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4. Soil Health Management Under Conservation Agriculture

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Abstract:

Soil health is a key issue in agro ecosystems. Conservation agriculture (CA) aims to conserve, improve, and make more efficient use of natural resources through integrated management of available soil, water and biological resources combined with external inputs. CA can be defined as the minimal soil disturbance (no-till) and permanent soil cover (mulch) combined with rotations can be considered as an effective strategy against soil degradation and consequent improvement of soil health and quality. This chapter has made an effort to compile scientific data on how conservation agricultural practices are influencing soil health improvement. Ultimately, it is evident that CA practices positively impact soil microorganisms and microbial processes ascribed to changes in the quantity and quality of plant residues that enter the soil, their spatial distribution, change in the provision of nutrients, and physical alterations. The microbiological activity of the soil is improved by agricultural practices that offer a greater crop diversity, a decrease in mechanical soil disturbance, and/or an increase in organic amendment inputs that are characteristics to CA systems. It is necessary to develop new technologies and tools to guarantee soil's long-term productivity and environmental sustainability in preserving and improving soil health.

Keywords:

Conservation agriculture, Soil health, Soil quality, Long term productivity, Environmental sustainability

4.1 Introduction:

Soil is a natural body comprised of solids (minerals and organic matter), liquid and gases that occurs on land surface occupies space and is characterized by one or both of the following: horizons or layers that are distinguishable from the initial material as a result of additions, losses, transfers and transformations of energy and matter or the ability to support rooted plants in a natural environment. The upper limit of soil is the boundary between soil and air, shallow water live plants or plant materials that that have not begun to decompose, while lower boundary that separates soil from the non-soil underneath is most difficult to define. Soil Consists of the horizons near the earth surface that in contrast to the underlying parent material have been altered by the interaction of climate, relief and living organists over time.

The soil is a living, four-dimensional natural entity containing solids, water (or ice) and air. Most soils are outside and are open systems, but soils also occur in shallow lakes and underneath pavement. A soil can have any colour, any age, be very shallow or deep, and consists mostly of a structured mixture of sand, silt and clay (inorganics), rocks and organic material (dead and alive).

The soil has one or more genetic horizons, is an intrinsic part of the landscape, and changes over time. Soil are distributed across the earth mostly in a systematic manner. Soils store and transform energy and matter. The soil often supports vegetation, carries all terrestrial life, and produces most of our food. It is an integral part of the natural world interacting with the climate, lithosphere and hydrosphere. Soils are often studied in combination with land-use, climate, geomorphology or the hydrology of an area.Soil acts as an interface between environment and agriculture and thus it’s health and quality has a key role in determining environmental quality and agricultural sustainability which jointly determine plant, animal, and human health. Figure 4.1 shows the main functions exerted by soil.

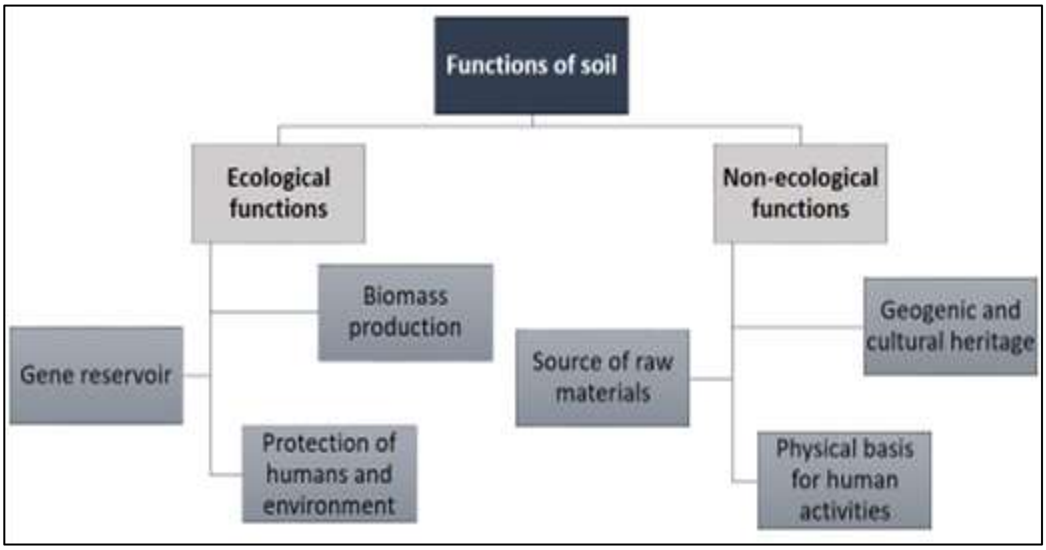

Figure 4.1: Functions of Soil (Blum, 2005)

