REVIEW ARTICLE

Conservation Tillage: A Sustainable Approach for Carbon Sequestration and Soil Preservation. A Review

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Abstract

Minimum tillage is a soil conservation tillage aimed at minimizing soil disturbance required for productive crop production. Unlike intense tillage, which uses ploughs to alter the soil's structure, this tillage technique does not turn the soil over. Only secondary tillage is used sparingly in minimum tillage, with primary tillage being totally avoided. Practices like minimum furrowing, using organic fertilizer, using biological pest control techniques, and using less pesticides are all included in minimum tillage. Soil erosion and soil degradation have been increased by the use of conventional agricultural techniques, such as extensive tillage centered on the removal of crop residue. Global interest in finding various sustainable ways to lower the concentration of greenhouse gases in the atmosphere has grown in recent years as a result of the gradual increase in their concentration. The amount of carbon stored in soil is 2-4 times greater than that in the atmosphere and four times greater than that in vegetation. In order to prevent or, carbon sequestration (CS) delay dangerous climate change entails storing other forms of carbon or transferring CO2 from the atmosphere into the soil. The potential of soils to store carbon and reduce the accelerated greenhouse effects by implementing various agricultural management strategies is covered in the current review. Conservation tillage techniques improve carbon sequestration in agricultural soils. Conservation tillage can be a practical way to store carbon in the soil and minimize the effects of climate change. Conservation tillage reduced the green house gas. Zero tillage has been identified as the most environmentally friendly tillage practice for the mitigation and adaptation to climate change processes. No-till farming is thought to make it possible to increase crop production sustainably in order to fulfill future agricultural demands.

Keywords: climate change; carbon sequestration; soil conservation; global warming; zero tillage; Soils degradation

Introduction

The growing concern for food security through improved soil management techniques demands identification of an environmentally friendly and crop yield sustainable system of tillage. Tillage is defined as the mechanical manipulation of the soil for the purpose of crop production affecting significantly the soil characteristics such as soil water conservation, soil temperature, infiltration and evapotranspiration processes. This suggests that tillage exerts impact on the soil purposely to produce crop and consequently affects the environment. As world population is increasing so the demand for food is increasing and as such the need to open more lands for crop production arises.

The yearning for yield increases to meet growing demand must be done in a way that soil degradation is minimal and the soil is prepared to serve as a sink rather than a source of atmospheric pollutants. Thus, conservation tillage, along with some complimentary practices such as soil cover and crop diversity (Corsi, Friedrich, Kassam, Pisante, & de Moraes Sà, 2012) has emerged as a viable option to ensure sustainable food production and maintain environmental integrity. This implies that conservation tillage is a component of conservation agriculture (CA).

Conservation Agriculture

define as a method of managing agro-ecosystems for improved and sustained productivity, increased profits and food security while preserving and enhancing the resource base and the environment. They added that minimum mechanical soil disturbance, permanent organic soil cover and crop diversification are the three basic principles of CA (Corsi *et al.*,2012). According to CTIC (2004), conservation tillage is any tillage system that leaves at least 30% of the soil surface covered with crop residue after planting to reduce soil erosion by water. (Lal *et al.*,1990) described conservation tillage as the method of seedbed preparation that includes the presence of residue mulch and an increase in surface roughness as the key criteria. Conservation tillage is an ecological approach to soil surface management and seedbed preparation. Conversion from conventional to conservation tillage, when this is done in line with the principle of CA, may improve soil structure, increase soil organic carbon, minimize soil erosion risks, conserve soil water, decrease fluctuations in soil temperature and enhance soil quality and its environmental regulatory capacity. Crop residue is an important and a renewable resource. Developing techniques for effective utilization of this vast resource is a major challenge. Improper uses of crop residues (e.g. removal, burning or ploughing under) can aid accelerated erosion, soil fertility depletion and environmental pollution through burning. The principle of conservation tillage involves maintenance of surface soil cover through retention of crop residues achievable by practicing zero tillage and minimal mechanical soil disturbance. Retention of crop residue protects the soil from direct impact of raindrops and sunlight while the minimal soil disturbance enhances soil biological activities as well as soil air and water movement. The aim of this review, therefore, was to examine the effects of conservation tillage on soil, crop and the net effect on the environment. This may provide farmers and other land users the information on the desirability of a conservation tillage system for sustainable crop yield increases with minimal negative impact on the soil and the environment.

