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Conservation Agriculture to Improve Soil Health

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By 2050, agricultural output should have doubled from current levels to fulfil the demands of the growing world population. The amount of land that can be used for agriculture is limited due to the world's population growth, and the lack of water resources and land degradation that limits crop productivity all contribute to increased climate variability. The multifaceted, all-encompassing strategy that can be taken into consideration to achieve entire system intensification is conservation agriculture (CA). The scientific community worldwide is becoming increasingly interested in and supportive of conservation agriculture, particularly due to its potential to preserve or enhance soil quality and environmental sustainability. CA improves the link between crop input and production, conserves natural resources by minimizing soil erosion, stops water losses by decreasing soil evaporation, stores atmospheric carbon in the soil, and lowers the energy requirements of the agricultural sector. Additionally, by using conservation agricultural techniques like no-till farming and increasing crop rotation, as well as by optimizing agronomic techniques like fertilizer, pesticides, irrigation, etc., soil carbon can be increased. One of the main components of CA is soil organic matter, which is mostly found at the soil's surface and is linked to improvements in the soil's biological, structural, and fertility characteristics as compared to conventional agricultural systems.

Conservation agriculture (CA) plays a crucial role in promoting and maintaining soil health. The three main principles of CA- minimal soil disturbance, permanent soil cover, and diversification of crops contribute significantly to improving soil health in various ways:

Minimal Soil Disturbance

Reduced Soil Erosion

Traditional ploughing and tillage practices can lead to soil erosion, as the soil is exposed to the elements. By minimizing soil disturbance or adopting no-till practices, CA helps retain the topsoil, reducing erosion and preserving valuable nutrients.

Preservation of Soil Structure: Excessive tillage can destroy soil structure by breaking down aggregates. CA promotes the preservation of soil structure, which is crucial for water retention, root penetration, and nutrient availability.

Permanent Soil Cover

Moisture Conservation

Keeping the soil covered with crop residues or cover crops helps retain soil moisture. This is especially important in arid or semi-arid regions where water conservation is critical for crop growth.

Weed Suppression

The presence of cover crops or crop residues helps suppress weed growth. This minimizes the competition for nutrients and water, allowing crops to thrive.

Diversification of Crops

Nutrient Cycling

Crop rotation in conservation agriculture systems enhances nutrient cycling in the soil. Different crops have varying

nutrient requirements, and by diversifying crops, farmers can optimize nutrient availability and reduce the risk of nutrient depletion.

Pest and Disease Management

Crop diversification disrupts the life cycles of pests and diseases, reducing the need for chemical interventions. This promotes a healthier soil ecosystem with a balance of beneficial organisms that can contribute to pest control.

Status of Conservation Agriculture in World and India

All agricultural land with regionally appropriate procedures can use CA production systems. Between 2008–09 and 2013–14, the global area covered by CA cropland was approximately 106 M ha and 157 M ha, or 7.5% and 11% of all cropland, respectively. This represents a difference of 51 M ha (47%) over five years, while in 2015–16, it was approximately 180 M ha, or 12.5% of all cropland, representing a difference of 74 M ha (69%) over seven years since 2008–09 ((Kassam et al., 2018). Currently, about 10 Mha of arable cropland in Asia is covered by the CA system, making up roughly 6.5% of the global CA area. China accounts for 65.4% of the overall Asian CA area, followed by Kazakhstan (19%) and India (19%) (FAO, 2017). Farmers in India have only started to rapidly absorb CA technologies in the last eight to ten years, even though they have been accepted and promoted over the past ten years. To advance conservation agriculture, several State Agricultural Universities, ICAR institutes, and the Rice-Wheat Consortium for the Indo-Gangetic Plains have partnered. Innovations are proliferating in India's irrigated regions of the Indo-Gangetic plains, where rice-wheat cropping patterns are common. Zero-till seed cum fertilizer drills have been the primary focus of conservation technology development and promotion in the rice-wheat system (Bhan & Behera, 2014). Raised-bed planting methods, residue management, and laser-assisted ground levelling are examples of other treatments.

Effect of conservation agriculture on soil properties

I. Effect on soil physical properties

Bulk density

The surface soil layer is primarily affected by tillage and residue retention about soil bulk density (BD). As a result of the ongoing use of the conventional farming method, a plough pan forms beneath the furrow slice; this is explained by the higher BD in this horizon relative to CA. Reductions in tillage intensity brought about by the implementation of CA methods eventually lead to a progressive decrease in soil compaction. It's possible that improved aggregation, biomass, root growth, and higher SOC contributed to the decrease in soil BD under CA (Rao et al., 2021). Furthermore, when compared to monocultures, the presence of legumes in crop rotations led to a considerable decrease in soil BD.