4.2 Soil Health:

Defining and evaluating the soil quality and health is essential to comprehend soil as a critically important component of biosphere for the production of food and fiber, ecosystems functioning and to maintain local, regional, and global environmental quality. Concepts such as soil health and soil quality has been receiving increasing political and scientific interest in recent times. Soil health has been broadly defined as the capacity of a living soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and promote plant and animal health. The terms soil health and soil quality are often used interchangeably. The potential ability of the soil to sustain biological productivity, improve environmental quality, and promote plant and animal health is referred to as its soil health, while soil quality concerns the capacity of a specific kind of soil to sustain a particular use, such as crop production. There exists an equilibrium between soil function for productivity, environmental quality, and plant and animal health for optimal soil health. The most important criteria for selecting indicators of soil quality and health are their usefulness in defining ecosystem processes and integrating physical, chemical, and biological properties; their sensitivity to management and climatic variations; and their accessibility and utility to agricultural experts, producers, conservationists, and policy makers. Six essential characteristics which are depicted below were considered by [1] as indicators of a healthy soil.

Figure 4.2: Characteristics of Soil Health (Wang and Hooks, 2011)

Apart from these conceptual definitions, operational definitions establish a series of key indicators to evaluate soil health, which can be divided into physical, chemical and biological properties. It is impractical to measure soil health in the field or in a lab; instead, it can only be determined through the measurement of soil indicators. These factors can be measured in the soil and have an impact on ecosystem services and soil function.

No single indicator will give an idea of soil health clearly, so it's necessary to adopt an integrative approach by establishing a minimum data set (MDS) including physical, chemical, and biological parameters of the soil in order to get a more valid idea on soil health. Major criteria adopted while choosing a MDS include, easiness to measure, rapidity, sensitiveness to management, relevance to soil ecosystem functions and informative for management.

Key soil health parameters

Physical indicators	Resistance to penetration
	Aggregation
	Infilteration
	Texture
	Water holding capacity
Chemical indicators	pH
	Electrical conductivity
	Cation exchange capacity
	Bio-availabale nutrient
	Organic carbon
Biological indicators	Microbial activity
	Microbial biomass
	N-Mineralization
	Respiration

Tab. 1. Minimum data set (MDS) for soil health assessments

Figure 4.3: Key Soil Health Parameters (Wang and Hooks, 2011)

4.3 Conservation Agriculture (CA):

The Food and Agriculture Organization (FAO) defines CA as an agro ecosystem management system to ensure food security and improve profits while preserving environmental resources. Conservation agriculture (CA) aims to conserve, improve and make more efficient use of natural resources through integrated management of available soil, water and biological resources combined with external inputs. It contributes to environmental conservation as well as to enhanced and sustained agricultural production. It can also be referred to as resource efficient or resource effective agriculture [2]. A constant or semi-permanent organic soil cover is maintained by conservation agriculture, according to the FAO. This could be dead mulch or a living plant, which physically shield the soil from the sun, rain, wind or other climatic disturbances as well as to provide food for the soil biota. The tillage process and soil nutrient balancing are taken over by the soil microorganisms and soil fauna, where mechanical ploughing interferes with this process. Direct sowing and zero or minimum tillage are crucial components of CA. To prevent disease and pest issues, a diverse crop rotation is also essential.

Adoption of crop rotation to control pest and diseases and practicing zero or minimum tillage along with direct seeding are important elements of CA [2]. Currently, more than 2 billion people struggle with critical micronutrient deficiencies, almost 800 million people lack access to enough food, and roughly 60% of people in developing countries suffer food insecurity.

