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Review Article

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An Appraisal of Conservation Agriculture on Soil Properties and Crop-A Review

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ABSTRACT

To meet the demand of food for increasing world population from limited land and water resources, a key issue in modern agriculture, could be achieved through adoption of conservation agriculture (CA). CA has the ability to achieve expected yield in the long run with the help of modification/restored of physical, chemical, and biological properties of soil. The role of soil in the soil-plant-atmosphere continuum is unique. The crops are grown in the soil, and soil properties directly or indirectly affect the availability of water and nutrients to crops. This review of literature provides an overview of the impact of CA on soil quality with particular emphasis on key soil physical, chemical and biological properties. The review of numerous studies indicated that soil quality and yield improvements are possible in CA although some negative results have also been reported under contrasting environments. CA is particularly relevant to the areas which have high level of soil degradation, water scarcity and low soil fertility status.

Key words: *Conservation agriculture, Soil properties, Crop yield, Zero tillage, Residues retention*

INTRODUCTION

The world population continues to increase and it is projected to reach 9.1 billion by 2050[18]. This increase is expected to come mostly from developing world. Therefore, the pressing need to ensure increased food supply and food security on the limited amount of land in the world is obvious. In the long run, climate change is predicted to impact negatively with more frequent and prolonged drought and higher temperature[20]. The combination of these problems put more pressure on limited arable land available fresh water needed for food production. This is of great concern when viewed in the context of climate change and its impact that will have on agricultural production and vulnerability of subsistence farmers and poor urban communities concerning food security[56].

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This is most likely because the incidence of crop failure will probably rise due to extreme weather events[21,50]. In response to these challenges, conservation agriculture (CA) has been proposed by many researchers[28,33,34] to buffer these effects because of its powerful mechanism to adapt by increasing resilience to land degradation, drought and increasing water use efficiency[19]. FAO[20] has defined CA as a concept for resource saving agricultural productivity that strives to achieve acceptable profits together with high and sustained production levels while concurrently saving the environment. CA and conservation tillage definition have created some confusion among scientist and also the farming community and according to Hobbs[33] the differences is that conservation tillage uses some of the principle of CA but has got more soil disturbance than CA. CA on the other hand maintain permanent soil cover and this can be a decomposed organic matter or it can be a growing mulch. In its definition, CA contributes to environmental conservation as well as improved and sustained agricultural production as compared with conservation tillage. In addition, area less than 30% ground cover is not considered as CA. As a result, conservation tillage system is considered as the transitional stage towards and/one leg of CA[53]. The three central themes around CA are based on systematic crop rotation, permanent soil cover by crop residues and minimum tillage/zero tillage[48]. The benefits associated with CA include crop sequence intensification[9], better use of cropping season window permitted by earlier field entry[34], increased SOC[48], soil moisture retention while sharply reducing run-off, soil erosion and surface soil temperatures[22]. According to FAO[21], the long term effects of CA when practiced comprehensively include improved crop yield and reduction of the production costs. In recent years, farmers interested in sustainable crop production have began to adopt and adapt improved crop management practices, a step towards conservation agriculture (CA) which may be consider as ultimate solution. World wide spread of CA is about 127.9 m ha. Friedrich *et al*[25]., reported that 87% of CA adoption is concentrated in just 5 countries *viz*. USA (26.50 m ha), Argentina (25.55 m ha), Brazil (25.50 m ha), Australia (17.00 m ha), and South Africa (36.80 m ha). This review of literature discusses effects of CA on the soil characteristics including physical, chemical and biological properties as well as crop yield. The present text deals in observed trends, technical challenges, and future research avenues on CA.

CA effect on soil physical properties

Conventional tillage (CT) is one of the major drivers of soil destruction through physical breakdown of the soil structure as compared to reduced tillage or no tillage[16] due to reduced aggregation and increased turnover of aggregates and fragments of roots and mycorrhizal hyphae which are the major binding agents in soil. In CA, soil is protected by permanent residue cover and this protects the soil from the impact of the rain drop, water and wind erosion[54]. In CT, there is no protection of soil by the soil cover which increases chances of further destruction. Zero tillage (ZT) rice and wheat on permanent bed had improved the soil aggregates as compared to CT rice and wheat because puddling may destroy soil aggregates, breaks capillary pores reduce permeability in sub surface layer and form hard pan that have a negative effect on succeeding crop[36].

Greater aggregate stability was observed by Liebig *et al*[39]., under ZT system relative to the CT system. Macro aggregates increased under ZT rice and wheat rotation with the 2-4 mm fraction greater than that of the 0.25-2 mm fraction[5]. Similarly, mean weight diameter (MWD) of aggregates was higher under double ZT and permanent beds and increased over time compared to CT in maize and wheat crops, respectively[36].