Soil Aggregation and Aggregate Stability

The ability of the soil to resist change under natural or man-made conditions is known as soil aggregate stability. By leaving the majority of crop residues on the soil's surface, CA techniques enhance aggregate stability and soil aggregation. Additionally, it shields surface aggregates from splash erosion and the effects of rain. CA promotes aggregate stability and soil aggregation (Rao et al 2021; Mondal et al 2021). Enough soil cover is necessary for CA to carry out several essential tasks, such as enhancing infiltration, producing water that is accessible to plants, and maintaining aggregate stability. It also raises the soil's water-holding capacity, decreases surface evaporation, and increases the percentage of micro-pores in the soil.

Soil temperature

The temperature of the soil is a significant, ephemeral physical attribute that controls the physical, chemical, and biological processes of the soil and influences crop growth and development. When comparing zero tillage (ZT) soils with residue retention to conventional tillage, the daytime surface soil temperatures in may be considerably reduced. Crop residue and other surface mulches alter the thermal characteristics of the soil, such as its thermal conductivity, thermal diffusivity, and volumetric heat capacity, to change the temperature of the soil.

II. Soil chemical properties

Soil Organic Matter

In addition to being a crucial indication of soil quality, soil organic matter (SOM) is essential for preserving soil fertility, production, and sustainability. By using previous crop residues or cultivating green manure or cover crops and storing these residues as surface mulch instead of burning them, CA methods often increase the SOM content and nutrient availability. SOM was reduced by 16% to 77% at higher tillage levels, while the total amount of carbon in the soil decreased at higher tillage intervals.

Macronutrient status

The type of crop leftovers and how they are managed have a significant impact on the ability of soils to deliver nutrients and increase the availability of nutrients for plants. For instance, although overall reserves of nitrogen (N) may be larger under CA, plant-available N may decrease, especially in the immediate aftermath of CA implementation, and N fertilizer treatments may be necessary to sustain production. This is a result of increased crop residue addition under CA, which lowers the rate of N mineralization and increases the rate of N immobilization in the soil (Sithole & Magwaza, 2019).

Because P stratification in the soil is seen under different tillage systems, zero tillage is associated with a higher concentration of P due to preferential movement of P in the soil the concentration of nutrients like phosphorus and potassium was higher near the soil surface than in tilled soil (Dorneles et al., 2015). Additionally, adding crop residues and fertilizer P under CA causes the least amount of P to be lost to water erosion, which raises the P concentration in the surface soil. Regarding P availability, no-till and reduced tillage have additional benefits over conservation tillage. These benefits include decreased soil erosion, the build-up of labile forms of P resulting from the presence of organic residues in the soil, and the maintenance of freely available phosphate due to the effect of OM negative charges. Therefore, because minimum soil disturbance favours phosphorus accumulation and reduces the contact surface between adsorption sites and phosphate ions, conservation tillage combined with P fertilization serves to improve soil P availability.

According to Yadav et al. (2016), following seven years of CA, PB planting produced the greatest amounts of N, P, and K (219, 25, and 203 kg ha^{-1}) in the 0-15 cm soil surface, whereas conventional tillage produced the lowest amounts of these nutrients. In comparison to conservation tillage, more nutrients are added in PB treatments due to the recycling of a larger quantity of crop residue from earlier greater biomass yields. On the other hand, when straw is mixed into a deep soil layer during conservation tillage, it decomposes quickly and may cause mineralized nutrients in deeper soil layers to leak out, which lowers the amount of nutrients that are accessible during conservation tillage. Additionally, the chelation of these minerals with organic matter in undisturbed soil results in an improvement in the nutrient status of the soil at various soil depths, which in turn leads to an improvement in the NPK status of the soil.

Secondary and micro-nutrients in the soil

The biochemical breakdown of organic crop wastes at the soil surface, which is also significant as nutritional material for soil microbes, improves soil nutrient cycles and supplies. Exchangeable Ca, Mg, and K were found to be considerably greater in the surface soil under no-tillage than in the ploughed soil. When compared to conservation tillage, micronutrients (Zn, Fe, Cu, and Mn) are generally more abundant under zero tillage with residue retentions, particularly close to the soil surface. Nevertheless, Govaerts et al. (2007) found that whereas the tillage method had no discernible impact on the concentration of extractable Fe, Mn, or Cu, extractable Zn was substantially more concentrated in the 0–5 cm layer after PB planting compared to conservation tillage with full residue retention.

III. Soil biological properties

In contrast to traditional agriculture, the main factor contributing to the buildup of the higher amount of soil organic carbon under CA techniques is the combination of no-tillage and residue retention. The presence of soil organic carbon in CA systems provides soil microorganisms with an excellent energy source, fosters their growth, and subsequently modifies their dispersion. Extended periods of intensive soil cultivation result in decreased microbial biodiversity when compared to uncultivated and/or less disturbed soil. Changes in crop rotation, tillage, and crop residue practices cause significant changes in the amount and makeup of beneficial and pest organisms in the soil.