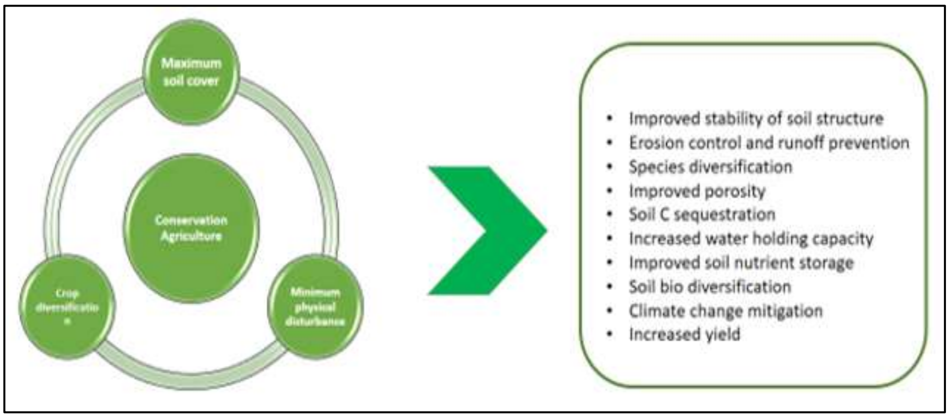

Figure 4.4: Benefits of Conservation Agriculture on Soils

The three primary principals followed in conservation agriculture which are, minimum mechanical disturbance, permanent soil organic cover with crop residues and species diversification (crop rotations, sequences, and associations), can be considered as a classical approach to define CA. The new sustainable agricultural intensification plan developed by the FAO is centered on CA. The fact that CA is more affordable in terms of both money and effort is one of its key benefits, which makes it popular with farmers. Some of the benefits of CA are summarized in fig.3.

4.4 Soil Health Management Under Conservation Agriculture (CA):

Global estimates indicate that 45% of the arable land is affected by degradation. Agricultural, industrial, and commercial pollution, urban expansion, overgrazing, long-term climatic changes, unsustainable agricultural practices viz., conventional tillage, continuous cropping with insufficient inorganic and organic fertilizers inputs and reduced organic matter addition in soil can be considered as the major factors leading to land degradation. Many practices can be adopted to prevent land degradation, which include afforestation, proper management of grazing land, control on mining activities and sustainable agricultural practices. Simple acts such as leaving vegetation on soil to allow nutrients to return into the earth, planting of shelter belts, promotion of crop diversification, agroforestry practices etc. helps in reversing soil degradation in particular.

Conservation agriculture which is defined as the minimal soil disturbance (no-till) and permanent soil cover (mulch) combined with rotations can be considered as an effective strategy against soil degradation and consequent improvement of soil health and quality. CA measures have been proven effective in terms of maintaining major soil functions viz. C cycling and transformation, nutrient cycling, and soil structure maintenance etc.

Contrarily, there is an almost general believe that certain practices of conventional agriculture to increase agricultural production have negative effects on the health of the soil. The total effect of CA systems on soil health is site-specific and depend on climatic conditions. It also depends upon the amount of time operating under a CA system and types of practices involved like types of cover crops, intensity of the crop rotation, etc. Influence of CA on soil health can be broadly classified under three categories:

4.4.1 Influence of CA On Soil Physical Properties:

A. Soil Structure:

Soil structural development can be enhanced by management systems that reduce soil disturbances, increase organic matter inputs, increase plant cover, and improve soil fertility. In this sense, one of the major negative impacts of conventional long-term tillage is the deterioration of the soil structure due to the reduction in soil organic matter. Numerous studies have reported an improvement in the stability of soil aggregates due to the application of CA practices [3].

Higher aggregate stability under CA practices can be summed up in following heads: (i) the retention of organic residue on the soil surface protects soil aggregates from raindrop impact and avoids soil compaction; (ii) organic matter decomposition increases the aggregate formation in soil ; (iii) least soil disturbance in CA enhances fungal populations and the persistence of root networks promote aggregate stability ; and (iv) reduced soil disturbance in CA systems causes a more stable soil structure than in CT systems. These CA-induced improvements in soil structure promote other favourable impacts on the soil, such as higher water infiltration through the soil profile, greater erosion protection, increased water-holding capacity, improved habitats for microbial activity, and so on.