The faster infiltration rate was observed by Liebig *et al*[39]., and Bhushan *et al*[5]., under ZT system than CT system. As compared to the CT, infiltration rate was 1.16 times, 1.21 times and 1.11 times higher in minimum tillage (MT), no tillage (NT) and raised bed (RB), respectively in *kharif* season.

Similar results were also found in *rabi* season[51].

After 16 years, volumetric soil water content in the 0-5 cm soil layer significantly increased by 3.1% and 4.0% under reduced tillage (RT) and no tillage (NT), respectively as compared to CT due to shading effect and reduced evaporation[40].

Soil temperatures in surface layers may be significantly lowerd during day time in summer in ZT soils with residue retention compared to CT[38,42]. In the same studies, during night time the insulation effect of the residues led to higher temperatures so there was lower amplitude of soil temperature variation with ZT.

Bulk density was more in NT compared with CT[46] due to tillage practices, having the highest reduction of this property and the highest increase of porosity and field capacity in ZT[1]. The impact of tillage and residue retention on soil bulk density (BD) is mainly confined to surface soil layer. In deeper soil layers, BD is generally similar in zero and conventional tillage[6,11,27]. A plough pan may be formed by tillage immediately underneath the tilled soil, causing higher bulk density in this horizon in tilled situations[13,58]. Malecka *et al*[40]., reported that RT and NT caused an increase in soil bulk density (BD) of 0.15 and 0.30 g cm^{-3} as compared to CT in 0-15 cm soil layer. In contrast, there was no significant difference obtained in 10-20 cm soil layer. Zero tilled plots showed more compactness after rice, and the level of compaction reduced after wheat at both the depth *i.e*. 0-15 and 15-30 cm due to accumulation and decomposition of crop residues[4].

Hydraulic conductivity recorded generally higher in ZT with residue retention compared to CT due to the larger macropore conductivity as a result of the increased number of biopores[17,41]. Azooz and Arshad[3] found that both the saturated and unsaturated hydraulic conductivities were higher under ZT conditions than under CT on two Luvisols (silty loam and sandy loam soils). Soil hydraulic conductivity after rice crop, through the bulk density, in zero tilled plots were significantly higher than that of tilled plots at 0-15 and 15-30 cm soil depths[4]. Decrease in hydraulic conductivity by tillage was probably due to destruction of soil aggregate and reduction of non-capillary pores. In contrast, the significant increment in hydraulic conductivity in tilled plots over zero tilled plots after wheat might be due to arrangement of soil pores and more macro pores continuity[4].

CA effect on soil chemical properties

The judicious use of tillage practices overcomes edaphic constraints, whereas inopportune tillage may cause a variety of undesirable outcomes for example, loss of organic matter & fertility, organic carbon, plant nutrient, and disruption in cycles of water. During the first 4 years of tillage, a 10% loss of initial soil organic matter content was determined with plough tillage. Soil organic matter depletion between 16% and 77% was caused by the tillage. In most instances, increased levels of tillage or increased tillage periods resulted in reductions of soil carbon. When CT is converted to conservation tillage, both CO_2 emissions from soil and N uptake by the crop are reduced. Rice straw is characterized by a high C: N ratio and abundant K, Si, and C. Wheat straw have comparable properties except for low Si and low K concentration. The successful utilization of crop residues as a nutrient source and manipulating the biological processes in the soil optimize nutrient availability with respect to plant demand[44].Blanco-Canqui and Lal[6] assessed long-term (10 years) impacts of three levels (0, 8, and 16 Mg ha^{-1} on a dry matter basis) of wheat straw applied annually on SOC under ZT on a Aeric Epiaqualf in central Ohio. Overall, SOC from 0 to 50 cm depth was 82.5 Mg ha^{-1} in the unmulched soil, 94.1 Mg ha^{-1} with 8 Mg ha^{-1} mulch, and 104.9 Mg ha^{-1} with 16 Mg ha^{-1} mulch. Sisti *et al*[52]., found that under a continuous sequence of wheat and soyabean the concentrations of SOC to 100 cm depth under ZT were not significantly different from those under CT.

