and fungistasis by competing for nutrients, producing antagonistic compounds and occupying the potential niches of pathogens. Fungistasis was suggested previously to be important for the general suppressiveness of fungal pathogens (Termorshuizen *et al*., 2006). Microbial community composition can affect soil fungistasis (De Boer *et al.,* 2003). When agricultural management changes the soil general microbial activities and biomass, it can potentially also affect soil suppressiveness. The management of tillage intensity, which may affect microbial activities and microbial biomass, has been hypothesized to have an effect on soil fungistasis. The relationship of the general microbial community structure and specific bacterial groups to fungistasis is not understood, and it is not known if certain microbial populations are important for the establishment of fungistasis.

The knowledge of how soil management changes microbial community structures is a prerequisite for optimized management practices, since soil microbial communities constitute a central factor controlling soil processes (Bell *et al.,* 2005). These communities offer important ecosystem services, e.g., the decomposing of organic matter, the recycling of nutrients essential for plant growth, and soil suppressivity. However, tillage management practices have rarely been studied by modern microbiological methods, including microbial community analysis, to show the structural and functional diversity of microorganisms (Vargas *et al.,* 2011). Previous microbial ecology studies that recognized the diversity of microbes were performed mostly within single fields, describing treatment effects at the site level (Balota *et al*., 2003). The generalization of treatment-specific changes from single-field studies into a larger ecological context is difficult, because microbial communities are largely affected by environmental variables at the site, e.g., cultivation history, soil type, weather parameters, and management practices performed at the site (Girvan *et al*., 2003).

A cross-site study of soil microbial communities and *Fusarium* fungistasis was conducted on six long-term agricultural fields with no-till and moldboard-plowed treatments. Microbial communities were studied at the topsoil surface (0 to 5 cm) and bottom (10 to 20 cm) by general bacterial and actinobacterial terminal restriction fragment length polymorphism (T-RFLP) and phospholipid fatty acid (PLFA) analyses. *Fusarium culmorum* soil fungistasis describing soil receptivity to plant-pathogenic fungi was explored by using the surface layer method. Soil depth had a significant impact on general bacterial as well as actinobacterial communities and PLFA profiles in no-till treatment, with a clear spatial distinction of communities ($P < 0.05$), whereas the depth-related separation of microbial communities was not observed in plowed fields. The fungal biomass was higher in no-till surface soil than in plowed soil ($P <$ 0.07). Soil total microbial biomass and fungal biomass correlated with fungistasis ($P < 0.02$ for the sum of PLFAs; $P < 0.001$ for PLFA 18:2ù6). The cross-site study demonstrated that agricultural management strategies can have a major impact on soil microbial community structures, indicating that it is possible to influence the soil processes with management decisions. The interactions between plant-pathogenic fungi and soil microbial communities are multifaceted, and a high level of fungistasis could be linked to the high microbial biomass in soil but not to the specific management strategy (Timo *et al*., 2012).

Adoption of conservation tillage increases the soil aggregation (Lal 2004) and mycorrhizal biomass and population in soil (Sharma *et al*., 2012). Tillage can disrupt the soil network formed by AMF filaments and colonized root systems left by previous AM crops, affecting the potential colonization of subsequent crops. The AMF hyphae can remain viable for long and wait for colonization with newly germinated plants and provide plants to acquire more nutrients and water. Sharma *et al*., (2012) evaluated the impact of tillage practices and crop sequences on AM fungal propagates and soil enzyme activities in a 10-year long-term field trial in Vertisols of soybean–wheat–maize (S–W–M) cropping system where S–M–W or S–W–M–W rotations under reduced-reduced tillage system showed higher soil dehydrogenase activity and fluorescein diacetate hydrolytic activity compared to other combinations. The inclusion of maize in the rotation irrespective of tillage systems showed comparatively higher mycorrhizal and higher phosphatase activities and organic carbon and maintained higher soybean yield.

CA and Soil Health

It is well accepted that CA improves soil health due to several factors which is directly or indirectly reduces the disease either by improved crop health or by increasing antagonistic microflora. CA based crop management practices significantly alters soil physical, chemical and biological properties (Jat *et al*., 2017), which in turn alter the microbial community in the soil (Choudhary *et al*., 2018b). These communities include both plant pathogens and soil antagonists. Interactions between the soil microbial communities and soil organic matter have important role in driving soil functions in any agroecosystem, and understanding of this interaction can be supported by soil microbial biomass concept (Stockdale and Murphy, 2017). Soil microbial biomasses help in regulating nutrients like carbon (C) and nitrogen (N) through the process of immobilization and mineralization and considered as sensitive indicators towards crop management practices (Benintendee*et al*., 2008; Gosai *et al.,* 2010). Changes in microbial dynamics can be reflected by differences in enzyme activities in soils (Dick and Kandeler, 2005). Soil enzymes are important to catalyze many important reactions necessary for decomposition of organic waste, soil structure stabilization, formation of organic matter and nutrient cycling. Soil enzyme activity assay is a way to measure the status of soils in the ecosystem (Utobo and Tewari, 2015). Soil enzymes have been reported as important soil quality indicators in any production system, due to their relationship with soil biology and are described as "biological fingerprints" of past soil management. Soil enzymes are constantly being synthesized, accumulated, inactivated, and decomposed in the soil, hence play a vital role in nutrients cycling (Karaca *et al.,* 2010). These are very sensitive to the changes in the soil environment due to different crop management practices like tillage, cropping system, residue and nutrient management (Lehman *et al*., 2015; Choudhary *et al*., 2018 a). â-glucosidase is involved in the enzymatic degradation of cellulose by hydrolyzing various â-glucosides present in plant debris. â-glucosidase give reflection of past biological activity, soil stabilization capacity, and thus can be used to perceive crop management effect on soils (Ndiaye *et al.,* 2000; Choudhary *et al*., 2018a). Phosphatases play important roles in the bioavailability of organic P and these are affected by different system management practices (Wang *et al*., 2011). Dehydrogenase activity is considered as an important indicator of soil health and quality (Bera *et al.,* 2017), it also reflects the real picture of overall soil microbial activities. Because of dehydrogenase activity present only in viable cells; it is thought to reflect the total range of oxidative activity of soil microflora and consequently are considered as a good indicator of microbial activity.

CONCLUSION

Conservation agriculture is a new paradigm in farming practices through out the world. The adoption of CA was mainly due to wind and soil erosion faced by the farmers. Beside this, the excessive cost of energy and production inputs, prompted the farmers to adopt CA without yield penalty to mitigate the consequences of climate change. However, this agriculture practices having the presence of crop residues in the soil surface provide the residue- and soil-borne microorganisms including plant pathogens with a favourable habitat as observed by several researchers. On the contrary, several diseases were reduced under conservation agriculture practices mainly due to increase in population of soil antagonistic microflora and improved soil health.

The increase in disease severity due to residue borne pathogens may be tackled with additional control efforts like disease control chemicals, biological control and host plant resistance so that more growers adopt CA practices for the interest of the farmer's income and sustainability of agriculture production system.

To improve the sustainability of conservation tillage from a plant pathology perspective, more knowledge is required on pathogens and microbial interactions with residue and also on the direct effects of reduced tillage on host-pathogen interaction in different environmental conditions. The adoption of CA practices coupled with effective crop rotation holds the most promise for effective management of soil- and residue-borne pathogens in the near future.

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