B. Bulk Density:

The bulk density is one of the most common physical parameters to assess the impact of tillage and crop residue on agricultural soils, as it is an indicator of the soil's compaction and reflects the soil's ability to function in terms of structural support, water and solute movement, and soil aeration. The effect of conservation tillage systems (minimum/reduced tillage and no tillage) on the apparent density of the soil is not immediate; it is necessary that a few years elapse from the conversion from CT to reduce it. Some studies have shown that, the deposition of crop residues and soil organic carbon (SOC) on the soil surface in the first few centimetres of NT resulted in a reduced bulk density. Under no-tillage systems, the amount of residue may not always be sufficient to control the increase in bulk density. In these circumstances, the wastes can be shredded, increasing the covered area and reducing soil hardening. In conservation tillage, crop residue assimilation into the soil plays a critical role in lowering bulk density. In this sense, attributed that lowering of bulk density in CA systems is due to the presence of higher amounts of organic matter, which tends to improve soil structure and increase porosity. At 0 to 15 cm depth, the greatest difference compared to CT occurs with 35 years of continuous zero tillage. The bulk density at depths of 15–30 cm decreased linearly over the years of NT. This decrease in bulk density is associated with an increase in total soil porosity.

C. Surface Seal and Soil Crust:

Bare soil in conventional systems leads to increased surface seal and crust formation due to the lack of protection against the impact of raindrops. The impact of rainfall causes the breakdown of soil aggregates and the release of finer particles, which are redistributed by the near-surface and fill the most superficial pores. This process causes sealing and surface waterproofing, decreasing water infiltration and, consequently, enhancing the runoff and soil loss.

The presence of crop residues in CA practices can help protect the surface of the soil from raindrop impact and prevent surface sealing. In structurally unstable soils or regions where crusting is a serious problem, the maintenance of adequate surface cover is paramount to avoid surface sealing and crust formation. Thus, a permanent soil surface cover by crop residues significantly reduces surface sealing. Various studies report on the preventive effect against surface sealing in CA exerted by crop residues on the soil surface, protecting the soil from the direct impact of raindrops.

D. Soil Compaction:

Soil compaction is a form of physical degradation that consists of the densification of the soil, which often results in the destruction of the soil structure; a reduction in biological activity, porosity, and permeability; an increased risk of erosion; a restriction on root development; and, consequently, decreased crop performance. On farmland, the traffic of heavy agricultural machinery is the main cause of soil compaction, and its magnitude increases with the number and intensity of tillage operations and when these are carried out in inappropriate soil moisture conditions.

The influence of the machinery is so important that "controlling in-field traffic" is considered a component of CA. Bed planting, which decreases compaction by limiting traffic to the furrow bottoms, or the application of nutrients during seedbed preparation or seeding to reduce machinery transit, are both recommended techniques. Tillage causes soil compaction and the creation of a plough pan in the subsoil over time. Crop rotation, cover crops, and crop residue addition can all help to alleviate soil compaction in CA systems.

E. Soil Moisture Content:

CA practices improve soil moisture availability, especially under low-rainfall conditions and could contribute to maintaining crop yield in a changing climate scenario. In this sense, several studies have reported a greater availability of water in CA systems with respect to CT.

Residue retention and cover crops in CA systems improve infiltration and reduce runoff rates and evaporation losses, as they protect soil from direct contact with solar radiation and act as a barrier to air flow, contributing to higher soil moisture. In irrigated plantations, crop residues conserve soil moisture and delay irrigation timing, allowing farmers to save irrigation water.

F. Water Runoff and Soil Loss:

Conventional agriculture promotes runoff and soil loss by causing soil compaction, crusting, and surface sealing, and by decreasing porosity. In contrast, CA is associated with a decreased soil erosion. Cover crops and their residues also moderate the velocity of agricultural runoff along the slope, enhancing infiltration and minimising soil erosion.

According to [4] conservation methods reduce surface runoff and erosion by 67 and 80%, respectively, when compared to conventional approaches; cover crops are the most effective at reducing erosion and runoff.

4.4.2 Influence of CA On Soil Chemical Properties:

A. Soil Organic Carbon:

SOM is a keystone indicator of soil quality because it is linked to other physical, chemical, and biological soil quality indicators, playing a crucial role in soil fertility and sustainability. It increases soil aggregate stability and water retention and provides a reservoir of essential nutrients for crops. Increased SOC has a positive influence on soil quality, which can improve soil resilience and contribute to climate change adaption.

