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Review Paper

Impact of Conservation Tillage on Soil Properties for Agricultural Sustainability: A Review

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ABSTRACT

The impact of conservation tillage (CT) on soil health and its implications for achieving agricultural sustainability are of paramount importance in modern agriculture. Conservation tillage practices, such zero and reduced tillage, mulch tillage, ridge tillage, and contour tillage have gained significant attention for their potential to enhance soil health while mitigating adverse environmental effects. CT technologies are known to improve soil health in several ways. These practices reduce soil disturbance, preserving soil structure and preventing erosion. By leaving crop residues on the field, CT enhances organic matter content, fostering microbial activity and nutrient cycling. This, facilitates to enhance soil health and productivity by improving soil physico-chemical and biological activities. The benefits of CT extend beyond soil health to broader agricultural sustainability. Reduced soil erosion and improved moisture retention contribute to enhanced resilience in the consequences of climate change. CT also reduces the need for fuel and equipment, leading to cost savings for farmers and a reduction in greenhouse gas emissions. The adoption of CT is a significant step toward a more sustainable and resilient agriculture system in the face of global challenges. The present study investigates the influence of CT on soil health for achieving agricultural sustainability.

HIGHLIGHTS

- CT practices are important in the present context of climate change as they are ecologically friendly and sustainable approaches.
- CT is beneficial for improving the physical, chemical and biological properties of the soil.

Keywords: Zero tillage, soil properties, water use efficiency, soil microbes enrichment, soil health improvement, carbon sink

Concurrent agriculture is facing an enormous burden because of the continuously increasing demand for enhanced production to fulfill the requirements of the ever-growing human population (Sahoo *et al.* 2023a; Sairam *et al.* 2023a). Food and nutritional security are prime challenges ahead when the world population will reach 9.7 billion in 2050 (UN, 2023). In contrast, degradation and pollution of natural resource bases, global warming as well as climate change-associated abiotic and biotic stresses are causing *havoc* impacts on farm productivity (Tomar *et al.* 2021; Sairam *et al.* 2023b; Sagar *et al.* 2023). During previous decades, enough

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research was carried out on cropping systems and intercropping (Maitra *et al.* 2019; Panda *et al.* 2022a; Sahoo *et al.* 2023b), crop diversification (Neogi and Ghosh, 2022), efficient soil and water management (Maitra and Pine, 2020; Sairam *et al.* 2020; Santosh *et al.* 2021, 2022), holistic approaches in nutrient management (Midya *et al.* 2021; Nandi *et al.* 2022; Maitra *et al.* 2023a), integrated farming system (Panda *et al.* 2022b)and crop protection (Gaikwad *et al.* 2022; Deguine *et al.* 2023). The food and nutritional security, achieved by efficient soil management practices, necessitates the exploration of an eco-friendly and sustainable tillage system that boosts crop yields (Pramanick *et al.* 2021; Zahan *et al.* 2021; Hassan *et al.* 2022; Maitra *et al.* 2022; Bhattacharya *et al.* 2023). Tillage involves the mechanical manipulation of soil, which influences soil properties such as water storage, temperature, infiltration, and evaporation processes (Pramanick *et al.* 2022; Sairam *et al.* 2023c). Consequently, tillage directly impacts the environment as it is carried out with the aim of enhancing crop production (Choudhary *et al.* 2021; Hossain *et al.* 2021a; Islam *et al.* 2023).

The intensification of crop cultivation must be undertaken in a manner that minimizes soil deterioration ensuring that the soil serves as a sink for carbon, not as a source (Maitra *et al.* 2023b). Conventional tillage practices under the intensive crop cultivation, which may comprise of deep tillage, can significantly disturb soil physical and chemical properties, leading to decreased aggregate formation and structural stability, as well as impacting biogeochemical processes like increasing volatilization and evaporation (Choudhary *et al.* 2014; Gitari *et al.* 2020). Therefore, the adoption of conservation tillage (CT), coupled with complementary practices like soil cover and diversification of crops, has appeared as a feasible strategy to promote sustainability in food production while preserving ecological integrity (Busari *et al.* 2015; Hossain *et al.* 2021b). Transitioning from conventional tillage to CT holds significant potential for sustainable agricultural production without environmental pollution. Stubble incorporation enhances infiltration rate and drainage, aggregate stability, hydraulic conductivity, and ensures a healthy agroecosystem (Gajda *et al.* 2018).

This approach highlights the role of conservation tillage as an integral component of conservation agriculture (CA). CA is a comprehensive method for managing agroecosystems to improve and sustain crop yields, enhanceviability, ensure food and nutritional security, and simultaneously safeguard and improve the agricultural resource base and the ecology (Corsi *et al.* 2012). There are three fundamental philosophies of CA: minimal mechanical soil disturbance, permanent organic soil cover, and diversification of crops (FAO, 2023) (Fig. 1).

