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Conservation Agriculture and its Impact on Physical, Chemical and Biological Properties of Soil: A Review

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ABSTRACT

The growing global population and climate change demand more food to be produced in an environment in which the quality of natural resources is declining and our environment is increasingly variable as well. Due to its influence on soil properties, soil tillage is regarded as one of the fundamental agrotechnical operations in agriculture. It is essential to apply tillage practices that avoid soil degradation, maintain crop yield, and ensure ecosystem stability. The practice of conservation agriculture, which practices agriculture in a way that minimizes damage to the environment, is being advocated on a large scale throughout the world. Conservation agriculture is primarily focused on soil health, plant growth, and environmental protection. The purpose of this paper is to review the work done on conservation agriculture to evaluate its impact on the soil, the crop, and the environment. Research reports have shown that conservation tillage offers several advantages over conventional tillage with regard to soil physical, chemical and biological properties. The largest contribution of CA to reducing emissions from farming activities is made by the reduction of tillage operations.

HIGHLIGHTS

- Conservation agriculture is an important practice under changing climate scenario.
- CA affects physical properties of soil.
- Conservation agriculture also affect chemical and biological properties of soil.
- For improved soil properties and to avoid land degradation CA is an important practice.

Keywords: Conservation agriculture, soil physical, chemical and biological properties

World has faced several problems, one of which is feeding a rising and ever-increasing population under a changing climate with reduced external inputs (Kar *et al.* 2021; Pittelkow *et al.* 2015). To feed these extra people, it will undoubtedly be required to increase global food production, particularly in developing nations like India, where population growth is now at its highest (Singh *et al.* 2021). This must occur in a world where the ability to expand agricultural land is restricted, and our ability to boost productivity on current agricultural land is endangered by soil degradation, water shortages, and climate variability and extreme events associated to climate change (Kumar *et al.* 2021). In order to meet the world's food needs, agricultural systems worldwide need to become more sustainable, thereby producing more food. The conventional intensive tillage-based production systems have many adverse impacts on natural resources, such as

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soil, water, terrain, and biodiversity (Montgomery, 2007; Kassam *et al.* 2013; Dumansky *et al.* 2014; Das *et al.* 2021). Due to the degradation of land resources and the decline of factor productivity, crop production is negatively impacted (Goddard *et al.* 2006; Jat *et al.* 2014; Farooq and Siddique, 2014; Pramanick *et al.* 2012) and 30 percent of greenhouse gas emissions (IPCC, 2014), there is a need for sustainable yet intensified production system that ensures profitable agriculture and natural resource conservation and reducing environmental services (FAO, 2011). It is not without challenges, but conservation agriculture has been hailed as an agricultural system capable of achieving the sustainable intensification required to meet world food demand (Kassam *et al.* 2009; Lal, 2015a). The conservation agriculture (CA) model is based on three interrelated principles of regenerative sustainable agriculture and land management: (1) continuous no or minimum mechanical soil disturbance, (2) permanent maintenance of soil mulch (crop biomass and cover crops) and (3) diversification of cropping system (economically, environmentally and socially adapted rotations including legumes and cover crops), in addition to other good agricultural practices and land management practices (Jat et al. 2020; Hossain *et al.* 2021).

According to Hubbard *et al.* (1994) and Karlen *et al.* (1994) CA is a common term for a set of agricultural practices aimed at enhancing sustainable food production through conserving and protecting existing and available soil, water, and biological resources in order to minimize external inputs (Garcia-Torres *et al.* 2003). The term conservation tillage refers to any planting or tillage method where at least 30% of the soil surface is covered by plant residue to reduce wind and water erosion (Choudhary *et al.* 2021). Additionally, other complementary practices, such as integrated pest management and nutrient management, are often incorporated into the CA system on a site-specific basis to ensure its success (Lal, 2015; Thierfelder *et al.* 2018). There are many benefits associated with conservation agriculture, such as the ability to store more water in the soil (Verhulst *et al.* 2011; Page *et al.* 2019), enhanced soil quality (Jat *et al.* 2019; Somasundaram *et al.* 2019), decreased erosion (Montgomery, 2007), and in some cases, higher yield and net income of farm (Pradhan *et al.* 2018; Page *et al.* 2019). By reducing mechanical tillage, micro flora and macro flora become more active, which helps improve biological tillage of soil, which in turn improves soil structure and enhances plant growth (Kar *et al.* 2021).