The transition from conventional to conservation tillage increases SOC deposition in the soil surface layer. CA improves SOC stock through reducing SOC losses owing to oxidation and erosion, increasing organic carbon inputs to the soil (plant leftovers), or a combination of the two. In an intense cereal-based cropping system in India, long-term CA increased SOC concentration in the 0-5 cm soil layer.

In a study conducted in northern Italy, [5] discovered that CA systems resulted in much higher SOC content and SOC stock in the medium term than traditional systems

B. Soil PH:

Conservation methods have a limited effect on soil pH in the topsoil layers. The effect of crop residues on soil pH is determined by the chemical composition of the residues as well as the soil parameters. Residues high in ash alkalinity and N, such as some legume residues, will have a greater effect on pH compared to residues with lower content, such as wheat.

The initial pH of the soil has a significant impact on the change in soil pH caused by crop residue incorporation because it affects the mineralization of N in the residue and the rate of decomposition of organic components. Many studies discovered that reduced tillage treatments increased acidity in topsoil layers compared to CT.

This rise in acidity is attributable to more soil organic matter accumulating on the soil surface in NT, which decomposes and causes acidity. When the soluble component of the residues flows across the soil profile and contributes to the alkalization of the subsurface layers, there is an increase in pH in the deeper layers.

C. Cation Exchange Capacity:

CA techniques enhance SOM content, which raises CEC by increasing the number of negative charges. Cover cropping practices which promotes organic matter addition has been shown to increase CEC. On the contrary there is chances for reduction of CEC in CA plots under conditions of high litter fall which lowers the soil pH and results in decrease of pH-dependent cation exchange sites.

D. Nutrient Availability:

CA techniques have a major impact on nutrients distribution and transformation in soil, and as a result, they can have a significant impact on soil nutrient dynamics. That is, CA systems that increase organic matter due to residue addition can increase nutrient reserves for plants by registering higher concentrations of nitrogen (N) phosphorus (P) potassium (K) calcium, magnesium, zinc, and manganese in the soil. The composition and management of agricultural leftovers have a substantial impact on soil plant nutrient availability. In the case of N, for example, the addition of legume residues with a low C/N ratio can result in N mineralization, whereas cereal residues with a high C/N ratio can result in N mineralization.

4.4.3 Influence of CA On Soil Biological Properties:

Soil biota, which represents one of the largest reservoirs of biodiversity on earth plays an important role in soil health and sustainable crop production by providing habitat for aboveground and underground biota, regulating climatic factors and water quality, controlling pollution, and supporting food production. CA increases biotic diversity in the soil as a result of the mulch and reduced soil disturbance. Surface mulch helps moderate soil temperatures and moisture, which is favourable for microbial activity. Parameters like the size and activity of the microbial population and soil enzymatic activities are used to gauge how soil microorganisms and biochemical properties respond to soil management techniques. The following are some key considerations for healthy soils: ’ Soil OM formation and the multitude of organisms involved – fauna and flora; ’ Healthy roots and the synergistic associations with biological organisms, e.g. rhizobia, mycorrhiza, and antifungal agents; ’ Soil microbes protect their territory and through microbial competition maintain a balance that stabilizes the population; ’ Some microbes help roots control disease – antifungal agents; ’ Healthy soils have more microbes than unhealthy soils; ’ Mulching helps promote more diversity of microbes through temperature and moisture moderation.

A. Microbial Activity:

Soil microbial biomass (SMB) is commonly used to evaluate soil microbial activity, as it’s a very sensitive parameter to changes in soil microbial activity. So it can be used as an indicator to change in soil management practices. Reduced physical disturbance to soil, increased SOM, favorable water and thermal environments, and a wider array of substrates are all factors that CA employs to produce the most favorable conditions for microorganisms. Release of root exudates and secretions from roots of crops in rotation or intercropping system supports the microbial growth and enhance their activity.

This will enhance the biomass bounded to microbial body and there is an increase in microbial biomass carbon (MBC) in soil under intercropping system compared to monocropped area. A more diverse soil bacterial community can be observed in soils under conservation tillage than soils under conventional tillage practices. Soil tillage is the agronomic practice that most influences soil bacterial diversity, with a greater functional and taxonomic diversity of bacteria in agricultural soils with minimal tillage compared to conventional tillage. Greater microbial diversity has been found in soils with a cereal based cropping system, which indicates the influence of crop system on microbial activity.

