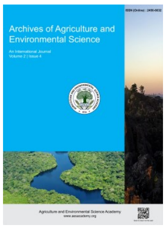
Archives of Agriculture and Environmental Science 9(3): 612-617 (2024)
https://doi.org/10.26832/24566632.2024.0903028

e-ISSN: 2456-6632

This content is available online at AESA

Archives of Agriculture and Environmental Science

Journal homepage: journals.aesacademy.org/index.php/aaes



REVIEW ARTICLE

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A review on tillage system and no-till agriculture and its impact on soil health

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ARTICLE HISTORY

Received: 23 July 2024
Revised received: 03 September 2024
Accepted: 10 September 2024

Keywords

Conservation agriculture
Cover crops
Soil health
Soil erosion
Zero tillage adoption

ABSTRACT

Soil tillage is a fundamental agriculture practice aimed at preparing the soil for planting, managing crop residues, controlling weeds, preparing the ground for the next crop, integrating leftover crops and nutrients into the soil, and enhancing soil structure. However, tillage practice significantly influences activities like soil moisture, temperature, aeration, and mixing the crop residues within the soil. This article explores the impacts of traditional tillage methods and alternative approaches to reduce production costs, environmental consequences, and safeguard soil for sustainable crop production through the secondary source of results as published research papers, documents, government official and institution reports. Traditional tillage method involves the mechanical disruption of soil, which affects critical factors such as moisture retention, temperature regulation, and aeration. While use of such heavy machines can improve short-term productivity, its long-term impacts include soil compaction, erosion, and loss of organic matter, leading to environmental degradation and declining soil health. In contrast, No-till and reduced tillage practices offers a promising solution to contemporary challenges such as global climate change, water conservation, rapid soil degradation, and desertification. Under this system, wide range of crops can be grown effectively in low production cost by reducing fuel and labor requirements. No-tillage and minimal tillage is being adopted across a wide range of farm sizes, from small plots of land to vast expanses, in various countries around the world with promising sustainability.

Citation of this article: Thapa, B., & Dura, R. (2024). A review on tillage system and no-till agriculture and its impact on soil health. *Archives of Agriculture and Environmental Science*, 9(3), 612-617, https://dx.doi.org/10.26832/24566632.2024.0903028

INTRODUCTION

The alarming rate of increment in global population which is expected to rise up to 9.7 billion (26% increase) by 2050 (United Nations, 2019) has created an urge to improve soil health for ensuring food security and to build a sustainable future (Amundson *et al*., 2015). Agriculture can assist to achieve the majority of the United Nations' sustainable development objectives, and no-tillage is the best way to do so (Mondal & Chakraborty, 2022). These issues could be addressed in part by management practices such as conservation tillage and cover cropping, which protect the soil surface from erosion, restore soil fertility through organic matter cycling, improve soil health through habitat enhancement, and reduce greenhouse gas emissions through soil carbon accumulation and improved fertilizer use efficiency (Farmaha *et al*., 2022). Turning the soil before planting a fresh crop is an age-old practice that contributes to farmland degradation (Derpsch *et al*., 2010). Tillage is a major contributor to agricultural land degradation, which is one of the world's most critical environmental issues, posing a threat to food production and rural lives. Soil conservation for agriculture is centered on increasing agricultural production by improving soil fertility while minimizing environmental damage, notably in terms of soil and water management (Cassol *et al*., 2007; Kumar and Chopra, 2013 and 2016). Conservation tillage strategies with minimal soil disturbances, such as no-tillage or subsoiling, and straw retention or mulching systems, can help increase agricultural sustainability (Chen *et al*., 2019). To maintain and preserve soil health, conservation agriculture management approaches such as minimum soil disturbance, maximum soil cover, and crop diversity have been recommended (Farmaha *et al*., 2022). Soil conservation strategies include no tillage (NT), reduced tillage (RT), and minimum tillage (MT), which can be combined, or not combined, with crop residue mulching on the soil surface, crop rotation, cover cropping, and integrated pest and weed control practices (Lal, 1993). As a result, no-tillage agriculture is a long-term agricultural system that meets farmers' economic needs, solves consumer concerns, and has a low environmental impact (Bagwell *et al*., 1989). The objective of this critical assessment is to evaluate and analyze the impact of tillage on agricultural practices in order to increase agricultural sustainability and efficiency. Further to analyze the present level of knowledge, identify key patterns, while assessing the strengths and shortcomings of research in this topic by critically analyzing existing literature. Also included in this review's objectives are the identification of research gaps and possibilities, as well as insights and suggestions for agriculture industry workers, leaders, and constituents.