Types of conservation tillage

Conservation tillage practices range from zero tillage (No-till), reduced (minimum) tillage, mulch tillage, ridge tillage to contour tillage. No tillage (NT) involves land cultivation with little or no soil surface disturbance, the only disturbance being during planting while minimum tillage means reduced level of soil manipulation involving ploughing using primary tillage implements. In mulch tillage, the soil is prepared or tilled in such a way that the plant residues or other materials are left to cover the surface to a maximum extent. Ridge tillage involves planting crops in rows either along both sides or on top of the ridges which are prepared at the commencement of the cropping season. When tillage is at right angles to the direction of the slope it is referred to as contour tillage. Table 1. Differences between conservation tillage and conventional tillage (Shahane et al., 2021)

Table 1. Differences between conservation tillage and conventional tillage (Shahane et al., 2021)

S.No.	Particulars	Conventional Tillage	Conservation Tillage
1	Soil health	Poor/degraded	Healthy soil
2	Tillage System	High Intensity plough based tillage system	Minimal tillage or zero tillage
3	Energy requirement	higher	Lower
4	Fallowing System	Ideal fallow land without any crop cover on soil surface	Growing of cover crops
5	sustainability	lower	Higher
6	Residue Management	Complete removal or burning of crop residue	Maintaining 30% soil surface covered with residues
7	Foot print on natural resources	Higher	Lower
8	Nutrient Management	Chemical based nutrient management or intensive use of chemical fertilizers	Integrated nutrient management with inclusion of organic sources and microbial inoculations
9	Fallowing System	Ideal fallow land without any crop cover on soil surface	Growing of cover crops

Conservation tillage and soil properties

Tillage impact is noticeable on soil physical, chemical and biological properties though in different magnitudes. Tillage impact also includes the effect on the soil environment in the form of runoff and soil erosion (Bhatt & Khera, 2006).

Soil physical properties

The effects of conservation tillage on soil properties are variable and depend on the specific system implemented. No-till (NT) systems, which maintain high soil coverage, have shown significant changes in soil properties, particularly in the upper few centimeters (Anikwe & Ubochi, 2007). Lal (1997a) suggests that soil physical properties generally favor no-till systems over traditional tillage-based systems. Many researchers have observed that NT improves both saturated and unsaturated hydraulic conductivity due to the continuity of pores (Benjamin, 1993) or flow through larger pores (Allmaras, Rickman, Ekin, & Kimball, 1977). Well-drained soils with lighter to medium textures and low humus content are particularly responsive to conservation tillage, especially no-till (Butorac, 1994).

NT technologies, according to Lal, Reicosky, and Hanson (2007), effectively reduce soil and crop residue disturbance, moderate soil evaporation, and minimize erosion losses. No-till soils also tend to exhibit more stable aggregates in the upper surface, resulting in higher total porosity. In a long-term experiment in Gottingen, Germany, Jacobs, Rauber, and Ludwig (2009) found that minimum tillage (MT) increased aggregate stability and concentrations of soil organic carbon (SOC) and nitrogen (N) in the upper 5-8 cm depth after several decades of tillage treatments.

In terms of water conservation, NT has shown greater effectiveness in humid and sub-humid tropics. Kargas, Kerkides, and Poulovassilis (2012) found that untilled plots retain more water compared to tilled plots. Minimum tillage has been reported to improve the soil pore system, increasing storage pores and elongated transmission pores (Pagliai, Vignozzi, & Pellegrini, 2004). Higher water holding capacity and moisture content have also been observed in the topsoil under NT compared to conventional ploughing (McVay et al., 2006). Therefore, replacing traditional tillage with conservation tillage has been proposed by many researchers to improve soil water storage and increase water use efficiency (WUE) (Fabrizzi et al., 2005, Silburn et al., 2007). Reduced tillage systems, including NT, have been found to result in greater water use efficiency compared to traditional tillage (McVay et al., 2006; Li, Huang, & Zhang, 2005). A study by Su et al. (2007) demonstrated that soil water storage and WUE were significantly higher in zero-tillage (ZT) than in conventional tillage (CT) over a six-year period.

In a study conducted in southwestern Nigeria, Busari and Salako (2012) observed higher unsaturated water flow parameters and infiltration rates under CT and MT than under ZT during the first year, but ZT showed higher infiltration parameters compared to CT by the end of the second year. This is because CT initially created fast-draining macro-pores (FDP) that facilitated infiltration, but these FDP decreased over time due to soil aggregate repackaging (Martínez, Fuentes, Silva, Valle, & Acevedo, 2008), resulting in lower infiltration rates under CT in the long term. Other studies (Pikul and Aase, 1995; Shukla et al., 2003) have also found higher infiltration rates under NT due to the protective effect of surface residue and the influence of SOC.

Additionally, less intense tillage practices not only preserve crop residue at the soil surface but also increase the activity of surface-feeding earthworms, creating numerous surface-connected macro-pores and inter-pedal voids, leading to higher rates of infiltration (Kemper, Trout, Segeren, & Bullock, 1987).