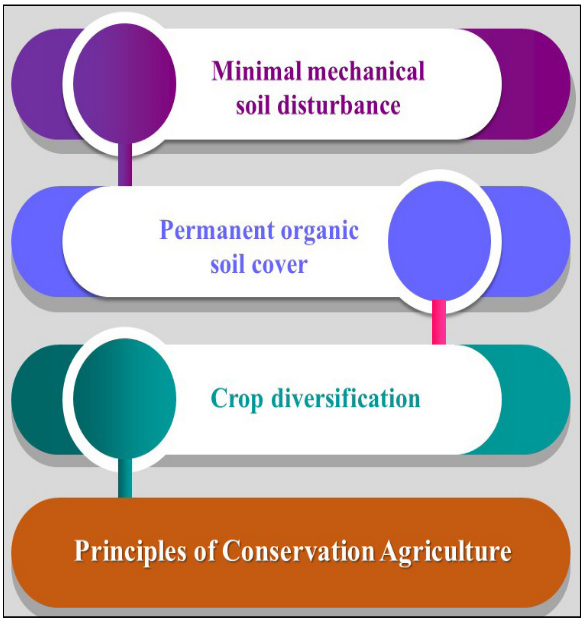

Fig. 1: Principles of conservation agriculture

CT refers to a tillage practice that ensures that as minimum as 30% of the soil exterior remains covered with crop residue after sowing of the next crop (CTIC, 2004). This practice is aimed at reducing soil erosion caused by water. CT involves making seedbed ready inclusive of incorporation of a crop residues mulch for increasing surface coarseness as essential criteria (Cárceles Rodríguez *et al.* 2022). It is important to note that CT is an ecologically friendly approach for managing soil surfaces and preparing seedbeds. Crop residue plays a pivotal role as a valuable and renewable resource (Nandi *et al.* 2022; Kumar *et al.* 2023). The challenge lies in developing effective techniques for its utilization. Mismanagement of crop remainders, such as exclusion, burning, or excessive tillage, can exacerbate issues like faster erosion, deterioration of soil fertility, and pollution to the environment caused by burning. The core principle of CT centres around maintaining a cover on the soil surface by retaining the crop residues, often achieved through minimum soil disturbance as tillage. This practice serves to protect the soil from the striking actions of raindrop and sunlight, while the nominal soil disturbance fosters essential biological properties of the soil and enhances porosity as well as movement of soil air and water. The article aimed to explore the impact of CT on soil, crops, and its overall impacts on the ecosystem towards achieving agricultural sustainability.

Types of conservation tillage

CT practices encompass five important approaches that include zero tillage (no-till), reduced (minimum) tillage, mulch tillage, ridge tillage, and contour tillage (Fig. 2). Zero tillage (ZT) involves minimal or no disturbance of the soil surface, with the primary disruption occurring during the planting process (Wardak *et al.* 2022). Minimum tillage (MT), on the other hand, involves a minimum level of soil disturbance, often entailing ploughing by means of primary tillage implements (Angon *et al.* 2023). In case of mulch tillage, the soil is tilled in a style that allows crop remains or other materials for covering the top soilas much as possible (Shahane and Shivay, 2021). Ridge tillage includes sowing of crops in rows that are created at the initial stage of the crop season (Alagbo *et al.* 2022). When tilling operation occurs at right angles to the slope's direction, it is termed to as contour tillage.

Fig. 2: Different conservation tillage practices

Effect of conservation tillage on soil properties

ZT showed a positive impact of soil physical, chemical and biological properties (Table 1). ZT practices lead to better soil aggregation, resulting in the formation of macroaggregates in tropics and subtropics (Sekaran *et al.* 2021). This improvement is attributed to the increased activity of macro-fauna, soil microbes, and enzyme activity in ZT as compared to conventional tillage (Hassan *et al.* 2022). Additionally, Choudhary *et al.* (2014) observed a significant increase in macroaggregates (50.13%), total water-stable aggregates (15.65%), soil organic carbon (SOC) (33.6%), and macroaggregate-associated carbon (20.8%) in Indian soils when ZT management was applied, in contrast to conventional tillage management.

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

The enhancement of the aggregate stability index in soils under ZT was documented by the FAO (2001). The retaining crop residues in ZT leads to an enhanced soil aggregates and structural stability, facilitated by the release of polysaccharides, formed during crop residue decomposition, and increased content of glomalin (Zhang *et al.* 2021). ZT is recognised as a vital step to mitigate the ruin of soil's physico-chemical properties (Huang *et al.*

2012) while enhancing the overall agro-ecosystem for the longer term (Ussiri and Lal, 2009).