The higher C: N ration of cereal straw stimulated the microbial community to break down the organic substrate and promote microbial activity. Exudates released by plants and roots stimulate and maintain particular rhizo-bacterial communities that improve nitrogen fixation, nutrient cycling, pathogen bio-control, plant disease resilience, and plant growth stimulation.

B. 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. [6]

Minimum tillage promotes soil enzymatic activities viz., β-glucosidase, soil urease, dehydrogenase, and total phosphate activities activity due to the augmentation in microbial biomass, more substrate availability, and reduced soil disturbance. Soil enzyme activity were dramatically boosted in a conservation agriculture fields compared to conventionally cultivation plots. When compared to CT, CA methods like zero-tilled flatbed and permanent bed significantly boosts dehydrogenase, alkaline phosphatase, and urease activities resulted from the adoption of minimum tillage which improves -glucosidase activity due to increased microbial biomass, increased substrate availability, and decreased soil disturbance. Ultimately, it is evident that CA practices positively impact soil microorganisms and microbial processes ascribed to changes in the quantity and quality of plant residues that enter the soil, their spatial distribution, changes in the provision of nutrients, and physical alterations.

C. Earthworms:

Earthworms are one of the most significant soil macro faunal groups, and their influence on soil qualities and the availability of resources for other creatures have earned them the moniker "ecosystem engineers". Soil tillage harms earthworms physically and alters their environment, altering the community structure and relative abundance of earthworms. Consequently, the species that live in the topsoil are particularly vulnerable to the effects of ploughing. CA techniques have been observed to be beneficial to earthworms. The rise in earthworm density under no-till systems is due to the combination of several impacts, including reduced injuries, less exposure to predators at the soil surface, reduced microclimate variations, and improved organic matter availability. Agricultural residues left on the soil surface and little soil disturbance improve soil structure, serve as a food source, and lower the soil temperature, allowing earthworm populations to grow. Furthermore, decreasing soil tillage intensity increased functional diversity and the number of anecic earthworms.

D. Soil Respiration:

Soil respiration includes microorganisms oxidising organic materials and rhizosphere respiration. It is a measure of the soil microbial community's metabolic activity. It is one of the most extensively utilised soil biological markers in assessing soil quality. Soil management influences soil microclimate and biotic variables (soil organic carbon, aboveground biomass, root biomass, and plant residues) that influence soil respiration indirectly. Many research studies have reported the effect of conservation agricultural methods on soil microbial respiration, although there are no clear trends, and [7] found no significant differences in soil respiration between conventional tillage and conservation agricultural approaches. This could be because tillage appears to impact the temporal distribution of CO_2 emissions from the soil more than the total amount. The microbiological activity of the soil is improved by agricultural practices that offer a greater crop diversity, a decrease in mechanical soil disturbance, and/or an increase in organic amendment inputs that are characteristics to CA systems.

4.5 Conclusions:

This chapter has made an effort to compile scientific data on how conservation agricultural practices are influencing soil health improvement. In the coming years, crop production will need to use natural resources more effectively in order to create more food on a smaller amount of land while also having little negative environmental impact. Assuring soil's long-term productivity and environmental sustainability is the primary challenge in preserving and improving soil health. As discussed earlier in this chapter, CA systems can be used to improve soil health, reduce erosion, rebuild soil organic matter, support beneficial soil life and encourage the sustainability and multi functionality of agro ecosystems, thereby reducing the socioeconomic and environmental offsets resulting from soil degradation.

However, the promotion of CA technologies is still subject to a number of obstacles, including the lack of suitable seeders, particularly for small and marginal farmers, use of crop residues for livestock feed and fuel, burning of crop residues, the lack of skilled labour, lack of technical and financial support from governments and other related organizations, and more over lack of awareness among farming community. So it is urgent to create a framework of policy and marketing plans to foster CA and its principles. Some of the ways which we can adopt to promote CA practices among farming community include:

Identification of site specific or locally adaptable crop rotation and management practices to deal with agronomic challenges Identification and removal of social, cultural, technological and institutional barriers along with promotion of research studies and improvement in research efficiency of extension services, Availability and supply of machinery and balanced plant nutrition.

Rather than solely depending on conservation agricultural practices, it's necessary to develop new technologies and tools to guarantee soil's long-term productivity and environmental sustainability in preserving and improving soil health.

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