Aims and Objectives

1. To investigate the conservation agriculture is improve plant growth and soil health.
2. To discusses the potential of soils in sequestering carbon and mitigating the accelerated greenhouse effects by adopting different agricultural management practices.
3. To Investigate soils degradation soil degradation cause

Major Causes and Factors Affecting Soil Organic Carbon Depletion

The soil organic carbon pool is being quickly depleted as natural habitats give way to farmed ones. The amount of soil organic carbon pool depletion is 25–50% over 20–50 years in temperate temperature zones and 50–75% over 5–20 years in tropical climate zones after deforestation (Lal et al., 2004). When the C inputs in managed ecosystems (via crop residue retention, combined with the application of other biosolids) are greater than the outputs, the degree of depletion is minimal. The latter includes soil organic carbon losses due to leaching, mineralization, and increased erosion (caused by humans removing natural vegetation). By moving organic carbon-rich sediment from an agricultural land unit and surface runoff, agricultural soil erosion has been shown to disturb the global carbon cycle (Olson et al., 2016; Lal et al., 2009). Additionally, it has been noted that the emission of CO_2 and the depletion of the source of soil organic carbon are positively correlated (Navarro-Pedreño et al., 2021). According to reports, the loss of the soil organic carbon pool has a negative effect on soil quality and the equilibrium of nutrients and elements. Through runoff losses and high evaporation rates, it also affects the equilibrium of soil water and can cause a significant decline in soil biodiversity, including the activity of soil microbes. (Lal et al., 2004). asserts that deteriorating soil quality has a detrimental impact on net primary productivity and reduces the quantity and quality of plant biomass produced, leading to a significant depletion of the soil organic carbon pool.

Management of Soil Organic Carbon

The process of moving atmospheric carbon dioxide into the soil's C pool via humifying agricultural waste and other organic soil components (such biosolids), which are not quickly released back into the atmosphere, is known as soil organic carbon sequestration (Olson et al., 2014). The main determinants of soil organic carbon sequestration are an increase in soil organic carbon content, its management through soil-based and crop-based management, applied by the use of C-enriched material (including mulches and biochar) prudent use of land resources and organic fertilizers. Low carbon agriculture is referred to as a sustainable method for reducing the effects of global warming, enhancing crop yields, and conserving the environment. Low-C agriculture practices are characterized by low GHG (including carbon dioxide) emissions and high soil organic carbon and vegetation storage. Utilizing best management practices to safeguard the environment, natural resources, and eventually crop productivity is the strategy's main objective. It is one of the best methods for reducing GHG emissions Zhang et al., 2017; Lal et al., 2018; De Gouvello et al., 2010; Gebara et al.,2013; de Magalhães et al., 2014). Table 2. Function of Soil organic Carbon (Shahane *et al.*, 2021)

Table 2. Function of Soil organic Carbon (Shahane *et al.*, 2021)

Plant	**Improvement**	**Soil Maintenance**	**Reduce**	**Ecosystem**
Increase in duration of shifting cultivation area available for cultivation	Enhanced the decomposition of soil pollutants Microbial population and diversity Biogeochemical cycling of nutirents	N/A	N/A	N/A
Crop Yield Improvement	Agregate Stability	Temperature	Bulk Density	Increase in Carbon Sequestration
Sustainability in Production System	Cation Exhanage Capacity and base saturation	PH	Soil crusting and compaction	N/A
Quality improvement	Porosity	Soil Consistence	Erodibility and Erosion	Reduce greenhouse gas emission
Enhance resource and use efficiency	Infilitration	Air Circulation	Accumulation of toxic Material	Prevent station of tanks and enhance and their storage capacity and life
Profitability enhancement	Chelation of Micronutrients	Optium soil moisture	Reduce the leaching loss of nutrients	N/A
Reduced bioaccumulation of soil pollutants in the plants products	Water and nutrient retention capacity	Desirable soil structure spheriodal granular and crumby structure	N/A	N/A

Mechanism of Soil C Sequestration

The three main processes that lead to soil carbon sequestration are the formation of soil microaggregates, the soil's long-term stability, and the enhancement of soil structure through the deep insertion of SOC in the subsoil layers Lal et al., 1997; Tisdall et al.,1982 Six Bossuyt et al.,2000). The stability of macro-aggregates might protect soil organic matter (OM) from microbial activity. The concentration of clay and mineralogy have a major impact on aggregation. Furthermore, a positive relationship between aggregate size and total soil organic carbon content was shown by Beare *et al.,*1994; Puget *et al.,* 2005). The way biomass C humifies is also influenced by soil properties, tillage practices, climate, and soil nutrient availability. The humidification efficiency of biomass C is lower in warm, dry regions compared to cold, humid conditions. In addition, large surface area clayey soils perform better in terms of humification efficiency than coarse-textured soils. The no-till farming method had a positive effect on the effectiveness of humification. (Puget et al.,2005) found that 8.3% of the total carbon in crop residue for plow-tillage crops and 11.9% for no-till practices was converted to sulfur dioxide soil organic carbon in maize crops grown in Coshocton, Ohio. In a separate study, (Allmaras et al.,2004) discovered that humification was 26% more successful for no-till soils than it was for traditional tillage methods like using moldboard plows and chisels, which were reported to be 11% more effective. The availability of soil components such as N, P, S, Zn, and Cu affects the efficiency of humification because C is the main component of humus. (Himes et al., 2018). found that 28 mg of carbon in 62 mg of oven-dry residue is needed to store the 10 mg of carbon in crop residue into 17.241 mg of humus. It also requires 143 kg S, 200 kg P, and 833 kg N, according to the writers. Consequently, for the leftover C to be humified, essential nutrients like Nitrogen, Phosphrous, and Sulfur must be present. Regarding this, (Jacinthe et al., 2002).found that residue-C conversion into soil organic carbon for Luvisol in central Ohio was 32% when fertilizer treatment was applied, compared to 14% when it wasn't. Under the mulched soils, comparable soil organic carbon stocks (25.6 Mg C ha 1) have been identified, both with and without fertilizer treatment. Nevertheless, additional SOC deposition only occurs in regions where more fertilizer was applied when mulching material is employed. The no-till approach does not greatly increase the soil organic carbon pool in the absence of adequate fertilizer (Campbell et al., 2001). The amount of SOC sequestered is significantly influenced by the rates and locations of N fertilizer application Gregorich et al., 1995; Wanniarachchi et al., 1999; Murungu et al., 2011). The illuviation and translocation of C into the subsurface layers is another important mechanism. The results of the bioturbation generated by earthworms, termites, and the deep root system are climate changes and the translocation of deep C away from the anthropogenic zone (Lavelle et al., 1989; Lorenz et al., 2005).