Effect of CT on soil physical properties

The impact of conservation tillage on soil properties exhibits variability, with specific outcomes contingent on the chosen system. ZT systems, characterized by their substantial soil coverage, have been observed to bring about noteworthy alterations in soil properties, particularly in the top soil (Sarkar *et al.* 2000; Sairam *et al.* 2020; Yuan *et al.* 2023). Under ZT practices, soil physical properties tend to be more favourable compared to traditional tillage-based systems (Khan *et al.* 2017; Nduwimana *et al.* 2020; Panda *et al.* 2020). Numerous studies have indicated that ZT practices can significantly enhance both saturated and unsaturated hydraulic conductivity (Krauss *et al.* 2020; Manasa *et al.* 2020; Maitra and Gitari, 2020). This improvement is attributed to the continuity of pores or the flow of water through a limited number of larger pores. It's worth noting that porous soils with lower humus tend to exhibit the most favourable response to CT, particularly in the case of ZT (Busari *et al.* 2015). ZT practices help prevent soil erosion because soil massesare fixed tightly because of the higher content of organic matter present in the soil (Dorneles *et al.* 2015).

The effectiveness of CT technologies by minimizing soil and crop residue disturbance, mitigating soil evaporation, and reducing erosion losses. Furthermore, no-till soils typically exhibit more stable aggregation in the uppermost soil layer, leading to increased total porosity when compared to conventionally tilled soils (Nduwimana *et al.* 2020; Chappa *et al.* 2022). CT not only enhances stable aggregates but increases the soil organic carbon (SOC) and nitrogen (N) content within aggregates in the soil (Jacobs *et al.* 2009). Regarding water conservation, it has been observed that no-till (NT) is particularly efficient in humid and sub-humid tropical regions (Kargas *et al.* 2012). In comparison with traditional tillage, minimum tillage led to an improvement in the soil pores, enhancing the presence of storage pores (0.5–50 mm) and elongated transmission pores (50–500 mm). This greater microporosity in minimum tillage soils was linked to increased soil moisture content, resulting in a higher availability of water for plants (Busari *et al.* 2015) because of the retention of organic matter (OM) and the promotion of aggregation (Hassan *et al.* 2022). Moreover, more soil moisture content was identified in the topsoil (0–10 cm) under ZT compared to conventional tillage, as reported by McVay *et al.* (2006). Consequently, researchers have suggested to replace the conventional tillage with CT to enhance soil water storage and improve water use efficiency (WUE) (McVay *et al.* 2006; Silburn *et al.* 2007; Su *et al.* 2007; Ali *et al.* 2009).

ZT exhibited superior infiltration parameters compared to conventional tillage on as sandy Alfisol (Busari and Salako, 2012). In as study, Shukla *et al.* (2003), have reported higher infiltration rates under NT due to the protective effect of crop residue on the top soil and the influence of soil organic carbon (SOC). CT not only preserves crop residue on the soil surface but also increases the efficiency of surface-feeding earthworms, leaving root channels uninterrupted. This facilitates the surface-connected macro-pores and inter-pedal voids, ensuing an enhanced infiltration. ZT exhibits higher evapo-transpiration (ET) compared to conventional tillage. This increase in ET is attributed to the greater and deeper storage of soil water in NT plots, as detailed by Su *et al.* (2007). Extensive tillage practices typically expose the soil to increased evaporation. The process of evaporation from the soil surface is intricate and influenced by various factors, including soil characteristics, tillage practices, and environmental conditions. CT has been associated with reduced evaporation because of higher soil moisture in the topsoil and the presence of crop residues on the soil surface, which in turn leads to lower soil temperatures. The adoption of ZT practices is recognized for its capacity to enhance crop growth and yield by conserving soil and water resources (Wang *et al.* 2016). Under ZT, the maintenance of surface mulches leads to improved water infiltration and a reduction in water loss through evaporation (Hassan *et al.* 2022). Further, ZT exhibited a greater volumetric water content and water retention in comparison to traditional tillage (Basamba *et al.* 2006).

Soil Chemical Properties

Tillage systems can have a significant impact on various soil chemical properties, including pH, cation exchange capacity (CEC), exchangeable cations, soil organic carbon and total nitrogen content (Bolliger *et al.* 2006; Veiga *et al.* 2008). The surface layer of soil tends to exhibit more favourable chemical properties when the ZT method is employed compared to tilled soil. The annual NT results in an enhancement in OM on the soil surface, particularly in the topsoil. Furthermore, research by Dalal (1992) has shown that reduced total nitrogen loss is observed under ZT as opposed to conventional tillage. This difference in nitrogen loss can be attributed to higher rates of mineralization and/or leaching in tilled plots due to soil structure degradation following conventional tillage. Regarding soil pH, researchers recorded various findings such as unchanged pH (Rasmussen, 1999), lowering pH and increasing pH (Lal, 1997; Gajda *et al.* 2018). Probably, such a variation in soil pH might be occurred because of various factors such as climatic conditions, soil type, residue incorporation and management practices adopted.