Tillage

Soil tillage is used for a variety of reasons, including preparing a seedbed for the next crop, incorporating crop leftovers and nutrients into the soil, suppressing weeds, and improving the soil's bio-physical structure (Chen *et al*., 2022). Tillage has also aided in the control of insects and diseases by burying crop leftovers (Givens *et al*., 2009). Tilling for crop production is one of the most well-known human interventions that disrupts soil aggregation, pore-size distribution, and water transport, among other things (Guo and Gifford, 2002; Kumar and Chopra, 2016). Tillage procedures, on the other hand, have been linked to the dangers of subsurface compaction (plough pan) and soil erosion (Busari *et al*., 2015). Soil health has been found to be harmed by repeated tillage and residue burning for fine seedbed preparation (Somasundaram *et al*., 2017). Tillage procedures alter the amount of water in the soil, the temperature, aeration, and the degree of crop residue mixing within the soil matrix (Kladivko, 2001). Because of changes in infiltration, surface runoff, and evaporation caused by tillage, soil water content is another factor that is affected (Fabrizzi *et al*., 2005). Soil erosion, degradation of soil structure, increased nutrient depletion, and lower water retention capacity are all consequences of traditional tillage techniques (Saleem *et al*., 2022). Because of the physical disruption of the soil, the burying of crop residue, and the change in soil water and temperature caused by residue assimilation, larger creatures appear to be more susceptible to tillage operations than smaller organisms (Kladivko, 2001). Tillage erosion has been highlighted as a major global soil degradation process that must be taken into account when evaluating erosional effects on soil productivity, environmental quality, or landscape development (Van Oost *et al*., 2006). After several decades of tillage, the scope and severity of tillage erosion becomes apparent.

Environmental implications of plow tillage

Soil erosion has become a global problem as a result of intensive tillage by after the use of heavy machinery. Plow ploughing exacerbates both water and wind erosion. It loosens the soil, burries crop residues, and exposes it to high-intensity rainfall and strong wind speeds, all of which contribute to severe erosion (Lal *et al*., 2007). Compaction-induced soil deterioration is becoming more of a worry as farm machinery's power and mass increase, a trend that has been seen for the previous 30 years (Antille *et al*., 2015). Soil compaction is common, and its effects can be exacerbated when it extends deep into the profile (e.g., 0.4 m) (Spoor *et al*., 2003). Compaction of the soil can have a deleterious impact on a variety of soil hydrologic, biogeochemical, and plant physiological processes (Botta *et al*., 2022). Tillage erosion is also common in developing countries, especially when tillage is done in dissected landscapes on steep slopes with animal or human-powered tillage implements (Kimaro *et al*., 2005). Tillage erosion is increasingly acknowledged as a significant global soil degradation process that must be taken into consideration when evaluating erosional effects on soil productivity (Heckrath *et al*., 2005). The tillage strategy utilized impacts soil aggregation, which affects the amount of C and N in the various aggregate fractions. Soil compaction, surface sealing, crusting, lower hydraulic conductivity, increased run-off, and erosion can all occur from excessive tillage. Tillage has a number of drawbacks, including the destruction of soil structure, the burying of surface leftovers, and increased evaporation from the tilled zone (Jones *et al*., 1990). Tillage with a moldboard-plow burries the majority of crop leftovers and leaves the soil surface almost bare (Munawar *et al*., 1990). Tillage erosivity rises in direct proportion to tillage depth. As a result, reducing the depth of tillage might be regarded a successful soil conservation approach (Van Oost *et al*., 2006). Traditional tillage has been condemned for wasting energy and leading to soil erosion, as well as other air and water pollution issues (Bultena and Heiberg, 1983).

