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Conservation Agriculture: A Tool of Sustainable Agriculture and Soil Health

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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.

Sustainable agriculture is a difficult concept to define, since the environmental, social and economic impacts of agriculture are diverse and interact with one another. In general, it can be stated that sustainable crop production systems are those that respect the environment, improve efficiency in the use of resources and promote human well-being. They are those food production practices that integrate ecological, biological, physical and chemical principles, without harming the environment, as opposed to unsuitable agricultural practices.

Soil health refers to the condition of the soil concerning its capacity to sustain biological productivity, enhance environmental quality, and support the well-being of plants and animals. Sustainable agriculture is characterized as a form of farming that can be conducted in a productive and profitable manner without compromising soil health. Soil conservation farming methods prevent soil erosion, thereby preserving water bodies from pollution and sedimentation. Additionally, conservation practices protect bare surfaces from cracking and erosion caused by water, wind, and excessive heat. These efforts contribute to maintaining the integrity of the soil and preventing environmental degradation.

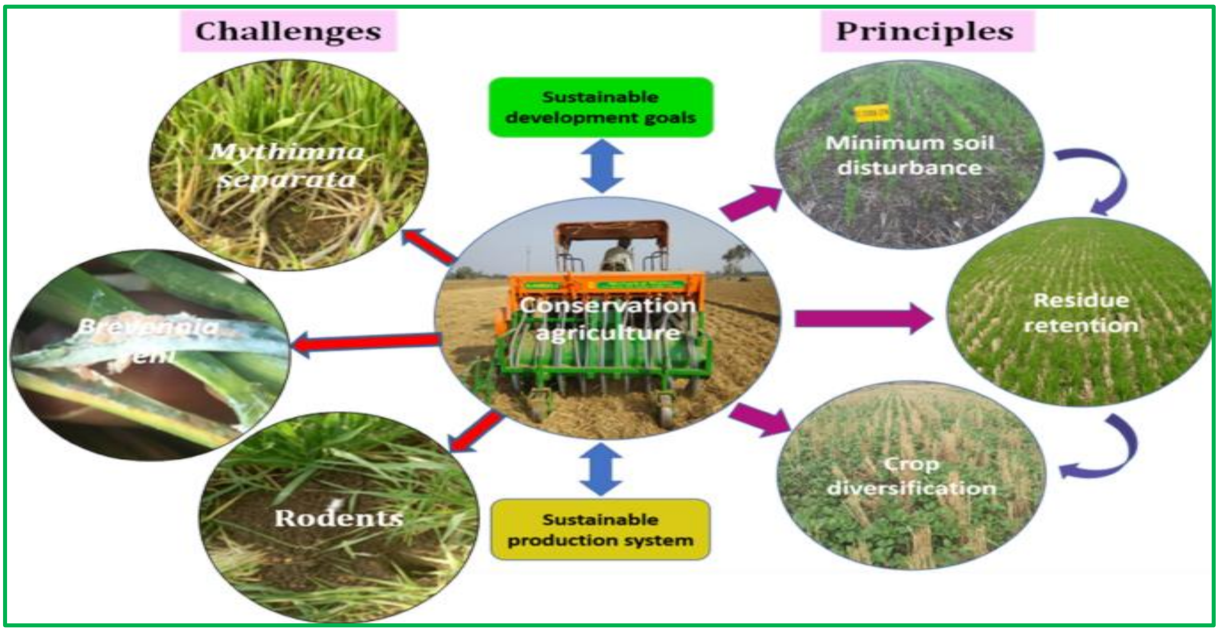
What is Conservation Agriculture?

Conservation agriculture is an agroecosystem management approach that can be considered as one of the main ways to achieve the sustainability of agriculture, allowing the goal of greater protection while protecting the environment. CA emerged in the 1930s in the USA to combat soil degradation due to water and wind erosion. CA is characterized by the application of three interlinked principles implemented with locally adapted practices, together with other complementary agricultural practices. Conservation agriculture is one of the many ways of managing resources on the farm to reduce erosion, build resilient soil systems, and improve productivity.