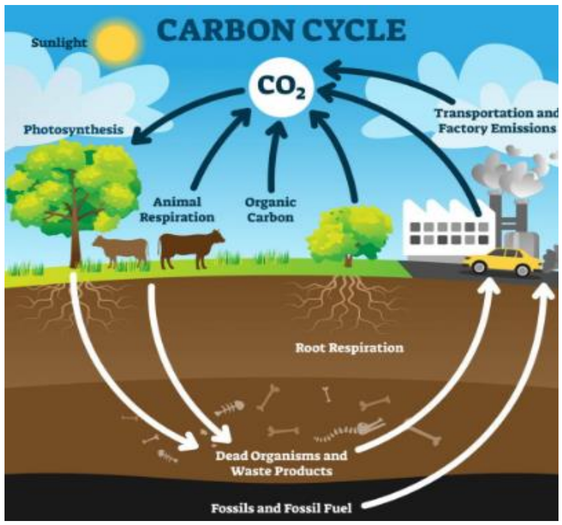

Figure 1. Sequestering Carbon in Soils to Reduce Climate Change

Conventional Tillage and Soil Carbon Stocks (CS)

Developing a soil environment that is favourable to improved plant growth and development is the primary goal of any tillage technique. One of the key elements determining soil C stocks is tillage. SOM is significantly reduced as a result of the aggressive tillage techniques. While ground cover removal exposes the organic-rich topsoil layers to wind and water erosion, tillage exposes soils to air, which promotes SOM decomposition by soil bacteria (Wani et al., 2016). Moreover, soil microbial activity and the holes left by plant roots are disturbed by intensive tillage techniques. The SOM is rapidly degraded and lost as a result of the fast-mechanical cultivation; the SOM gets protected within the soil aggregates. Tillage techniques also cause the soil aggregates to break down, increasing the amount of oxygen available and the surface area that organic material is exposed to.

Physiochemical Properties of Conventional Tillage Practices

Poor Infiltration and excess runoff. Deep layers compaction and structure disability. Nutrient loss and reduced CEC. Salainization and acidification.

Biological Properties of Convential Tillage Practices

Reduced diversity of soil organisms. Reduced enzymatic activity and affect nutrient cycling. Reduced number of plants associated microorganisms. (Hussain et al.,2021)

Conservation Agriculture and NT for SOC

A different approach to increasing agricultural output in a sustainable way has been mentioned: the conservation agriculture (CA) system. In agricultural environments, this technique is widely thought to increase infiltration rates, lessen erosion problems and improve soil quality and organic C levels (Kahlon et al., 2013). According to a different study by (Prasad et al., 2016). conservation agriculture lessens the problems with soil degradation associated with rainfed agriculture. Conservation agriculture includes crop mulching, proper crop rotation, and no-till farming, which involves less soil disturbance. (Somasundaram et al., 2020). Conservation agriculture, in contrast to traditional agriculture operations, primarily aims to maximize yields at the expense of the environment. (Dumanski et al., 2006) state that conservation agriculture involves the supply of modern agricultural technology to improve crop production and maintain the health and integrity of the eco-system. The FAO recognized that the CA system lessens the negative effects of climate change, improves sustainable land management, and improves crop productivity without endangering the environment. (Pisante et al., 2015; Pisante et al., 2012). Over the past few years, Californian agriculture (CA) has been more well-known because of its many advantages, which include improved soil fertility and water retention, long-term sustainable productivity, and the reduction of climate change (González-Sánchez et al., 2012; Palm et al., 2014; Busari et al., 2015). Contrary to traditional systems, conservation agricultural methods in highland crop production systems enhance soil water and nutrient status, residual water content, soil infiltration rate, and organic carbon content (Thierfelder et al., 2009; Ella et al., 2016). Three fundamental ideas underlying CA: minimizing soil disturbance through no-till practices, keeping soil cover with mulching, and modifying crop rotation and intercropping techniques. Using woody crops to increase yields in low-fertility soils without impacting the environment was also suggested by several researchers (Assessment et al., 2015). Based on integrated nutrient management, (Lal et al., 1990).