Implication of conservation agriculture

Conservation Agriculture (CA) is defined as a set of conservationist techniques for soil, water, and biodiversity that are utilized systemically in agriculture, such as integrated pest, disease, and weed management (Cassol *et al*., 2007). Conservation Agriculture improves the porosity of the soil, which has two key benefits: (a) A higher proportion of incident rainfall enters the soil; (b) a better distribution of pore-spaces of optimal sizes leads in a higher proportion of received water being stored at plant-available tensions (Lal, 2015). (Derpsch *et al*., 1991) the situation in the rooting zone with respect to soil moisture conditions throughout the growing season under CA is much better than under minimum tillage and under conventional tillage. It enhances soil internal drainage and aeration, as well as avoiding anaerobic zones in the soil profile, assuming that soil compactions from heavy mechanical movement are avoided and irrigation water management is acceptable. CA has evolved into a technically viable, long-term (Broman & Robert 2017), and cost-effective crop production alternative (Derpsch & Friedrich, 2009).

Enhancing efficiency of agriculture through conservation tillage practices

Conservation tillage is a word that refers to a variety of agricultural strategies that conserve water and soil through insect pest management strategy, use of traditional tools, indigenous practices, crop residue management. Conservation tillage has been proved in numerous studies to boost crop yields and reduce soil water demand (Mairghany *et al*., 2019). Subsoiling, a conservation tillage approach, breaks up soil compaction and improves soil structure, increasing the soil's water retention capacity through improving infiltration and straw cover (Kuang *et al*., 2020). In arid places with rainfed circumstances, this form of plowing increased crop yields (Su *et al*., 2007). When compared to fresh bed and traditional tillage procedures, the effect of such a tillage system had a substantial impact on growth character, yield attributes, and yields (Kumar *et al*., 2022). Strip tillage, cover cropping, contour farming, zero or chemical tillage, mulch tillage, and reduced tillage are examples of these approaches, with the goal being low disturbance no-till or direct sowing. The amount and distribution of plant residues left on the soil surface determine the efficiency of a conservation tillage technique (Munawar *et al*., 1990). Tillage can also lower production costs, as many farmers use excessive tillage to establish wheat following rice, with tillage accounting for nearly a third of total production costs (Hobbs & Giri, 1997).

No tillage

Traditional tillage poses a major danger to soil ecosystem integrity (Liu *et al*., 2022). No-tillage farming, also known as zero-tillage farming or conservation agriculture, was adopted on around 45 million hectares worldwide in 1999, increasing to 72 million hectares in 2003 and 111 million hectares in 2009, a growth rate of 6 million hectares per year (Derpsch *et al*., 2010). The concept of No-Tillage System (NTS) evolved over time as an evolution of direct sowing without soil preparation, referred to as No-Tillage (NT) in England and the United States (Cassol *et al*., 2007). NTS also known as "Sistema Plantio Direto" or "Plantio Direto," was founded in Brazil, where Sistema Plantio Direto describes itself as an agricultural production system based on the simultaneous adoption of minimum soil disturbance, maintenance of permanent soil cover, crop rotation and Plantio Direto is a conservationist practice (Possamai *et al*., 2022). NTS is a crop rotation, permanent soil cover, and sowing without preceding soil mobilization agricultural production system, whereas NT is merely viewed as a sowing technique without previous soil preparation, or little soil disturbance, as proposed by NTS (Hernani & Salton, 1998). In the NTS, all crops can be sufficiently produced, and no crop has yet been discovered that will not grow and yield under this system, including root and tuber crops. (NT) technique can essentially contribute to establish a sustainable, low carbon and resource efficient agriculture, and stimulate the utilization of crop residues for further soil advantages (Mondal & Chakraborty, 2022). Under arid climatic circumstances, minimum tillage and zero tillage approaches boost the availability of soil phosphorus, potassium, and soil organic matter (Busari *et al*., 2015), (Bhatt, 2017). In general, NT or any other tillage strategy that leave a mulch of plant debris on the surface will enhance soil moisture content (Garifullin & Fedorov, 1997). From an environmental standpoint, the NTS lowers siltation of water bodies, eutrophication of surface waters, and agrochemical transportation while also enhancing groundwater and aquifer replenish-

Table 1. Advantages and disadvantages of tillage and no-tillage agriculture system.