ZT is generally associated with a lower N availability because of greater immobilization by the residues left on the soil surface[8,43,47]. According to Schoenau and Campbell[49], a greater immobilization in CA can enhance the conservation of soil and fertilizer N in the long run, with higher initial N fertilizer requirements, and decreasing over time because of reduced losses by erosion and the build-up of a larger pool of readily mineralizable organic N. Numerous studies have reported higher extractable P levels in ZT than in tilled soil[15,16,23], largely due to reduced mixing of the fertilizer P with the soil, leading to lower P-fixation. After 20 years of ZT, extractable P was 42% greater at 0-5 cm, but 8-18% lower at 5-30 cm depth compared with CT in a silt loam[35]. ZT conserves and increases availability of nutrients, such as K, near the soil surface where crop roots proliferate[23]. According to Govaerts *et al*[32]., permanent raised beds (RB) had a concentration of K 1.65 times and 1.43 times higher in the 0-5 cm and 5-20 cm layer, respectively, than conventionally tilled raised beds, with crop residue retention of both rice and wheat crops. In both tillage systems (CT and RB), K accumulated in the 0-5 cm layer, but this was more accentuated in permanent than in conventionally tilled raised beds. Most studies have shown that tillage does not affect extractable Ca and Mg levels[15,16,32] especially, where the cation exchange capacity (CEC) is primarily associated with clay particles[16]. The Ca concentrations were higher in the 0-5 cm layer of ZT as compared to the deeper layers in the work of Duiker and Beegle[16] but the reverse was true for mouldboard tillage. Increasing supply to food crops of essential micronutrients might result in significant increases in their concentrations in edible plant products, contributing to consumer's health[57]. Long-term continuous use of NT on a fine-textured, high-fertility (except for N) soil had no apparent adverse effects on nutrient distributions relative to CT, but enhanced conservation and availability of P, K, Zn, Fe, Mn, and Cu near the soil surface where crop roots proliferate due to surface placement of crop residues[23]. In contrast, Govaerts *et al*[32]., reported that tillage practice had no significant effect on the concentration of extractable Fe, Mn and Cu, but that the concentration of extractable Zn was significantly higher in the 0-5 cm layer of permanent raised beds compared to conventionally till raised beds with full residue retention.

CA effect on soil biological properties

Alteration in tillage, crop residue, and crop rotation practices induce major shifts in the number and composition of soil fauna and flora, including both pests and beneficial organisms[2,7]. The soil micro- and macro-organism play an important role in physical stabilization of soil aggregates[14,24]. The rate of organic C input from crop biomass is generally considered the dominant factor controlling the amount of soil microbial biomass (SMB) in soil. The SMB reflects the soil's ability to store and cycle nutrients (C, N, P and S) and organic matter, and has a high turnover rate relative to the total soil organic matter[10,12]. Due to its dynamic character, SMB responds to changes in soil management often before effects are measured in terms of SOC and N[45]. In the subtropical highlands of Mexico, residue retention resulted in significantly higher amounts of SMB-C and N in the 0-15 cm layer compared to residue removal[29]. Spedding *et al*[55]., found that residue management had more influence than tillage system on microbial characteristics, and higher SMBC and N levels were found in plots with residue retention than with residue removal, although the differences were significant only in the 0-10 cm layer. NT system increased total carbon by 45%, microbial biomass by 83% and SMBC: total carbon ratio by 23% at 0-5 cm depth over CT after 21 years. Carbon and nitrogen mineralization increased by 74% with NT compared to CT systems for the 0-20 cm depth. These soil microbial properties were shown to be sensitive indicators of long term tillage management under tropical condition.

CA effect on crop yield

Better plant growth and higher yield depend on well-developed root system. Restricted root growth resulted in reduced nutrient uptake and poor growth of plants[43]. Govaerts *et al*[31]., evaluated the soil quality of plots after more than 10 years of different tillage and residue management treatments. They showed the direct and significant relation between the soil quality status and the crop yield, and observed that ZT with crop residue retention obtained the highest crop yields as well as the highest soil quality status[30,31]. In contrast, the uncovered soil under ZT showed the poorest soil quality *i.e*. low SOC and aggregate stability; more compaction; lack of moisture resulting in the lowest yields of maize monoculture[26,31]. Jat *et al*[37]., reported the effect of 3 tillage systems (conventional flat, CTF; no-till flat, NTF; permanent raised beds, NTB) on crop production in maize-wheat rotation and observed the highest grain yield of maize (8.2-73.4%) under NTB followed by NTF and CTF across the years. Wheat yield was significantly higher under NTF during the 1st year while tillage practices had non-significant effect in the succeeding two years. Thus, CA, that combines reduced tillage, crop residue retention, and functional crop rotations, together with adequate crop and system management, permit the adequate productivity, stability and sustainability of agriculture.

CONCLUSION

Conservation agriculture (CA) practices are ecological approach to soil surface management. Proper use of crop residues with ZT favored the nutrient buildup, improved the soil environment and resulted in increased crop yield in a wide variety of soil. There is some evidence that the soil physical properties, organic carbon and nutrient availability in the top 5 cm of the profile may be greater under ZT when residue is retained. Combinations of tillage, residue management and crop rotation had a significant impact on nutrient distribution and transformation in soils. ZT practices without residues retention also improved the SOM and nutrients but to a lesser extent as compared to ZT with residues retention. ZT with residues retention on flat as well as bed planting was the most beneficial in cropping system. CA based crop production system is one of the pathways for improving productivity and food security while sustaining the natural resources in variety of ecological region. ZT with residues retention may be recommended to farmers in the best interest of food security and soil quality.

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