Our purpose is to provide an overview of our current knowledge on the impact of CA and its components on soil physical, chemical, and biological properties by reviewing the peer-reviewed research published worldwide over the past decades. The changes in soil physical, chemical and biological properties will be explored.

Principles of conservation agriculture

CA practices followed in many parts of world are built on sustainable ecological principles (Wassmann *et al.* 2009; Behera *et al.* 2010 and Lal, 2013). Balancing Resource use efficiency (RUE) and crop productivity is utmost essential for managing natural resources and to accomplish agriculture sustainability. Conservation agriculture fundamentally relies on following principles:

Minimal mechanical soil disturbance

Biological tillage is the process by which soil microorganisms, through their biological activities, produce stable soil aggregates and a range of holes in soil that allow air and water to enter and infiltrate. The process is comparable to mechanical tillage, however mechanical tillage impedes the soil's biological structure (Kassam and Friedrich, 2009; Kumar *et al.* 2021; Kar *et al.* 2021).

Permanent soil organic cover

The maintenance of permanent soil organic cover with crop residues or cover crops will suppress weeds and protect soils from extreme weather events; Maintains soil moisture and prevents compaction of soil, protects soil from exposure to rain and sunlight, provides soil organisms with food and alters soil microclimate for growth and development of soil organisms. Therefore, it promotes biological activity in soil aggregation of soil particles and carbon sequestration (Ghosh *et al.* 2010).

Rotation of crops

Through rotation of crops, soil microorganisms are exposed to diverse "diets" and nutrients are recycled from deeper soil layers to the surface (Kassam and Friedrich, 2009; Dumanski *et al.* 2006).

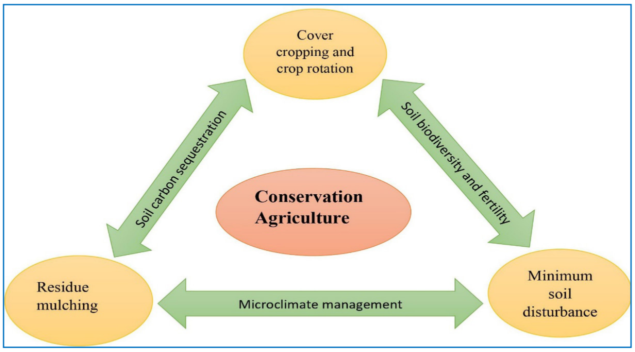

Fig 1: Components of conservation agriculture and its positive interaction with environment

Impacts of CA on soil physical, chemical, and biological properties

By increasing soil organic carbon, CA has a positive impact on soil physical, chemical, and biological properties (Liang *et al.* 2002; Nyamangara *et al.* 2014).

Physical properties

CA affects soil properties in a spatiotemporal manner, and these changes depend on the type of system chosen. Anikwe and Ubochi (2007) found that high soil surface coverage by No-Till (NT) systems did not significantly affect soil properties, especially in the upper few centimeters of the soil surface. From the beginning of a tillage trial in both conventional and CA tillage, Rai *et al.* (2018) found that porosity, bulk density (BD), and mean weight diameter of soil aggregates improved.

(a) Aggregate Stability

The organic matter in the soil plays a key role in the stability of soil aggregates and thus in the maintenance of good soil structure. Soils that are depleted of organic matter are more likely to slake into smaller sub-units when wet, resulting in a soil structure that is more likely to erode and restrict water infiltration and seedling emergence (Tisdall and Oades, 1982; Blanco Canqui and Ruis, 2018; Laik *et al.* 2021). Generally, CA increases SOC, which results in improved soil aggregate stability (Blanco-Canqui and Ruis, 2018; Li *et al.* 2019). Positive effects are especially seen when root systems persist without tillage and fungal populations are high (Wang *et al.* 2010; Spurgeon *et al.* 2013). In accordance with this, a recent worldwide meta-analysis found that the number of water-stable aggregates in NT systems is 31% higher than in conventionally tilled systems without residue retention (Li *et al.* 2019). As a result of these improvements, soil water infiltration is increased, wind and water erosion is reduced, organic matter is more effectively protected, and microbial activity is enhanced in the soil (Helgason *et al.* 2010; Spurgeon *et al.* 2013; Li *et al.* 2019).