Rahman *et al*. (2008) found that exchangeable calcium (Ca), magnesium (Mg), and potassium (K) levels were notably greater in the surface soil of ZT systems in comparison to conventionally tilled soil. According to Ali *et al*. (2006), the lowest values of SOM, nitrogen (N), phosphorus (P), K, Ca, and Mg were recorded in conventional ploughing practices. This could be attributed to the inversion of topsoil during ploughing, which brings less fertile subsoil to the surface and may lead to leaching. In the realm of sustainable agriculture, ZT is recognized as a valuable tool for strengthening the relationship between CEC and soil organic carbon (SOC), thus contributing to improvements in soil physico-chemical properties (Busari *et al.* 2015).

Biological properties

Tillage has a notable impact on soil biological properties, with soil organic carbon (SOC) content being particularly affected (Szostek *et al.* 2022). The level of soil organic matter greatly influences the activities of soil organisms, which, in turn, play a significant role in SOC dynamics. Earthworms contribute to soil fertility dynamics through their burrowing activities, which improve soil aeration and water infiltration under ZT soils (Ahmed and Al-Mutairi, 2022). Soil microorganisms play a significant role in assessing soil quality and health, and they are fundamental contributors to the proper functioning of ecosystems (Mirriam *et al.* 2020; Palai *et al.* 2021). These microscopic life forms, found in the soil, perform a wide range of essential ecosystem services, including the cycling of nutrients, decomposition of organic matter, detoxification of pollutants, suppression of diseases, regulation of climate, and the maintenance of soil fertility and productivity (Melero *et al.* 2011). In comparison to conventional tillage, ZT practices have been shown to enhance both the population and diversity of soil microorganisms (Morugán-Coronado *et al.* 2022). Globally, the adoption of zero tillage (ZT) or no-till techniques in agriculture is on the rise, primarily motivated by the growing emphasis on soil conservation (Hassan *et al.* 2022). The augmented availability of nutrients under ZT practices has a direct and positive impact on the population and activity of soil microorganisms. Furthermore, ZT practices lead to the accumulation of SOM in the upper layers of the soil, providing a substantial source of substrates and a habitat for soil biota (Wang *et al.* 2016). ZT represents a sustainable approach to crop management that not only safeguards soil, water, air, and biodiversity but also promotes increased microbial activity and biomass (Memon *et al.* 2018). In general, zero tillage (ZT) leads to soils with a greater hydraulic conductivity because of an enhanced biological activity, ensuing in higher porosity. The layer of crop residues on the top soil in CT serves the role of mulching material, preventing evaporation and conserving soil moisture. Furthermore, stubble mulch practices restrict the impact of raindrops, reduces pore sealing, and minimizes the formation of a hard crust (Sadiq *et al.* 2021; Choudhary *et al.* 2014).

Moreover, soil enzymes perform a crucial role in regulating numerous responses that are essential for microorganisms. They also administer processes like the decay of crop residues, nutrient cycling, the development of organic matter (OM) and soil structure (Ussiri *et al.* 2009). Enzymes play a dual role in both decomposing and storing OM and organic carbon. The end products of decomposition that persist in the soil are highly resistant to further degradation, thus enhancing the biochemical stability of SOM (Mangalassery *et al.* 2015; Melero *et al.* 2011). In a comparison between zero tillage (ZT) and conventional tillage practices, it was observed that acid phosphatase, alkaline phosphatase, arylsulfatase, invertase, amidase, and urease activities significantly increased in the top soil profile under ZT practices. This increase also contributed to improved humification and soil OM and carbon in soils (Fernandez *et al.* 2007). Furthermore, a significant and positive relationship has been noted between carbon sequestration and enzymatic activities in soils in the Eastern Midlands of the UK under CT (Mangalassery *et al.* 2015). ZT, with its minimal soil disturbance or none at all, preserves soil against such disturbances, promotes humification, and enhances its role as a natural carbon sink (Melero *et al.* 2011).

CONCLUSION

CT showed its multifaceted influences on soil properties that are crucial for agricultural sustainability. The primary advantage of CT is its positive impact on soil erosion control and enhancement of soil physical properties. By leaving crop residues on the field, conservation tillage reduces the exposure of soil to wind and water erosion. This not only helps in preserving the topsoil but also mitigates the loss of essential nutrients. These benefits are particularly important for sustainable agriculture in the tropical and sub-tropical regions, where soil erosion is a pressing issue. Additionally, CT promotes increased organic matter content in the soil with a dynamic and beneficial soil microorganism. The presence of crop residues helps enhance soil structure and fertility, leading to improved water retention and nutrient availability. Moreover, CT contributes to enhancement of natural carbon sink. CT helps sequester carbon in the soil, making it a relevant topic for sustainable farming practices. In conclusion, it may be stated that CT has a versatile impact on various soil properties, that improves targeting agricultural sustainability and fulfilment of some of the sustainable development goals (SDG) such as SDG 1 (no poverty), SDG 2 (zero hunger), SDG 13 (climate actions) and SDG 15 (life on land).