Conservation Tillage Enhanced the Biodiversity

In addition to reducing soil and nutrient erosion, conservation tillage techniques like RT and ZT improve soil microflora and faunal variety, SOC, and related soil characteristics (Das et al., 2019; Raj et al., 2022).

Soil Degradation

When a land-use system's potential productivity becomes detrimental and the land is unable to fulfill its environmental regulatory roles of absorbing, storing, and recycling nutrients, water, and energy, this is referred to as land degradation (Oldeman et al., 1992). Once more, the measured loss or decline of a soil's present or showed ability to yield plant materials of the right amount and quality is commonly referred to as soil degradation. Some scholars Blaikie et al., 2015;Chisholm et al., 1987;Blum et al., 2004).Contend that the phrase "land degradation" is more inclusive than "soil degradation." However, as land and soil are alike in the majority of soil management literature, the terms land degradation and soil degradation will be used synonymously in the parts that follow. Soil degradation is caused by a number of chemical, physical, and biological processes Lal et al., 2020; Eswaran et al., 2001). Crusting, hard setting, Deterioration of soil structure desertification, erosion, are some of the physical processes. fertility loss, Leaching, salinization, acidification and pollution are some of the chemical processes. The decrease in soil biodiversity and the depletion of carbon are two examples of the biological processes causing soil deterioration. A difference between land quality and land usage causes land deterioration, claims (Beinroth et al., 1994). In certain root-restrictive shallow soils in West Africa, yield decreases of 30–90% due to erosion have been reported by (Mbagwu et al., 1984; Lal et al., 1987). In Ohio and other Midwestern USA states, erosion decreased row crop yields by 20–40% (Fahnestock et al., 1996). In the Colombian Andes, (Schumacher et al., 1994)have noted significant losses on certain sites as a result of rapid erosion. Soil erosion and desertification have caused a 50% decrease in the production of some African farms (Dregne, 1990). Due to historical soil erosion, Africa's yield decline can vary from 2 to 40%, with a mean loss of 8.2% across the continent (Ruppenthal et al., 1995). Furthermore, Asia, which includes China, India, Israel, Iran, Lebanon, Jordan and Pakistan, Nepal, has significant productivity losses (20%) as a result of erosion (Lal *et al.*, 1995).Over a seven-year period, agricultural product decreases in 20% for soybeans, Ohio are 25% for maize and 30% for oats. (Lal *et al.*, 1996). Table 3. Impacts of soil deterioration on crop output and growth. (Shahane et al., 2021). Table 4. Characteristics of healthy soil(Shahane et al., 2021)

Table 3. Impacts of soil deterioration on crop output and growth. (Shahane et al., 2021)

S.No.	Crop	Soil degradation related problem	effect	Correction measure suggested
1	Wheat	Salinity due to irrigation water	decrease in wheat growth parameters, harvest index, and grain and straw yields as irrigation water's electric conductivity rises from 0.7 to 12 dS m−1	When Azospirillum sp. isolated from saline soil is used, wheat grain yield significantly increases over control.
2	Rice bean	Soil acidity	Soil acidity reduced crop growth and yield as well as	Utilizing lime at a rate of 0.6 t ha−1 improves all growth and yield

			economic metrics (gross and net return, B:C ratio, production efficiency, and economic efficiency).	characteristics, leading to an increase in yield of 0.42 t ha−1, or 221.31 and 164.34 US dollars in gross and net returns ha−1, respectively.
3	Rice	Acidity of soil (acid sulfate soil) and aluminum toxicity	decrease in rice output brought on by more aluminum toxicity and acidity in the soil; decreased availability of exchangeable cations (Ca, Mg, and K)	Positive effect of addition of amendments such as magnesium limestone, sugarcane based organic fertilizers and fused magnesium phosphate
4	Chickpea	Sensitivity of sodium salt (sodium chloride)	The rise in sodium chloride concentration has a considerable impact on vegetative and reproductive growth, or the quantity of flower buds and pods; the crop's podding stage was shown to be the most vulnerable.	N/A
5	Garden Pea	Acidic soil	Acidity of the soil has a negative impact on garden pea development and soil characteristics	Application of corn or lantana camera biochar (@ 6 to 18 t ha−1) had a positive impact on crop growth metrics. Improvements in the soil's total nitrogen, accessible

				phosphorus, potassium concentration, and porosity following crop harvest.
6	Pea	Acidity of soil	N/A	Lime application at 7.5 t ha−1 increased grain yield and dry matter production by 0.50–0.55 t ha−1 and 1.37–1.72 t ha−1, respectively.
7	Wheat	Waterlogging	After 21 days of sowing, waterlogging for 15 days lowers wheat yields in neutral soil (pH of 7.0), salty soil (pH of 8.2), acidic soil (pH of 9.0), and sodic soil (pH of 9.4).	N/A
8	Rice	Saline sodic soil	Saline sodic soil's detrimental effects on plant growth and yield	Rice growth and yield parameters were significantly improved by the use of gypsum at 9.5 t ha−1 and irrigation spaced four days apart. There was also a considerable increase in rice grain and straw yield.
9	French Bean	Chemical degradation (nutrient deficiency) in acidic soil	reduced growth and yield characteristics as a result of infertile soil	Growth and yield attributes improved as a result of applying three primary nutrients at the

		appropriate rate in addition to boron.