(b) Soil Water

A significant positive impact on soil water storage is often observed with improved aggregate stability combined with the retention of residues in CA systems (Page *et al.* 2019, Sun *et al.* 2019). This increase is typically caused by a combination of greater infiltration rates and decreased evaporation of soil water (Li *et al.* 2019). It is generally thought that increased infiltration is due to the improved aggregate stability in the surface of the profile as well as the greater number and continuity of macropores available to rapidly transmit water into the soil profile when tillage is not done (Blanco-Canqui and Ruis, 2018; Li *et al.* 2019). Crop residues may also help protect the soil surface from raindrop impact and prevent the formation of surface seals that may reduce infiltration (McGarry *et al.* 2000). Moreover, crop residue shades the soil and decrease wind speeds at the soil surface, which reduces evaporation losses (O'Leary and Connor, 1997; Nielsen *et al.* 2005).

(c) Bulk Density

According to Hu *et al.* (2007), NT significantly increased topsoil bulk density (0-5 cm) whereas reduced tillage (RT) maintained a lower BD. The bulk density of soil recorded in NT/NT (1.50 g/cm3) was significantly higher than that recorded in sequential fresh bed and permanent bed treatments, according to Ram *et al.* (2010). Dalal *et al.* (2011) also reported the residues management practices had not significant influence on the bulk density of vertisol soil of Australia. Moreover, Naresh *et al.*

2016 found that mean soil bulk density in the 0 to 20 cm soil layer of the FIRB with residue retention and ZT with residue retention plots was 12.4% and 6.8% lower, respectively ($P < 0.05$) than the CT plots. Furthermore, the FIRB treatment had significantly lower bulk densities in the 0 to 10 and 10 to 20 cm soil layers compared to CT by 14.3 and 12.8%, respectively. The changes in bulk density were mainly confined to top 10-15 cm layer. Fabrizzi *et al.* (2005) and Gantzer and Blake (1978) have reported higher BD and penetration resistance values under ZT compared with CT. In semi-arid regions, Bautista *et al.* (1996) observed that ZT with residue decreased bulk density (BD) considerably. Sayre and Hobbs 2004 have conceptualized that use of ZT along with a permanent residue retention, though BD was higher, showed greater infiltration rate under NT systems because of more stable soil structures (high MWD of aggregates) in the ZT system more number of uninterrupted earthworm networks that linked to the soil surface.

(d) Soil temperatures

When compared to conventional tillage, the surface soil temperature in zero tilled soils with residue retention during the daytime (in summer) can be significantly lower (often 2 to 8°C). (Oliveira *et al.* 2001). Naresh *et al.* 2015 showed that soil temperature at transplanting zone depth (5 cm) during rice crop establishment was lower in 2009 than in 2010 and did not differ in the years 2010 to 2011. Zero tillage reduced the effect of solar radiation by acting as a physical barrier, which led to lower soil temperatures than ploughed soils. This result is in agreement with Sekhon *et al.* (2005). The vegetation in the form of crop residues insulates the soil and captures a large amount of sunlight, reducing heat transfer to the soil and preventing the soil beneath from being as hot as the bare soil during the day (Zhang *et al.* 2009).

As a result of these depressive effects of crop residues, there is a reduction of soil temperature extremes in RT systems on a diurnal basis as compared to CT practices (Wall and Stobbe, 1984). Alletto *et al.* 2011 reported a decrease in surface temperature by about 0.8 to 2.8°C due to the presence of crop residues on the surface of RT.

Chemical properties

(a) **Soil pH**

An increased SOC at the surface of the profile is often associated with greater acidity in CA systems than in conventionally tilled systems (Dalal, 1989; Franzluebbers and Hons, 1996; Limousin and Tessier, 2007; Vieira *et al.* 2009; Mrabet *et al.* 2012; Sithole and Magwaza, 2019). Typically, this is because of the accumulation of organic acids and residues on the soil surface (Dalal, 1989; Heenan and Taylor, 1995; Franzluebbers and Hons, 1996) and an increased rate of nitrogen mineralization coupled with nitrate-nitrogen leaching (Heenan and Taylor, 1995). Acidification is also increased by greater rates of root exudation, which is caused by roots accumulating at the soil surface (Limousin and Tessier, 2007). Govaerts *et al.* (2007) found a higher pH in permanent bed with all the residues retained than with part or all of the residues removed in a rainfed experiment in the highlands of Mexico. According to Duiker and Beegle (2006), tillage did not have a noticeable effect on the average pH of the 0-15 cm layer. Kettler *et al.* (2000) found that ploughing induced a greater effect on soil pH at soil depths of 0–7.5 cm and that no-till and sub-till treatments, which leave plant residues at or near soil surface, had lower soil pH than mould board plowing treatments at all depths. In general, tillage and straw management had little to no effect on soil pH in any soil layer (Malhi *et al.* 2011).