Abbreviations used

CT: Conservation Tillage

CA: Conservation Agriculture

SDG: Sustainable Development Goal

ZT: Zero Tillage

SOC: Soil Organic Carbon

NT: No-till

WUE: Water Use Efficiency

ET: Evapo-transpiration

CEC: Cation Exchange Capacity

OM: Organic Matter

SOM: Soil Organic Matter

REFERENCES

Ahmed, N. and Al-Mutairi, K.A. 2022. Earthworms effect on microbial population and soil fertility as well as their interaction with agriculture practices. *Sustainability*, **14**: 7803.

Alagbo, O., Spaeth, M., Saile, M., Schumacher, M. and Gerhards, R. 2022. Weed management in ridge tillage systems—A review. *Agron.*, **12**(4): 910.

Ali, A., Ayuba, S.A. and Ojeniyi, S.O. 2006. Effect of tillage and fertilizer on soil chemical properties, leaf nutrient content and yield of soyabean in the Guinea Savanna zone of Nigeria. *Nig. J. Soil Sci.*, **16**: 126–130.

Ali, M.A., Lee, C.H., Lee, Y.B. and Kim, P.J. 2009. Silicate fertilization in no-tillage rice farming for mitigation of methane emission and increasing rice productivity. *Agric. Ecosys. Environ.*, **132:** 16-22.

Angon, P.B., Anjum, N., Mst. Akter, M.M., Shreejana K.C., Suma, R.P. and Sadia Jannat, S. 2023. An overview of the impact of tillage and cropping systems on soil health in agricultural practices. *Adv. Agric.*, **2023**: 8861216.

Basamba, T.A., Amezquita, E., Singh, B.R. and Rao, I.M. 2006. Effects of tillage systems on soil physical properties, root distribution and maize yield on a Colombian acid-savanna Oxisol. *Acta Agric. Scand. Sec. B - Soil Plant Sci.*, **56**: 255-262.

Bhattacharya, U., Naskar, M.K., Venugopalan, V.K., Sarkar, S., Bandopadhyay, P., Maitra, S., Gaber, A., Alsuhaibani, A.M. and Hossain, A. 2023. Implications of minimum tillage and integrated nutrient management on yield and soil health of rice-lentil cropping system – being a resource conservation technology. *Fron. Sustain. Food Syst.*, **7**: 1225986.

Bolliger, A., Magid, J., Amado, J.C.T., Neto, F.S., Ribeiro, M.F.D.S., Calegari, A., Ralisch, R. and de Neergaard, A. 2006. Taking stock of the Brazilian "zero-till revolution": A review of landmark research and farmers' practice. *Adv. Agron.*, **91**: 47-110.

Busari, M.A. and Salako, F.K. 2012. Effect of tillage and poultry manure application on soil infiltration rate and maize root growth in a sandy Alfisol. *Agro-sci. J. Trop. Agric., Food, Environ. Ext.*, **11**: 24–31.

Busari, M.A., Kukal, S.S., Amanpreet Kaur, A., Bhatt, R. and Dulazi, A.A. 2015. Conservation tillage impacts on soil, crop and the environment. *Int. Soil and Water Conserv. Res.*, **3**(2): 119–129.

Cárceles Rodríguez B., Durán-Zuazo, V.H, Soriano Rodríguez, M, García-Tejero I.F., Gálvez Ruiz, B. and Cuadros Tavira, S. 2022. Conservation agriculture as a sustainable system for soil health: A review. *Soil Syst*., **6**(4): 87.

Chappa, L.R., Mugwe, J., Maitra, S. and Gitari, H.I. 2022. Current status and prospects of improving sunflower production in Tanzania through intercropping with sunn hemp. *Int. J. Biores. Sci*., **09**: 01-08.

Choudhary, S., Pramanick, B., Maitra, S. and Kumar, B. 2021. Tillage practices for enhancing crop productivity under dryland conditions. *Just Agric*., **1**(5): 206 - 212.

Choudhary, S.G., Srivastava, S., Singh, R., Chaudhari, S., Sharma, D.K., Singh, S.K. and Sarkar, D. 2014. Tillage and residue management effects on soil aggregation, organic carbon dynamics and yield attribute in rice-wheat cropping system under reclaimed sodic soil. *Soil Till. Res*., **136**: 76-83.

Corsi, S., Friedrich, T., Kassam, A., Pisante, M. and de Moraes Sà, J.C. 2012. Soil organic carbon accumulation and greenhouse gas emission reductions from conservation agriculture: A literature review, integrated crop management (101 pp.). Vol. 16. Rome: AGP/FAO.

CTIC. 2004. Conservation Tillage Information Center. National crop residue management survey. West Lafayette, In: *Conservation Technology Information Center, Indiana*. Available online: https://www.ctic.org/resource_display/?id =255&title = CROP + RESIDUE + MANAGEMENT + SURVEY, accessed 29 August, 2023.