Soil microbial biomass carbon and enzyme activities

Consistent application of CA-based management techniques reduces soil disturbance, which can boost soil microbial biomass and metabolic rate, improving soil quality and ultimately raising crop output. The amount of soil microbial biomass (SMB) in the soil is generally thought to be primarily controlled by the pace at which organic carbon is inputted from crop biomass. The SMB has a high turnover rate about the overall amount of soil organic matter and represents the soil's capacity to store and cycle nutrients (C, N, P, and S) and organic matter. MBC and N levels were higher in plots with residue retention than in plots with residue removal, although the differences were not statistically significant. Residue management had a greater impact on microbiological features than the tillage system.

Due to the vertical distribution of organic residues and microbial activity, CA-based tillage increases the enzymatic activities in the soil profile. This positively alters soil enzymes, which are important for energy transfer, environmental quality improvement, and crop productivity. Soil enzymes are also required for the catalysis of reactions necessary for the decomposition of organic matter and the cycling of nutrients. In the 0–15 cm soil layer, zero tillage has higher levels of dehydrogenase and phosphatase than conservation tillage (Samal et al. 2017). Acid phosphatase activities were higher in the organic residue- and zero-tillage combination than in the residue-free condition.

Barriers to the Adoption of Conservation Agriculture

The scientific community and farmers face a huge challenge in the form of the CA to shift perspectives and investigate the potential for managing natural resources. One approach to sustainable agriculture is thought to be the CA. The current requirement is to switch from conventional farming, which decreases soil quality, to resource conservation practices, such as CA.

The following are the constraints which restrict wide-scale adoption of CA:

- The lack of suitable machinery, particularly for small and marginal farmers with small land holdings
- Competition for crop residues between CA practices and animal feeding
- Burning of crop residues: For the timely sowing of the next crop, farmers prefer to sow the crop in time by burning the residue which is becoming a common feature present in the rice-wheat system in North India.
- Knowledge gap about the potential of CA: The whole range of practices being included in CA i.e. planting, harvesting, water and nutrient management, diseases and pest control, etc., need to be properly explained, evolved, evaluated, and matched in the context of new systems to agriculture leaders, extension agents, and farmers.
- Skilled and scientific manpower
- Managing CA systems, the need for enhanced capacity of researchers to face

problems from a systems perspective and to be able to work in close relationships with farmers and other stakeholders.
- Strengthened knowledge and information-sharing mechanisms.

Future prospects

The benefits of CA can be realized across all kinds of agroecosystems since its farming methods represent the direction of sustainable agriculture going forward. The benefits of CA techniques are simple to implement in some situations and geographical areas, but action must be taken to set up awareness and demonstration programs to help farmers improve their skills. The development of locally suited species for crop rotations, cover crops, and seeding tools is necessary to address the issues with plant establishment and the pressures of weeds, pests, and diseases in no-till farming. One of the better ways to address nutrient availability issues is to combine CA practices with appropriate fertilizer application. This approach not only helps to increase plant biomass to increase residue cover and improve soil fertility, but it also helps to create more plant biomass. Crop leftovers that are kept on the surface serve as mulch and can provide an easily decomposable supply of organic matter. They may also harbour pest populations that are undesired or otherwise change the ecology of the system. In the future, CA will concentrate on addressing the technological requirements for Sustainable Intensification. As a result, CA is being recognized more and more as climate-smart agriculture, helping to preserve natural resources while also assisting in the adaptation and mitigation of climate change.

Conclusion

In addition to providing a new paradigm for agricultural research and development that differs from the conventional one, which was primarily focused on meeting predetermined targets for the production of food grains, conservation agriculture also presents a chance to stop and reverse the downward spiral of resource degradation, lower cultivation costs, and improve the efficiency, competitiveness, and sustainability of agriculture through resource use. Because CA systems are well-designed and locally appropriate, they can raise many soils' SOC content and produce notable gains in the physical, chemical, and biological characteristics of the soil to maintain soil health, reduce the effects of weather variability on the soil, and lessen adverse effects on productivity. In general, CA is a strategy that will allow new crops and management techniques to emerge under conservation management plans for sustainable production in the future. Over the long term, continuous use of CA will lead to the improvement of soil structure that will contribute to resilient soil systems that can withstand climate variability. By raising the awareness of experts, financial institutions, and policy advisers, the notion of conservation agriculture in India can be included into several government projects. In several agroecological zones, a CA-based agricultural production system is one option to increase productivity and food security while maintaining and protecting the natural resources.

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