Table 4. Characteristics of healthy soil(Shahane et al., 2021)

S. No	Attributes	Description
1	Resilience	Healthy soils can bounce back fast from adverse events like compaction.
2	Important function of healthy soil	Carbon cycles, nutrient cycles, preservation of soil structure, control of pests and diseases
3	Resistance to being degraded	Good tilth, internal drainage, low plant parasite populations, and these characteristics help soils resist the damaging impacts of compaction and wet durations.
4	Sufficient supply of nutrients although	For plants to flourish, there must be a sufficient supply of nutrients; at the end of the growing season, there shouldn't be an excessive amount of phosphorous and nitrogen left in highly soluble forms or enriching the soil's surface. The most likely times for fertilizer leaching and runoff are after crops are harvested and before the next crops are well-established.
5	Good soil tilth	Compared to soil with poor tilth, excellent tilth soil is less compacted, spongier, and allows roots to grow more fully. Water infiltration and storage for plant use later on is additionally supported by a soil with a stable and beneficial soil structure.
6	No chemicals that harm plants	Naturally occurring hazardous substances can include excess salts in arid areas or soluble aluminum in acidic soils. Human activity can introduce potentially dangerous chemicals through the application of sewage sludge containing high concentrations of toxic components or fuel-oil spills.
7	Low weed pressure	It is crucial to have minimal weeds so that the crop has less competition for nutrients, water, and light.
8	Sufficient depth	Full root system growth is supported by soils that are deep enough to contain a layer that can impede drainage and/or root development.
9	Good internal drainage	Soils that dry up rapidly can benefit from timely field operations. Additionally, for the best possible root health, oxygen needs to be able to enter the root zone, and proper drainage makes this possible.
10	high numbers of microbes that promote plant growth	Earthworms and a variety of bacteria, fungus, and actinomycetes are examples of organisms that aid in the cycling of nutrients and make them available to plants. Also, soil organisms generate compounds that stimulate plant growth.

Causes of Soil Degradation

Both natural and man-made factors can lead to soil degradation. Natural reasons include topographic and climatic elements like, frequent floods and tornadoes, steep slopes ,storms and strong winds, leaching in humid areas, intense rains and drought in arid areas. Anthropogenic causes of soil degradation include overextraction of ground water, shifting farming, desurfacing of the soil, excessive grazing, indiscriminate use of agrochemicals, and deforestation and overexploitation of vegetation.

Types of Soil Degradation

In 1991, ISRIC, in collaboration with FAO and UNEP, released a global map showing the state of soil degradation caused by human activity. A generic classification known as the GLASOD classification was created in advance of the map., Water erosion chemical deterioration, wind erosion, physical deterioration, and loss of biological activity are the five primary kinds of soil degradation, according to (Global Assessment of Soil Deterioration) (Oldeman *et al.*, 1992). Every type has multiple subtypes, with the exception of biological deterioration. The following lists these varieties and subtypes. Table 5. Soil degradation types and subtypes.

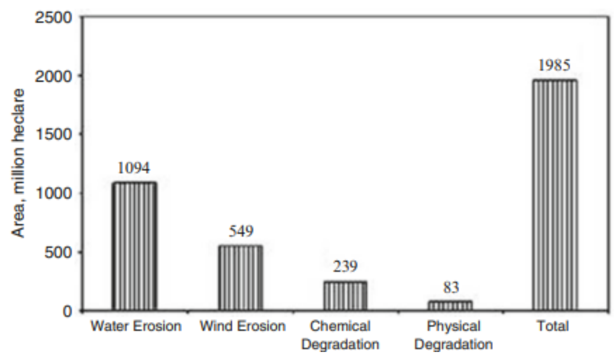

Figure 2. Land area so far degraded by different processes (Data) (Lal et al., 1996)

Table 5. Soil degradation types and subtypes

Type	Subtypes
Water Erosion	Loss topsoil
	Terrain deformation/mass movement
	site effect
	Reservior sedimentation
	Flooding
	Sea weed destruction
Wind Erosion	Loss topsoil
	Terrain deformation
	Overblowing
Chemical deterioration	Loss of Nutrient and organic matter
	Salination
	Acidification

	Eutrification
Physical deterioration	Compaction,sealing, and crusting Water Logging Lowering of water table Subsidence of organic soils

Extent of Soil Degradation

Approximately 38% of the planet's agricultural land have been deemed degraded. Africa has 65% of degraded territory, Central America has 74%, and South America has 45%. There is a significantly lower percentage of damaged grassland and forests—21% and 18%, respectively. If we simply take into account land that has been utilized (forests, permanent pasture, and agricultural areas), the percentage of degraded land is 14% and the percentage of severely degraded land is 23%. The area impacted by human-induced soil degradation was judged to be mildly deteriorated in 38% of the cases (749 M ha), moderately degraded in 46% of cases (910 M ha), strongly degraded in 15% of cases (296 M ha), and extremely degraded in fewer than 1% of cases (9.3 M ha) (Lal et al., 1996) In Asia, nutrient imbalances in the soil, overfertilization, pollution, and soil loss processes have a negative impact on soil health and quality.