Criteria	Tillage agriculture system		No- Tillage agriculture system		References
Amount of crop production	Advantage	Better soil aeration and weed control may initially lead to increased yields.	Advantage	There is less soil disturbance, yields can be maintained or even increased over time.	Bogunovic *et al*. (2019)
	Disadvantage	erosion and soil deterioration may eventually result in lower yields	Disadvantage	lower soil warming and weed suppression is that initial yields can be a little lower.	
Impact on Ecosystem	Advantage	By burying crop debris, it is possible to control some pests and diseases.	Advantage	Improves water retention and reduces soil erosion, which is good for the ecosystem as a whole.	Lal (1993)
	Disadvantage	Negative effects on soil structure, organic matter levels, and erosion	Disadvantage	May result in increased pest pressure and a need for pesticides.	
Biodiversity	Advantage	Can interfere with the habitats of some pests, thereby bringing down their populations	Advantage	Preserves soil biodiversity and promotes helpful species, which helps maintain the health of the ecosystem.	Dabney *et al*. (2001)
	Disadvantage	The habitat and food sources for helpful soil organisms may be reduced	Disadvantage	might not provide the same level of pest control.	
Extent of erosion	Advantage	By burying crop debris and loosening compacted soil, can aid in preventing erosion	Advantage	Decreases soil erosion significantly and enhances soil structure.	Blanco-Canqui & Lal (2008)
	Disadvantage	cause more erosion, particularly on fields with slopes.	Disadvantage	Until cover crops establish, inadequate residue cover may initially cause minor erosion.	
Unit of production per unit area	Advantage	May increase yield by necessitating more inputs (fertilizers, water, etc.)	Advantage	Less inputs are frequently needed because to the enhanced soil quality and decreased weed pressure.	Blanco-Canqui & Lal (2008)
	Disadvantage	Lower profitability may result from higher input costs	Disadvantage	the initial transition period is that cover crops and weed control may need additional inputs.	

ment and sequestering atmospheric carbon through enhanced Soil Organic Matter (SOM) (Cassol *et al*., 2007; Carvalho *et al*., 2009).

Differences in the microbial environment, number and activity of soil microorganisms, tillage effect on soil animals, decomposition of organic matter, nitrogen transformations, chemical properties, influence of mulches on soil physical properties, and effect of tillage on soil density and porosity are all factors to consider when comparing NT to conventional tillage (Garifullin & Fedorov, 1997). According to research by (Peng *et al*., 2020) on a winter wheat, no-tillage with straw cover boosted grain yield and precipitation use efficiency by 45 percent and 43 percent in comparison to conventional tillage. NT approach also improves soil aggregate stability and minimizes the danger of soil erosion and degradation, while increasing the number of water-stabilized aggregates further improves soil water storage (Zhang *et al*., 2022). It's the process of enabling agriculture to respond to some of the world's most pressing issues, such as climate change, land and environmental degradation, and rising food, energy, and production input costs (Rolf Derpsch *et al*., 2010). Farmers from the Arctic Circle (e.g., Finland) to the Tropics (e.g., Kenya, Uganda) to around 50o latitude South (e.g., Malvinas/Falkland Islands) are currently practicing no-tillage (Rolf Derpsch & Friedrich, 2009). NT technologies are extremely effective in minimizing soil and crop residue disturbance, controlling soil evaporation, minimizing erosion losses, sequestering carbon in the soil, and lowering energy requirements (Lal *et al*., 2007). It demands less energy input per unit area, per unit output, and lower equipment depreciation rates than previously. It entails decreasing production costs, hence boosting profit margins, while also reducing pollution from tractor-fuel combustion (Rolf Derpsch *et al*., 2010). No-tillage farming can address the rising concerns of the twenty-first century, such as global climate change, rapid soil degradation, and desertification, in some soils and climates. The no-tillage systems are more akin to natural ecosystems that haven't been disturbed (House and Parmelee, 1985). In contrast to intensive tillage systems, which constantly reduce the carbon content of the soil, no-tillage technologies have a great potential to increase organic matter content and sequester carbon (Rolf Derpsch & Friedrich, 2009). Despite no-tillage system getting recognized a lot lately there are several factors that is affecting its adoption.

Main barriers to No-tillage adoption are:

- Mindset is one of the most significant challenges to No-Tillage adoption.
- Knowledge on how to do it (know how).
- Reduces labour cost and easily effective available of machines.
- Inadequate policies to encourage the adoption of conservation agriculture.
- Loss of yield due to soil borne disease, fungal pathogens and nematodes.

