Review Article

Role of Conservation Tillage Practices in Sustainable Agricultural Systems

Abstract

Finding sustainable land management techniques is urgently needed to balance food supply with the growing global population.Nonetheless, the battle to attain food security needs to be waged with consideration for the environment in which life exists and the soil in which crops are cultivated.Conservation agriculture (CA), is the practice of farming in a way that causes the least amount of environmental harm. It is widely supported globally.The primary goal of conservation tillage (CT) is to protect the environment, plant development, and soil health.By minimising soil disturbance, these techniques protect soil structure and stop erosion. CT increases the amount of organic matter in the soil by leaving crop leftovers there, which promotes microbial activity and nutrient cycling. This improves the physico-chemical and biological activity of the soil, which helps to improve soil health and production. Beyond just improving soil health, CT also promotes greater agricultural sustainability and increases resistance to the effects of climate change. Additionally, CT lowers the demand for machinery and fuel, saving farmers money and lowering greenhouse gas emissions.

Keywords:*conservation agriculture, conservation tillage, soil health, crop productivity, environmental sustainability*

1. Introduction

The demands for increased output to meet the needs of the world's expanding population are placing a heavy pressure on concurrent agriculture [1,2].When the global population reaches 9.7 billion in 2050, food and nutritional security will be among the biggest issues [3].The need to identify an environmentally benign and crop yield-sustainable strategy is driven by the rising concern about food security through improved soil management practices. For efficient and environmentally responsible attribution to the ecosystem, research into a sustainable tillage system emerges[4].Consequently, conservation tillage (CA) has become a practical solution to guarantee sustainable food production and preserve environmental integrity, especially when combined with other complementary measures like soil cover and crop diversification [5]. This suggests that one aspect of conservation agriculture (CA) is conservation tillage.Tillage is the term used to describe the mechanical disturbance of soil for crop production, which has a substantial impact on soil properties including temperature, infiltration, and evapotranspiration processes. This implies that tillage intentionally alters the soil in order to grow crops, which has an influence on the ecosystem.

A sustainable production system is seen to be one that incorporates conservation agriculture, which minimises or avoids soil disturbance, together with crop variety and soil cover. CA is a technique for managing agro-ecosystems for better and sustained production, higher profitability, and food security while protecting and improving the environment and resource base, according to Corsi et al.[5]. The three fundamental tenets of CA, they said, are permanent organic soil cover, limited mechanical soil disturbance, and crop diversification (Fig. 1). Any tillage strategy that, after planting, leaves at least 30% of the soil surface covered with crop waste in order to minimise soil erosion by water is considered conservation tillage, according to CTIC [6]. Therefore, in order to achieve future output intensification in a sustainable manner, tillage-based production methods need to be modified.When done in accordance with the principles of conservation agriculture, the conversion from conventional to conservation tillage has the potential to improve soil structure, increase soil organic carbon, reduce the risk of soil erosion, conserve soil water, lessen temperature fluctuations in the soil, improve soil quality, and improve the soil's ability to regulate its environment [7]. Recycled crop residue is a valuable resource. Creating methods for efficiently using this enormous resource is a significant task. Crop wastes should not be removed, burned, or ploughed under since this can contribute to increased erosion, decreased soil fertility, and environmental contamination when burned.