Dalal, R.C. 1992. Long-term trends in total nitrogen of a Vertisol subjected in zero tillage, nitrogen application and stubble retention. *Aust. J. Soil Res*., **30**: 223–231.

Deguine, J.P., Aubertot, J.N., Bellon, S., Côte, F., Lauri, P.E., Lescourret, F., Ratnadass, A., Scopel, E., Andrieu, N., Bàrberi, P., Becker, N., Bouyer, J., Brevault, T., Cerdan, C., Cortesero, A.M., Cerdan, C., Dangles, O., Delatte, H., Dinh, P.T.Y., Dreyer, H., Duru, M., Flor, R.J., Gardarin, A., Husson, O., Jacquot, M., Javelle, A., Justes, E., Lam, M.T.X., Launay, M., Van Le, V., Longis, S., Martin, J., Munier-Jolain, N., Thu Nguyen, N.T., Ngoc Nguyen, T.T., Penvern, S., Petit, S., Poisot, A.S., Robin, M.H., Rolland, B., Rusch, A., Sabourin, E., Sanguin, H., Sarthou, J.P., Sester, M., Simon, S., Sourisseau, J.M., Steinberg, C., Tchamitchian, M., Thoumazeau, A., Tibi, A., Tivet, F., Tixier, P., Trinh, X.T., Vialatte, A., Wyckhuys, K. and Lamichhane, J.R. 2023. Agroecological crop protection for sustainable agriculture. *Adv. Agron*., **178**: 1-59.

Dorneles, E.P., Lisboa, B.B., Abichequer, A.D., Bissani, C.A., Meurer, E.J. and Vargas, L.K. 2015. Tillage, fertilization systems and chemical attributes of a Paleudult. *Sci. Agric*., **72**: 175-186.

FAO. 2001. No-till agriculture for sustainable land management: Lessons: Learned from the 2000 Brazil study tour. Draft for TCI occasional paper series, No. 12. Rome: FAO Investment Centre Division. Available online: https://www.fao.org/documents/ card/en/c/bd13564e-9705-5d18-aff8- 8f4b96f59383, acceded 29 August, 2023.

FAO. 2023. Conservation agriculture. Food and Agriculture Organization of the United Nations. Available online: https://www.fao.org/conservation- agriculture/en/, accessed 29 August, 2023.

Fernandez, R.O., Fernandez, P.G., Cervera, J.V.G. and Torres, F.P. 2007. Soil properties and crop yields after 21 years of direct drilling trials in southern Spain. *Soil Till. Res*., **94**: 47-54.

Gaikwad, D.J., Ubale, N.B., Pal, A., Singh, S., Ali, M.A. and Maitra, S. 2022. Abiotic stresses impact on major cereals and adaptation options - A review. *Res. Crop*., **23**(4): 896–915.

Gajda, A.M., Czyz, E.A., Dexter, A.R., Furtak, K.M., Grządziel, J. and Tarkowska, J.S. 2018. Effects of different soil management practices on soil properties and microbial diversity. *Int. Agrophy*., **32**: 81-91.

Gitari, H.I., Nyawade, S.O., Kamau, S., Karanja, N.N., Gachene, C.K.K., Raza, M.A., Maitra, S. and Geldermann, E.S. 2020. Revisiting intercropping indices with respect to potato-legume intercropping systems. *Field Crops Res*., **258**: 107957

Hassan, W., Li, Y., Saba, T., Jabbi, F., Wang, B., Andong Cai, A. and Wu, J. 2022. Improved and sustainable agroecosystem, food security and environmental resilience through zero tillage with emphasis on soils of temperate and subtropical climate regions: A review. *Int. Soil Water Conserv. Res*., **10**(3): 530-545.

Hossain, A., Mottaleb, K.A., Maitra, S., Mitra, B., Ahmed, S., Sarker, S., Chaki, A.K. and Laing, A.M. 2021a. Conservation agriculture: next-generation, climate resilient crop management practices for food security and environmental health. In: *Conservation Agriculture: A Sustainable Approach for Soil Health and Food Security*, Aftab, T. and Hakeem, K.R. (eds.), Academic Press, pp. 585 - 609. DOI: https://doi.org/10.1016/B978-0-323-90943-3.00008-0.

Hossain, A., Mottaleb, K.A., Maitra, S., Mitra, B., Alam, M., Ahmed, S., Islam, M., Sarker, K. K., Sarker, S., Chaki, A.K., Muhammad, A.H., Skalicky, M., Brestic, M. and Laing, A. M. 2021b. Conservation agriculture improves soil health: major research findings from Bangladesh, In: *Conservation Agriculture: A Sustainable Approach for Soil Health and Food Security*, S. Jayaraman *et al*. (eds.), Springer, Singapore, pp. 511 - 561. DOI: https://doi.org/10.1007/978-981-16-0827-8_26.