Principles of Conservation Agriculture

- Minimum mechanical soil disturbance: Minimum soil disturbance refers to low disturbance no-tillage and direct seeding. The disturbed area must be less than 15 cm wide or less than 25% of the cropped area (whichever is lower). There should be no periodic tillage that disturbs a greater area than the aforementioned limits. Strip tillage is allowed if the disturbed area is less than the set limits.

- Permanent soil organic cover: Three categories are distinguished: 30-60%, >60-90% and >90% ground cover, measured immediately after the direct seeding operation. Area with less than 30% cover is not considered as CA.
- Species diversification: Rotation/association should involve at least 3 different crop species.



What is Soil Health?

Soil health is a critical factor for sustainable agricultural production, encompassing the soil's ability to function within ecosystem boundaries. It involves sustaining biological activity, ensuring environmental quality, and supporting plant and animal health. Concepts such as soil health and soil quality are used to refer to this soil capability. The terms soil health and soil quality are often used interchangeably. In fact, the distinction between the two concepts is not clear. "Soil health is the actual capacity of a particular soil to function, contributing to ecosystem services", while "soil quality is the inherent capacity of a particular soil to function, contributing to ecosystem services". Both concepts, soil health and quality, are used to monitor soil status, analyze the influence of soil management on agricultural sustainability, and direct decision making to avoid degradation.

Impact of Conservation Agriculture on Soil Health

(A) Effect on Soil Physical Properties of Soil

Conservation agriculture (CA) has a profound impact on the physical properties of soil, positively influencing key factors that contribute to soil health and sustainability. Conservation agriculture positively impacts the physical properties of soil by promoting good soil structure, reducing erosion, enhancing water retention, mitigating compaction, regulating temperature, and fostering a healthy soil ecosystem. These improvements contribute to sustainable and resilient agricultural systems.

1. **Soil Structure:** CA practices, such as minimal tillage or no-till farming, help preserve soil structure by reducing soil disturbance. Traditional tillage can lead to soil compaction and the breakdown of soil aggregates, negatively affecting water infiltration and root penetration. CA promotes the formation and stability of soil aggregates, contributing to improved aeration and drainage.
2. **Reduced Soil Erosion:**CA mitigates soil erosion by maintaining crop residues on the soil surface. Crop residues act as a protective layer, shielding the soil from the impact of rainfall and preventing surface runoff. This helps retain topsoil and minimizes the loss of valuable nutrients.
3. **Soil Moisture Content:** The presence of crop residues in CA systems improves water-holding capacity. Mulches created by residues reduce evaporation, and their gradual decomposition adds organic matter to the soil, enhancing its ability to retain moisture. This is particularly beneficial in arid and semi-arid regions.
4. **Soil Compaction:** CA practices, such as reduced tillage and cover cropping, help alleviate soil compaction. Continuous tillage can lead to the formation of a plough pan, restricting root growth and water movement. CA reduces the frequency and intensity of soil disturbance, preventing compaction and promoting a more favorable environment for root development.
5. **Temperature:** Mulches formed by crop residues protect the soil surface from extreme temperature variations. This insulation effect helps moderate soil temperature, reducing the risk of overheating during hot periods and preventing excessive cooling in colder conditions. Maintaining a more stable soil temperature benefits microbial activity and overall soil health.
6. **Minimization of Soil Disturbance:** The reduced frequency and intensity of tillage in CA practices minimize soil disturbance. This allows the soil to maintain its natural composition and structure over time, promoting long-term sustainability.