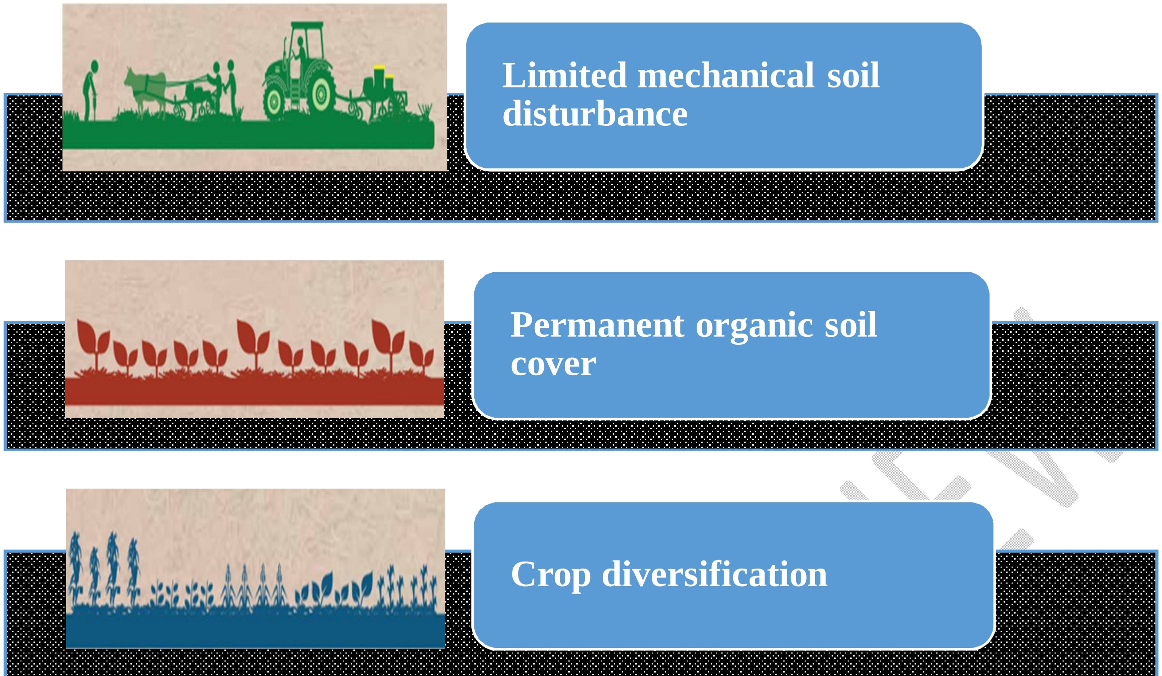

Fig. 1: Principle of Conservation Agriculture (CA)

Conventional tillage techniques used in intensive crop cultivation, which may include deep tillage, can seriously alter the physical and chemical characteristics of the soil. This can have an impact on biogeochemical processes such as increased volatilisation and evaporation, as well as reduce aggregate formation and structural stability [8]. Thus, the implementation of conservation tillage (CT) in conjunction with complementary practices such as crop diversification and soil cover has emerged as a workable plan to advance ecological integrity and food production sustainability [9,10].Thus, the purpose of this review was to explore the effects of conservation tillage on soil, crop, and the overall impact on the environment. This could give farmers and other land users insight into the viability of a conservation tillage system for increasing crop yields sustainably while minimising adverse effects on the environment and soil and achieving agricultural sustainability.

2. Conservation tillage (CT): Types

The many types of conservation tillage techniques include mulch tillage, ridge tillage, contour tillage, reduced (minimum) tillage, and zero tillage (No-till).With minimal tillage, there is less soil manipulation involved in ploughing with primary tillage tools, whereas no tillage (NT) entails cultivating land with little to no disturbance to the soil surface other than during planting.When a soil is prepared or tilled for mulch tillage, plant leftovers or other debris are allowed to cover the surface as much as possible.When the cropping season begins, ridges are prepared, and rows of crops are planted either on top of them or along their sides. This practice is known as ridge tillage. Contour tillage is defined as tillage that is carried out at a right angle to the slope's direction.

3. Conservation tillage (CT) and its effect on soil properties

Although to varying degrees, tillage has an influence on the physical, chemical, and biological aspects of soil (Table 1). Runoff and soil erosion are two additional effects of tillage on the soil ecosystem [11].

Table 1: Impacts of conservation tillage on soil properties

Soil properties	Salient features
Physical	✓ Enhanced hydraulic conductivity ✓ Prevention of soil erosion ✓ Stability in soil aggregation ✓ Increased soil organic carbon (SOC) ✓ Enhanced soil organic matter (SOM) ✓ Improvement in soil pores ✓ Greater infiltration of water ✓ Increased water holding capacity ✓ Enhanced water use efficiency ✓ Reduced soil moisture evaporation
Chemical	✓ Reduced N loss and higher mineralization ✓ Increased N, P, K, Ca and Mg content in soil ✓ Enhanced cation exchange capacity (CEC) ✓ Strengthened relationship between CEC and SOC ✓ Carbon sequestration
Biological	✓ Enhancement of soil macro, meso and micro fauna ✓ Harbouring of beneficial soil microbes ✓ Soil microbes-mediated nutrients cycling, decomposition of

	organic matter, detoxification of pollutants, suppression of diseases, climate regulation, and soil fertility and productivity improvement ✓ Decomposition of organic matter ✓ Enhanced enzymatic activities

3.1 Physical properties

Variability may be seen in the effects of conservation tillage on soil parameters, with particular results depending on the system selected. Significant changes in soil parameters, especially in the top soil, have been noted in ZT systems, which are distinguished by their high soil covering [12,13]. In comparison to conventional tillage-based systems, ZT techniques often result in more favourable soil physical qualities [14,15]. Because ZT techniques increase the amount of organic matter in the soil, soil masses are anchored firmly, preventing soil erosion [16].According to Jacobs et al. [17], CT not only improves stable aggregates but also raises the amount of nitrogen (N) and soil organic carbon (SOC) in aggregates. No-till (NT) agriculture has been found to be especially effective in humid and sub-humid tropical locations when it comes to conserving water [18]. When compared to conventional tillage, minimal tillage improved the soil's pore structure by increasing the amount of elongated transmission holes (50–500 mm) and storage pores (0.5–50 mm). This was due to the retention of organic matter (OM) and the encouragement of aggregation [19].