The soil's organic stuff is deteriorating daily. With the growth in the nation's population over the past few decades, it has grown increasingly intense. On Earth, 25% of all species are found in soil. Table 6. Indicators of soil health and their measurements (Shahane et al., 2021)

Table 6. Indicators of soil health and their measurements (Shahane et al., 2021)

Soil health indicator	Unit of measurement	Ideal values for health soil indicators (agricultural soil) and Method
Texture	tweleve classes based on the relative proportion of sand, clay and silt	For most crops, a soil texture of 7–27% clay, 28–50% silt, and 23–52% sand is thought to be optimal. (Bouyoucos hydrometer method andInternational pipette method)
Bulky density	Mg m−3 or Gram cm−3	1.33-1.35 g cm−3 (Direct and indirect methods)
Penetration resistance	MegaPascal (MPa); N m−2 (cone index N cm−2)	N/A Cone penitromete)
Aggregate stability	Mean weight diameter (mm); Geometric mean diameter (mm)	N/A (Wet sieving and dry sieving method)
Water holding capacity	mm m−1 depth of soil	Crops specific (Pressure plate and membrane apparatus)
Infiltration rate	mm hour−1	N/A (Ring infiltrometer)
Depth of hardpan	Indicated as depth from the surface at which hardpan observe	Based on the effective root zone depth and characteristics of plant (Determined by compaction of soil at different layers)

Depth ofwater table	Depth from the surface in meters	N/A (Paizometer and open well)
Porosity	Percentage%	50% of the total soil volume (Mercury intrusion porosimetry; Image analysis and soil micromorphology)
Erosive potential	Mg ha−1 soil lossyear−1	≤ 11 Mg ha−1 soil loss/year (permissible limit) (Universal soil loss equation)
Soil Structure	Expressed as types (Platy, prismatic, blocky and spheroidal),class (Very fine, fine/thin, medium, coarse/thick and very course) and grade (structureless, weak, moderate and strong)	N/A
Soil crust	Qualitative property indicated by either types of crust or by surface hardness measured by cone penitrometer	Soil should be crust free as all crust has adverse from cultivation point of view except soil biological crust in some cases (Optical and scanning electron microscopy)
PH	In scale of 1–14	Neutral (6.7–7.3) pH for most of the crops and soil functioning is considered as ideal
Electrical conductivity	dS m−1	N/A (Saturation soil extract or soil-water suspension)
Minor nutrients Maganese Copper zinc Boron	2.0 mg kg−1 soil Zinc (Zn) 0.6 mg kg−1 soil Copper (Cu) 0.2 mg kg−1 soil Boron (B) mg kg−1 0.5 mg kg−1 soil	N/A
Urease Enzyme	N/A	Soil incubation in tri(hydroxymethyl) aminomethane buffer
Microbial biomass carbon	(µg microbial biomass carbon g−1 soil)	N/A (Fumigation method)

Results

Important conclusions on conservation tillage's effects on soil preservation and carbon sequestration can be gathered from a survey of the research.

Conservation tillage techniques improve carbon sequestration in agricultural soils

It is well known that conservation tillage, a commonly used agricultural technique, protects soil resources by increasing soil organic carbon (SOC) (Zhu *et al.*, 2022).

(Lal *et al.*, 1997) one of the information collected the two main ways that conservation tillage sequesters carbon are by deep storing SOC in the subsoil horizons and promoting micro-aggregation. Increased biomass output through conservation tillage and related agricultural methods (e.g., soil fertility enhancement, improved crops and species, cover crops and fallowing, improved pastures and deep-rooted crops) are also beneficial.
(Haddaway *et al.*, 2017) reported conservation tillage, such as decreased fuel usage and erosion, there are also negative effects, such as N2O etc.
(Hussain *et al.*,2021) It has been suggested that the main goal of conservation agriculture is to enhance soil health and plant development without causing adverse effects on the environment.
(Francaviglia *et al.*, 2023) studied By improving soil organic carbon (SOC) sequestration in soils and its associated co-benefits, sustainable agricultural practices—such as reducing tillage, cultivating cover crops, and in place crop residue retention measures—have been suggested as low-cost solutions that can address land degradation, food security, and climate change mitigation and adaptation. Accordingly, a great deal of research has shown that conservation agriculture (CA) enhances the biological, chemical, and physical features of soil, all of which are essential for preserving soil health and improving the adaptability of agroecosystems to climate change.
as numerous studies have repeatedly shown. The fundamental reason for this is the decrease in soil disturbance, which promotes a favorable environment for carbon storage and aids in maintaining organic matter levels.