(b) Cation Exchange Capacity

The CEC of soil affects soil fertility, soil structural stability, and soil pH buffer capacity. In addition to mineralogy and clay content, changes in SOM and pH can also influence CEC. (McBride, 1994). Therefore, the CA has the potential to influence CEC. The changes are variable in size and direction (Pankhurst *et al.* 2002; Duiker and Beegle, 2006; Sa *et al.* 2009), decreases (Lal, 1999; Duiker and Beegle, 2006; Limousin and Tessier, 2007; Thomas *et al.* 2007; Sithole and Magwaza, 2019), and no change noticed (Bravo *et al.* 2007; Qin *et al.* 2010; Williams *et al.* 2018). Generally, a higher CEC corresponds to a higher organic matter content, which results in a higher negative charge (Chan *et al.* 1992; Sa *et al.* 2009). CEC may be lower in soils where pH has decreased, resulting in lower pH-dependent cation exchange sites (Thomas *et al.* 2007; Sithole and Magwaza, 2019). Kumar *et al.* 2015 reported an increase in cation exchange capacity (CEC) due to tillage crop establishment. This large loss in aggregate stability for a zero-till system is especially concerning because it suggests that the increased aggregate stability of surface soil under no-till is due to surface residues rather than to zero-tillage's inherent properties. Hamerbeck *et al.* (2012) made a similar observation.

(c) Plant Nutrients

In CA systems where SOC is improved, this can significantly affect plant nutrition since both the quantity of nutrients available, as well as their distribution, will change. If CA is successful in increasing residue addition and thus organic matter input into the soil, it can increase plant nutrient stores, with a higher N content. (Pankhurst *et al.* 2002; Thomas *et al.* 2007; Page *et al.* 2019; Sithole and Magwaza, 2019), P (Bravo *et al.* 2007; Qin *et al.* 2010; Zhao *et al.* 2017; Sithole and Magwaza, 2019), Ca (Chan *et al.* 1992), Mg (Chan *et al.* 1992), K (Bravo *et al.* 2007; Sithole and Magwaza, 2019), Mn (Rhoton, 2000) and Zn (Rhoton, 2000) concentrations all observed CA systems in response to an increase in organic matter.

(d) Particulate Organic C and N

Ogle *et al.* (2005) found the following order of management impacts, from largest to smallest changes in SOC, was: tropical moist > tropical dry > temperate moist > temperate dry. Aulakh *et al.* 2013 revealed that after 2 years of the experiment, in 0 - 5 cm soil layer of CT system, increased POC content from 390 mg/kg.

Biological Properties

(a) Soil Microbiology

The presence of additional soil organic carbon (SOC) in CA systems can provide an energy source to soil microorganisms, leading to a greater microbial biomass than conventional agriculture (Dou *et al.* 2008; Helgason *et al.* 2010; Mangalassery *et al.* 2015). Microbial abundance can also increase as a result of increased SOC and residue retention, which creates a better aggregation, moisture, and temperature environment for the microbial populations (Lupwayi *et al.* 2001; Zhang *et al.* 2018). Conservation agriculture has also been associated with an increase in both fungal and bacterial diversity, especially when crop rotations are more diverse (Wang *et al.* 2016; Yang *et al.* 2012). In CA systems incorporating NT, particularly at the surface of the profile, fungi often flourish in greater abundance due to the absence of tillage (Helgason *et al.* 2010).

(b) Macro-Fauna

Macro-fauna in the soil can be significantly affected by CA systems. Macro-fauna, such as earthworms, termites, and beetles, that burrow through soil and break up plant residues are vital for creating soil macro porosity and mixing organic matter into the soil to aid nutrient cycling and aggregate formation (Kladivko, 2001; Spurgeon *et al.* 2013). Through conventional agricultural practices, tillage can kill and injure macrofauna, bring them closer to the soil surface and expose them to adverse environmental conditions and predators, and destroy their burrows and tunnels as well as their source of food (Briones and Schmidt, 2017). The macro-fauna populations are commonly greater under CA systems, both in abundance and biomass, and this increases with the duration of the CA system (Stagnari *et al.* 2009; Soane *et al.* 2012; Briones and Schmidt, 2017).