Huang, D.D., Liu, S.X., Zhang, X.P., Xu, J.P., Wu, L.J. and Lou, Y.J. 2012. Constitute and organic carbon distribution of soil aggregates under conservation tillage. *J. Agro-Environ. Sci*., **31**: 1560-1565.

Islam, M.A., Sarkar, D., Alam, M.R., Jahangir, M.M.R., Ali, M.O., Sarker, D., Hossain, M.F., Sarker, A, Gaber, A., Maitra, S. and Hossain, A. 2023. Legumes in conservation agriculture: A sustainable approach in rice-based ecology of the Eastern Indo-Gangetic Plain of South Asia - an overview. *Tech. Agron*., **3**: 3.

Jacobs, A., Rauber, R. and Ludwig, B. 2009. Impact of reduced tillage on carbon and nitrogen storage of two Haplic Luvisols after 40 years. *Soil Tillage Res*., **102**: 158–164.

Kargas, G., Kerkides, P. and Poulovassilis, A. 2012. Infiltration of rain water in semi-arid areas under three land surface treatments. *Soil Tillage Res.*, **120**: 15–24.

Khan, S., Shah, A., Nawaz, M. and Khan, M. 2017. Impact of different tillage practices on soil physical properties, nitrate leaching and yield attributes of maize (*Zea mays* L.). *J. Soil Sci. Plant Nutr.*, **17**: 240–252.

Krauss, M., Berner, A., Perrochet, F., Frei, R., Niggli, U. and Mäder, P. 2020. Enhanced soil quality with reduced tillage and solid manures in organic farming – a synthesis of 15 years. *Sci. Rep.*, **10**: 4403.

Kumar, N., Ankur Chaudhary, A., Ahlawat, O.P., Naorem, A., Upadhyay, G., R.S. Chhokar, R.S., Gill, S.C., Khippal, A., S.C. Tripathi, S.C. and Singh, G.P. 2023. Crop residue management challenges, opportunities and way forward for sustainable food-energy security in India: A review. *Soil Tillage Res.*, **228**: 105641.

Lal, R. 1997. Long-term tillage and maize monoculture effects on a tropical Alfisol in western Nigeria. II. Soil chemical properties. *Soil Tillage Res.*, **42**: 161–174.

Maitra, S. and Gitari, H.I. 2020. Scope for adoption of intercropping system in organic agriculture. *Ind. J. Nat. Sci.*, **11**(63): 28624 - 28631.

Maitra, S. and Pine S. 2020. Smart irrigation for food security and agricultural sustainability. *Ind. J. Natural Sci.*, **10**(60): 20435 - 20439.

Maitra, S., Palai, J.B., Manasa, P. and Prasanna Kumar, D. 2019. Potential of intercropping system in sustaining crop productivity. *Int. J. Agric., Environ. Biotechnol.*, **12**(1): 39-45.

Maitra, S., Praharaj, S., Brestic, M., Sahoo, R.K., Sagar, L., Shankar, T., Palai, J.B., Sahoo, U., Sairam, M., Pramanick, B., Nath, S., Venugopalan, V.K., Skalicky, M. and Hossain. A. 2023. Rhizobium as biotechnological tools for green solutions: An environment-friendly approach for sustainable crop production in the modern era of climate change. *Curr. Microbiol.*, **80**: 219.

Maitra, S., Praharaj, S., Hossain, A., Patro, T.S.S.K., Pramanick, B., Shankar, T., Pudake, R. N., Gitari, H.I., Palai, J. B., Sairam, M., Sagar, L. and Sahoo, U. 2022. Small millets: The next-generation smart crops in the modern era of climate change. In: Omics of Climate Resilient Small Millets, Pukade, R.N., Solanke, A.U., Sevanthi, A.M., Rajendrakumar, P. (Eds.), Springer Nature, pp. 1 - 25.

Maitra, S., Sahoo, U., Sairam, M., Gitari, H.I., Rezaei-Chiyaneh, E., Battaglia, M.L. and Hossain, A. 2023b. Cultivating sustainability: A comprehensive review on intercropping in a changing climate. *Res. Crop,* **24**(4): 702-715.

Manasa, P., Maitra, S. and Barman S. 2020. Yield attributes, yield, competitive ability and economics of summer maize-legume intercropping system. *Int. J. Agric. Environ. Biotechnol.*, **13**(1): 33 - 38.

Mangalassery, S., Mooney, S.J., Sparkes, D.L., Fraser, W.T. and Sjogersten, S. 2015. Impacts of zero tillage on soil enzyme activities, microbial characteristics and organic matter functional chemistry in temperate soils. *Eur. J. Soil Biol.*, **68**: 9-17.

McVay, K.A., Budde, J.A., Fabrizzi, K., Mikha, M.M., Rice, C.W., Schlegel, A.J., Peterson, D.E., Sweeney, D.W. and Thompson, C. 2006. Management effects on soil physical properties in long-term tillage studies in Kansas. *Soil Sci. Soc. Ame. J.*, **70**: 434–438.