Shukla et al. [20] found that the protective impact of crop residue on the top soil and the influence of soil organic carbon (SOC) resulted in increased infiltration rates under NT. In addition to keeping crop residue on the soil's surface, CT improves infiltration by facilitating the surface-connected macropores and interpedal spaces. ZT demonstrates increased ET in comparison to traditional tillage. Because of the greater soil moisture in the topsoil and the crop residues on the soil surface, CT has been linked to reduced evaporation, which in turn results in lower soil temperatures. Adopting ZT techniques is acknowledged for its ability to improve agricultural output and growth while preserving soil and water resources [21]. Maintaining surface mulches improves water penetration and lowers evaporative water loss [19].

Additionally, compared to conventional tillage, ZT showed higher volumetric water content and water retention [22].

3.2 Chemical properties

Numerous soil chemical parameters, including as pH, cation exchange capacity (CEC), exchangeable cations, soil organic carbon, and total nitrogen content, can be significantly impacted by tillage techniques [23]. Compared to tilled soil, the soil's surface layer usually has more favourable chemical qualities when the ZT technique is used. The yearly NT causes an increase of organic matter (OM) on the soil's surface, especially in the topsoil. Researchers observed a range of pH values in soil, including unaltered, dropping, and rising pH [24]. Such a difference in soil pH might most likely be caused by a number of variables, including the type of soil, the climate, the incorporation of residue, and the management techniques used.According to Rahman et al. [25], the surface soil of ZT systems had significantly higher exchangeable calcium (Ca), magnesium (Mg), and potassium (K) levels than soil that had been conventionally tilled. ZT is acknowledged as an important strategy in sustainable agriculture for enhancing the connection between CEC and soil organic carbon (SOC), which helps to enhance the physicochemical characteristics of the soil [9].

3.3 Biological parameter

The biological characteristics of soil are significantly impacted by tillage, with the amount of soil organic carbon (SOC) being most significantly impacted [26]. The amount of soil organic matter has a significant impact on SOC dynamics as well as the actions of soil organisms. In addition to being essential to the healthy operation of ecosystems, soil microorganisms are an important factor in determining the quality and health of the soil [27]. ZT techniques have been demonstrated to increase soil microorganism variety and population when compared to conventional tillage [28]. The increasing emphasis on soil conservation is driving the global adoption of zero tillage (ZT) or no-till agricultural systems [19].The population and activity of soil microorganisms are positively impacted by the increased nutrient availability that results from ZT activities.Moreover, ZT techniques cause SOM to build up in the top soil layers, which offers a significant supply of substrates and a home for soil biota [21]. ZT is a sustainable crop management strategy that supports higher biomass and microbiological activity while simultaneously protecting the soil, water, air, and biodiversity [29]. Zero tillage (ZT) often produces soils with improved porosity and increased hydraulic conductivity due to increased biological activity.

Furthermore, a variety of reactions that are critical for microorganisms are regulated by soil enzymes. According to Devi et al. [30], they also oversee processes including soil structure, nitrogen cycling, organic matter (OM) production, and crop residue degradation. Enzymes are involved in the breakdown and storage of organic matter and carbon. The biochemical stability of SOM is improved by the end products of decomposition that remain in the soil because they are extremely resistant to further degradation [31]. The activities of acid phosphatase, alkaline phosphatase, arylsulfatase, amidase, urease, and invertase were shown to be considerably higher in the top soil profile under zero tillage (ZT) techniques compared to traditional tillage methods.Additionally, according to Fernandez et al. [32], this increase increased soil humification, organic matter, and carbon levels. Moreover, in soils in the UK's Eastern Midlands under CT, a noteworthy and favourable correlation has been seen between carbon sequestration and enzyme activity [31]. ZT strengthens the soil's capacity to act as a natural carbon sink, encourages humification, and protects the soil from such disturbances with little to no soil disturbance [33].