(c) **Diseases**

Despite the fact that much of the soil microbiology is positive for plant growth, many diseases exist, and disease prevalence can both increase and decrease in CA systems. For example, during the period between harvest and planting, when host plants are absent, some pathogens can thrive on residues, leading to greater disease prevalence (Bockus and Shroyer, 1998). Enhanced soil moisture, lower soil temperatures, and reduced soil disturbance can also provide a more favorable environment for many plant pathogens (Bockus and Shroyer, 1998). Pathogens generally noticed to increase in the absence of tillage and residue removal include *Gaeumannomyces graminis* var tritici (take all) (Pankhurst *et al.* 1995), *Fusarium pseudograminearum* (head blight, crown rot) (Wildermuth *et al.* 1997), *Pyrenophora tritici-repentis* (tan or yellow spot) (Bockus and Shroyer, 1998), *Pythium* spp. (Pythium seed and root rot) (Pankhurst *et al.* 1995), *Rhizoctonia* *solani* (Rhizoctonia root rot, bare patch, purple patch) (Pankhurst *et al.* 1995), and *Pratylenchus* spp. (root lesion nematode) (Pankhurst *et al.* 1995). Reduced tillage and residue retention combined with crop rotations that include diversification can lead to reductions of disease prevalence when incorporated into a CA system with reduced tillage and residue retention. A general increase in biological diversity under CA can lead to an increase in the abundance of microorganisms that suppress diseases (Govaerts *et al.* 2008).

(d) Emission of Gaseous and Aerosol Species

Chang *et al.* (2010) evaluated the emissions of open biomass burning over tropical Asia during seven fire years between 2000 and 2006. By using Moderate Resolution Imaging Spectro radiometer (MODIS) active fire and land cover data, Venkataraman *et al.* (2006) inventoried the emissions from open biomass burning as well as crop residues in India. According to Sahai *et al.* (2007), burning wheat straw in agricultural fields in Pant Nagar emits trace gases and particles. Sahai *et al.* (2011) have estimated that burning of 63 Mt of crop residue emitted 4.86 Mt of CO_2 equivalents of GHGs 3.4 Mt of CO and 0.14 Mt of NOx. ZT reduced the C emission of farm operations with 74 kg C ha/y compared to CT. Although this may seem like a small difference, while soil sequestration of carbon is limited, the reduction of net carbon dioxide flux into the atmosphere through reduced carbon dioxide emissions can continue indefinitely (West and Marland, 2002). By incorporating cereal residues into paddy fields at an optimum time before planting rice, adverse effects on rice growth and CH_4 emissions can be minimized. It was concluded that the incorporation of wheat straw before transplanting rice did not significantly affect N_2O emissions due to the immobilization of mineral N by the high C/N ratio of the straw (Ma *et al.* 2007). In subtropical Asian rice-based cropping systems, however, more N_2O has been observed from fields with mulch than from fields with incorporated residue.

CONCLUSION

CA practice improves soil aggregation; reduces bulk density in the long run by increasing the carbon pool and improving soil structure. As residues present in the surface prevent crust formation, reduce runoff velocity, and increase infiltration time, infiltration is generally higher under CA. The higher amount of SOC in surface soil layer in CA is due to higher crop residue accumulation, which increases mineral availability. There were significant differences in the emission of different air pollutants due to crop residue burning among different states of India, depending on the residues generated, their use patterns, and the fraction of residues burned. In Punjab, Uttar Pradesh, Haryana, and Maharashtra, there was the greatest amount of crop residue burned on farms. In Punjab, Haryana and western Uttar Pradesh, large-scale burning of crop residues from rice-wheat systems poses serious concerns not only for GHG emissions but also for pollution, health hazards, and the loss of nutrients. If residues are collected and managed properly, they can be used for a variety of productive purposes, including incorporation in fields and bio-energy. Farmers must be informed about the negative impacts of crop biomass burning and the importance of incorporating crop residues in soil in order to maintain sustainable agricultural productivity.

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