Conservation tillage can be a practical way to store carbon in the soil and minimize the effects of climate change

(Deng *et al.,* 2022) one of the information collected thus, conservation tillage improves climatic resilience and minimizes the effects of climate change on agriculture.
(Rahman *et al.*, 2021) suggested Intensive soil tillage and crop residue removal in conventional agricultural systems may have a greater severe impact on the environment.
(Alhassan *et al.*, 2021) reported shown that NTS, in particular, enhanced soil water content and decreased soil temperature through conservation tillage techniques.
(Yao *et al.,* 2023) investigated if conservation tillage techniques may decrease the impact of climate change on soil CO2 emissions from arid farms.
Based on our research, zero tillage may be a major factor in reducing greenhouse gas emissions from soils and aiding in the fight against climate change.
Moreover, conservation tillage is essential to preserving soil health, according to the examination of soil preservation indicators.
Under conservation tillage systems, studies regularly show benefits in soil structure, moisture retention, and nutrient levels. Improved water infiltration and decreased erosion are noted, which over time will lead to better soil maintenance. The findings support the sustainability of agricultural ecosystems by confirming that conservation tillage practices have a positive impact on a number of soil quality factors.

Conservation tillage reduce greenhouse gas intensity in organic farming

(D.E et al., 2001) showed that tillage has an organic soil-saving effect that can lower greenhouse gas emissions and future farm fuel usage while also preserving energy for increased profit.
(Rahman et al., 2021) suggests MT and ZT practices to reduce adverse environmental impacts in Bangladeshi wheat agriculture, as the results support CTS. When comparing the techniques, the MT method—which keeps the crop residue (20 cm) and applies CA principles—is more suited for Bangladesh's wheat agriculture, both for CSA and SI. This is because it can enhance SOC formation while preventing water loss and greenhouse gas emissions without compromising output.

(Valujeva et al., 2022) There have been suggestions for reduced tillage and alternative crops to lower greenhouse gas emissions from agricultural soils.
(Gryze et al., 2010) reported organic farming, winter cover crops, and conservation tillage have all been suggested as strategies to lower soil greenhouse gas emissions from agriculture.
(Khresat et al., 2016) showed that conservation agriculture practices lower the greenhouse gas emissions of farming systems. (Khan *et al.*, 2023) studied Carbon sequestration can reduced the green house gas emission.

Discussion

The findings are consistent with the idea that conservation tillage is a viable strategy for reducing the effects of climate change and maintaining soil health. Increased soil organic carbon content is a result of both crop residues remaining on the field surface as well as decreased soil disturbance. This thus helps with carbon sequestration, resolving the issue of greenhouse gas emissions. The benefits for preserving soil are examined in relation to better water management and erosion prevention. Conservation tillage techniques reduce soil erosion by keeping surface leftovers in place, which serve as a protective layer. Sustainable soil management necessitates improved water infiltration and moisture retention, both of which increase resistance to drought.
It is important to recognize potential challenges and limitations linked to conservation tillage. In some situations, localized variables like crop rotation techniques, soil composition, and climate might affect how effective conservation tillage is. Farmers may face initial difficulties if these practices are adopted since they may call for changes to machinery and management.
The debate and overall findings highlight the significance of conservation tillage as a sustainable farming method for soil protection and carbon sequestration. The results provide insightful information to guide future investigations as well as promote the adoption of strategies that improve agricultural systems' long-term sustainability.

Conclusions and future perspectives

The best way to combat the negative consequences of climate change on agriculture, a sector that is extremely sensitive to changing weather patterns, is to manage natural resources carefully. Transferring atmospheric CO2 into the soil through a process known as "soil C sequestration" is a mutually beneficial strategy that addresses both climate adaptation and mitigation. Plant photosynthesis is the main process that converts atmospheric CO2 into soil, and it entails defending the soil's carbon-based pools from soil microbial populations that would otherwise release the carbon back into the atmosphere. The no-till farming method is regarded as an efficient way to restore soil and absorb atmospheric carbon since it maintains ecosystems and soil health. In addition to improving the efficiency of water and fertilizer use, zero- or no-tillage when combined with keeping crop residue in the field or using it as mulch helps sequester a sizable amount of atmospheric CO2. Crop rotation has the potential to improve soil health and sequester carbon under a conservation agriculture system by accelerating SOC accumulation rates at different soil levels. The majority of agricultural management methods that support carbon sequestration also enhance soil fertility, increase soil aggregate stability, retain water better, and guarantee food security. However, taking action shouldn't be contingent on having a thorough understanding of soil C and the sequestration capacity. Numerous techniques to improve the sequestration of atmospheric C have recently been presented by diverse research projects on various agricultural management methods. The adaptation of conservation tillage practices is comparatively more effective than several other options for atmospheric drawdown, and it may be adapted soon. Risks involved in this system are low, and there are several established advantages to enhancing soil quality and sequestering C.

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