4.Conservation tillage (CT) and its effect on crop yield

Physical, chemical, and biological characteristics of the soil are what limit the ability to produce crops in a sustainable manner in the agricultural sector [34,35]. Sustainable crop production greatly depends on land management techniques that both meet the world's food needs and protect the ecological conditions that were previously under stress [36]. Conserving soil health and crop yield can be achieved by implementing conservation tillage techniques, such as residue mulching, straw retention, and no-tillage systems [37,38].The local socioeconomic and environmental circumstances have a significant impact on how agroecosystems react to various soil tillage management techniques [39].Conservation tillage can improve soil physical structure and water storage, protect moisture, and increase crop yield[40].Several kinds of mustard and rapeseed responded significantly to the adoption of zero tillage in terms of growth, yield, and yield characteristics. The variety TS-38 had the greatest harvest index (34.41%), whereas NRCHB-101 had the maximum stover output (1804.45 kg/ha) and seed yield (930.20 kg/ha). According to this research, growing mustard and rapeseed without tillage increases productivity and yield [15].A study by Sadiq and his colleague [41] showed that the plant height, number of spikes per plant, number of seeds per metre square, root yield, aboveground biomass yield, thousand-grain weight, grain yield, and dry matter yield increased significantly when compared to CT when using different conservative tillage systems (CTS, NTS, and NT). This shows the positive effect of conservation tillage suggesting that conservation tillage technique can improve productivity; it would be a sustainable and reliable agronomical practice in spring wheat in the semi-arid Dingxi belt. Further significant maximum agronomic trait values of conservative tillage systems are also reported by Li and his co-workers [42].

5. Conservation tillage (CT) and the environment

5.1 Soil environment

Reduction of runoff, which typically brings leftover agrochemicals and soil sediments with it, is one of the main advantages of conservation tillage [43]. For example, the decrease in runoff that comes with zero-till plots presents a wonderful chance to lessen contamination of surface and even ground water. According to Duiker and Myers [44], there is relatively little risk of surface water pollution under ZT due to the drastic decrease in erosion (runoff) and the speed at which soil organisms, which are often abundant under ZT, break down herbicides into innocuous molecules. Compared to land that has not been ploughed, these agrochemicals are able to go farther than the zone when applied to heavily ploughed soil.Bhatta and Khera [45] observed that in the sub-montaneous tract of Punjab, India, runoff and soil loss were, respectively, 5% and 40% greater under CT than under MT. In order to prevent soil erosion due to wind and water, conservation tillage techniques like NT and MT were created [46,47].

5.2 Greenhouse gas emission

Tillage contributes to global warming by releasing greenhouse gases like carbon dioxide [48]. The primary way that tillage affects the atmosphere is by releasing greenhouse gases into the environment from the soil [46]. According to reports, changes in land use and agriculture, especially deforestation in tropical regions, are responsible for nearly one-third of the world's greenhouse gas emissions and 74% of these emissions come from developing nations [49].According to Tubiello et al. [50], direct emissions from agriculture accounted for 10–12% of greenhouse gas emissions worldwide in 2010. In view of this, the UNEP [51] emission gap study named agriculture as the first of the four industries that effectively reduce greenhouse gas emissions while supporting national objectives. In order for agriculture to properly contribute to the reduction of greenhouse gas emissions, the study placed a strong emphasis on the adoption of no-tillage practices.

Conservation tillage techniques, according to Gambolati et al. [52], reduced the amount of un-mineralized organic matter that was exposed to microbial activities, which in turn reduced CO_2 emissions and SOM breakdown. Tillage practices have been shown to affect other greenhouse gases (GHGs) than C, most notably nitrous oxide (N_2O) and methane (NH_4) [53].One of the benefits of no-till farming has been high carbon sequestration [46] (Lal et al., 2007). A carbon sequestration rate of 367–3667 kg CO_2 ha^{-1} $year^{-1}$ has been reported to result from switching from conventional tillage to no-till [54]. No-till farming might improve carbon fixation.According to Bellarby [55], nitrous oxide from soils accounts for around 38% of emissions to the atmosphere, while methane is regarded as the most potential greenhouse gas after carbon dioxide [56-58] (IPCC, 2001).

6. Conclusion

Conventional tillage disturbs the soil, making it a source of pollution, and is therefore not ecologically friendly or sustainable. Conservation tillage demonstrated its complex effects on soil characteristics, which are essential for the sustainability of agriculture. The main benefits of conservation tillage are the improvement of soil physical, chemical and biological qualities and reduction of soil erosion. Conservation tillage such as (zero tillage or NT) lessens the vulnerability of soil degradation and undergo conservation of soil fauna activity than those that undergo conventional tillage.Increased organic matter content in the soil is encouraged by conservation tillage. Additionally, conservation tillage aids in the improvement of the soil's built-in carbon sink and aids in the sequestration of carbon. In summary, conservation tillage may be said to have a diverse influence on a range of soil qualities, which helps target agricultural sustainability and the achievement of some sustainable development goals.Therefore, conservation tillage techniques are more crucial than ever to achieving sustainable food production with little to no negative impact on the soil and climate.

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