(B) Effect on Soil Chemical Properties

1. **Soil Organic Carbon:** Soil organic matter (SOM) stands as a vital indicator of soil quality, tightly linked to various indicators of soil health. It holds a crucial role in soil fertility and sustainability by enhancing soil aggregate stability, water retention, and serving as a reservoir for essential crop nutrients. Presently, there is a growing emphasis on augmenting Soil Organic Carbon (SOC) in agroecosystems due to its potential to mitigate climate change. Agricultural practices that involve substantial organic inputs, coupled with reduced or no tillage and sustained soil cover, exhibit the capability to increase SOC stocks, functioning as a carbon sink and thereby mitigating the agricultural impact on climate change.
2. **Cation Exchange Capacity:** The cation exchange capacity (CEC) of soil, denoting its capacity to retain and release positive ions, is influenced by its clay and organic matter content and is indicative of soil fertility. Ben Moussa Machraoui et al. observed a positive correlation between SOM and CEC, emphasizing the influence of SOM on CEC. This rise in CEC, facilitated by improvements in SOM through practices like cover cropping, is also associated with increased stability in crop yields.
3. **Nutrient Availability:** Soil organic matter (SOM) is vital for soil fertility, productivity, and sustainability, serving as a key soil quality indicator. Conservation agriculture (CA) practices, such as retaining crop residues as surface mulch, enhance SOM content, nutrient availability, and support crop growth. The management of crop residues influences nutrient-supplying power, affecting plant nutrient availability, particularly nitrogen (N). Although CA increases total N stores, plant-available N may decrease initially, necessitating nitrogen fertilizer applications due to lower N mineralization and higher N immobilization rates. No-tillage practices result in negligible phosphorus and

potassium losses, with higher nutrient concentrations near the soil surface due to P stratification. CA, specifically zero tillage, minimizes P fixation by reducing mixing of fertilizer P with the soil, leading to increased P concentration in the surface soil. Permanent bed planting with residue retention enhances potassium (K) concentrations compared to conservation tillage. However, the effect of crop rotation on K concentrations varies. Conservation tillage may lead to leaching of mineralized nutrients in deeper soil layers, reducing nutrient availability. Chelation of nutrients with organic matter in undisturbed soil enhances soil nutrient status at different depths, contributing to improved soil NPK status.

(C) Effect on Soil Biological Properties

Conservation agriculture (CA), employing no-tillage and residue retention, significantly boosts soil organic carbon accumulation, acting as a vital energy source for microbes. With global food demands soaring due to population growth, the challenge lies in sustainable soil management to enhance food production while preserving biodiversity. Continuous, intensive soil cultivation diminishes microbial diversity, making CA practices pivotal in achieving safe productivity and sustaining soil biodiversity. Changes in tillage, residue, and crop rotation cause substantial shifts in soil flora and fauna, impacting both pests and beneficial organisms Microbial diversity inversely correlates with tillage intensity with soil tillage effects influenced by climate and environmental conditions.

1. **Soil Microbial Biomass:** The soil microbial biomass (SMB) is commonly used to assess soil microbial activity, as this parameter responds quickly to changes in soil management. SMB can be used as an indicator of early changes in cropland management practices. CA creates optimal conditions for microorganisms, with less frequent disturbance of the soil, increased SOM, improved water and thermal conditions, and increased diversity of substrates. Crop diversification can increase soil microbial diversity and activities because the roots of cover crops release exudates in intercropping systems, contributing to greater microbial biomass.
2. **Soil Enzymatic Activities:** The microbial enzymatic activities of the soil serve as an indicator of the potential of the soil to decompose organic C and mineralize nutrients (P and N), and thereby nutrients available for plants. Soil enzymatic functions are greatly influenced by the cropping system and the degree of soil disturbance. The main enzymes used to determine soil health are β-glucosidase, N-acetyl-glucosaminidase, and acid phosphatase, which are responsible for mediating C, N, and P cycling in the soil, respectively. CA practices, such as minimal soil disturbance and residue retention, promote a favorable environment for soil enzymes. Enzymatic activity involved in processes like organic matter decomposition, nutrient mineralization, and carbon cycling is often higher under CA, fostering a more active and diverse enzyme community.

Conclusion

Conservation Agriculture (CA) serves as a sustainable farming system with profound implications for soil health, encompassing physical, chemical, and biological aspects. CA's principles of minimal soil disturbance, permanent soil cover, and species diversification positively impact soil physical properties, promoting good structure, reducing erosion, enhancing water retention, mitigating compaction, regulating temperature, and fostering a healthy soil ecosystem. The effects extend to soil chemical properties, influencing Soil Organic Carbon (SOC), Cation Exchange Capacity (CEC), and nutrient availability, with a focus on mitigating climate change impacts. Additionally, CA practices significantly impact soil biological properties, influencing soil microbial biomass and enzymatic activities, contributing to increased microbial diversity and soil health.

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