Soil cover

Long-term usage of cover crops has been shown to improve soil microbial biomass, glomalin concentration, phosphatase, and arylsulfatase activity (Balota *et al*., 2014). Because of the vegetative mulch that might be formed when these crops were died, cover crops were a significant component in these no-tillage systems. When left on the soil surface, this vegetative mulch was found to be excellent at suppressing weeds (Carr, 2017). Crop leftovers from previous cash crops or green manure cover crops should cover the soil permanently, and most of these residues will remain undisturbed on the soil surface after sowing (R. Derpsch & Friedrich, 2009). The soil cover, also known as living or dead cover (straw), is a type of vegetative soil conservation practice in which the accumulated phytomass from previous crops acts as a shield against the energy of raindrop impact on the soil surface, as well as the shear energy of runoff. It is an important practice for erosion control (Maria *et al*., 2019).

Crop rotation

Crop rotation has been proven to be beneficial in soil management techniques (Farmaha *et al*., 2022). Crop rotation do not disrupt the soil over time, allowing for the exploration of different soil strata, nutrient cycling, and the biological fixation of atmospheric nitrogen via leguminous species. Crop rotation reduces the risk of certain weeds, disease cycle, insect attack and enhance soil fertility (Possamai *et al*., 2022).

Mulching system

Plastic film mulch is a useful soil water management tool for increasing soil moisture, reducing evaporation, and changing soil temperature (Li *et al*., 2019). Plastic films, on the other hand, are not biodegradable and can remain in soils for years, causing environmental problems; on the other hand, straw mulching on the soil surface can improve the soil environment, reduce water losses, and provide many external nutrients, especially in semi-arid areas with degraded soil and limited rainfall (Li *et al*., 2020).

Reduced greenhouse gas emissions

The intensification of industrial and agricultural activity has resulted in large increases in greenhouse gas (GHG) concentrations in the atmosphere (Madigan *et al*., 2022). Most critically, no-till farming avoids the needlessly quick oxidation of organic matter to CO_2 caused by tillage. Reduced use of tractors and other powered farm equipment resulting in lower emissions of exhaust gases and fuel savings of up to 70% have been reported with Conservation Agriculture (FAO, 2008). Zero tillage systems could be a better alternative to the current system since they improve yields and lower costs, while public benefits could include a reduction in greenhouse gas (GHG) emissions due to less heavy gear use (Maraseni & Cockfield, 2011). Increased soil organic carbon and reduced nitrous oxide(N_2O) emissions are thought to be two potential GHG benefits in zero-tillage systems (Maraseni & Cockfield, 2011).

Increase in the number of earthworms

Ploughing ruins the system of permanent burrows inhabited by anecic earthworms, making conventional plowing extremely damaging to litter-feeding earthworms, both surface-living epigeic earthworms and hypogenic earthworm (deep-burrowing anecic earthworms) (Briones and Schmidt, 2017). Agricultural practices can have a significant impact on earthworm populations and densities (Curry, 2004). Anecic earthworm densities were 17 times greater in no-tillage system than in conventional tillage, and bioturbation was more than four times higher in no-tillage than in conventional tillage (Torppa & Taylor, 2022). Earthworms dig into the soil, creating enormous pores that are essential for water retention, aeration, and root growth. They aid in the mixing of organic materials into the soil and the creation of aggregates (Kladivko, 2001). Changes in the soil decomposer population generated by earthworms could have a big impact on nutrient cycle processes, especially in reduced-tillage environments, and could be a good advantage for agriculturalists.

Conclusion

Conservation tillage and cover cropping protect the soil surface from erosion, restore soil fertility through organic matter cycling, improve soil health through habitat enhancement, and reduce greenhouse gas emissions through soil carbon accumulation and improved fertilizer use efficiency. Conservation farming techniques using cover crops and no-till or reduced tillage have been found to improve soil health. The goal today is to focus on long-term land development methods that allow existing populations to meet their demands without putting resources at risk, while also safeguarding resources for future generations.

DECLARATIONS

Author contribution statement: Conceptualization: B.T. and R.D.; Methodology: B.T., R.D.; Software and validation: B.; Formal analysis and investigation: R.D.; Resources: B.T.; Data curation: B.T.; Writing—original draft preparation: B.T.; Writing—review and editing: B.T.; Visualization: R.D.; Supervision: R.D.; Project administration: B.T.; Funding acquisition: B.T. All authors have read and agreed to the published version of the manuscript.

Conflicts of interest: The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

Ethics approval: This study did not involve any animal or human participant and thus ethical approval was not applicable.

Consent for publication: All co-authors gave their consent to publish this paper in AAES.

Data availability: Data will be made available on request.

Supplementary data: None.

Funding statement: None.

Additional information: No additional information is available for this paper.

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