Melero, S., Lopez-Bellido, R.J., Lopez-Bellido, L., Munoz-Romero, V., Moreno, F. and Murillo, J. M. 2011. Long-term effect of tillage, rotation and nitrogen fertiliser on soil quality in a Mediterranean Vertisol. *Soil Till. Res.*, **114**: 97-107.

Memon, M.S., Guo, J., Tagar, A.A., Perveen, N., Ji, C., Memon, S.A. and Memon, N. 2018. The effects of tillage and straw incorporation on soil organic carbon status, rice crop productivity, and sustainability in the rice-wheat cropping system of Eastern China. *Sustainability*, **10**: 961.

Midya, A., Saren, B.K., Dey, J.K., Maitra, S., Praharaj, S., Gaikwad, D.J., Gaber, A., Alhomrani, M. and Hossain, A. 2021. Crop establishment methods and integrated nutrient management improve: Part II. nutrient uptake and use efficiency and soil health in rice (*Oryza sativa* L.) field in the lower indo-gangetic plain. *Ind. Agron.*, **11**(9): 1894.

Mirriam, A., Mugwe, J., Raza, M.A., Seleiman, M.F., Maitra, S. and Gitari, H.H. 2022. Aggrandizing soybean yield, phosphorus uses efficiency and economic returns under phosphatic fertilizer application and inoculation with *Bradyrhizobium*. *J. Soil Sci. Plant Nutr.*, **22**: 5086–5098.

Morugán-Coronado, A., Pérez-Rodríguez, P., Insolia, E., Soto-Gómez, D., David Fernández-Calviño, D. and Raúl Zornoza, R. 2022. The impact of crop diversification, tillage and fertilization type on soil total microbial, fungal and bacterial abundance: A worldwide meta-analysis of agricultural sites. *Agric., Ecosyst. Environ.*, **329**: 107867.

Nandi, S., Panda, M., Sairam, M., Palai, J.B. and Sahoo, U. 2022. Suitable options for agricultural waste management in India. *Ind. J. Nat. Sci.*, **13**(71): 41421 - 41426.

Nduwimana, D., Mochoge, B., Danga, B., Masso, C., Maitra, S. and Gitari, H.I. 2020. Optimizing nitrogen use efficiency and maize yield under varying fertilizer rates in Kenya. *Int. J. Bioresour. Sci.*, **7**(2): 63 - 73.

Neogi, S. and Ghosh, B.K. 2022. Evaluation of Crop Diversification on Indian Farming Practices: A Panel Regression Approach. *Sustainability*, **14**: 16861.

Palai, J.B., Malik G.C., Maitra S. and Banerjee, M. 2021. Role of Rhizobium on Growth and Development of Groundnut: A Review. *Int. J. Agric. Environ. Biotechnol.*, **14**(1): 63-73.

Panda, M., Nandi, S., Sahoo, U. and Sairam, M. 2022b. Integrated farming system for agricultural sustainability. *Indian J. Nat. Sci.*, **13**(71): 41311-41317.

Panda, M., Sairam, M., Sahoo, U. and Maitra, S. 2022a. Adverse impacts of abiotic stresses on major cereals and climate resilient adaptation options. *Ind. J. Nat. Sci.*, **13**(71): 44434 - 44440.

Panda, S.K., Panda, P., Pramanick, B., Shankar, T., Praharaj, S., Saren, B.K., Gitari, H.I., Brahmachari, K., Hossain, A. and Maitra, S. 2020. Advantages of cotton based intercropping system: A review. *Int. J. Biores. Sci.*, **7**(2): 51 - 57.

Pramanick, B., Kumar, M., Naik, B.M., Kumar, M., Singh, S.K., Maitra, S., Naik, B.S.S.S., Rajput, V.D. and Minkina, T. 2022. Long-term conservation tillage and precision nutrient management in maize–wheat cropping system: effect on soil properties, crop production, and economics. *Agronomy*, **12**: 2766.

Pramanick, B., Kumar, M., Singh, S.K., Kumari, S. and Maitra, S. 2021. Soil-centric approaches towards climate-resilient agriculture. In: *Soil Sci.: Fundamentals to Recent Advances*, Rakshit, A., Singh, S., Abhilash, P., Biswas, A. (eds.), Springer, Singapore, https://doi.org/10.1007/978-981-16-0917-6-17.

Rahman, M.H., Okubo, A., Sugiyama, S. and Mayland, H.F. 2008. Physical, chemical and microbiological properties of an Andisol as related to land use and tillage practice. *Soil Tillage Res.*, **101**: 10–19.

Rasmussen, K.J. 1999. Impact of ploughless soil tillage on yield and soil quality: A Scandinavian review. *Soil Tillage Res.*, **53**: 3–14.

Sadiq, M., Li, G., Rahim, N. and Tahir, M.M. 2021. Sustainable conservation tillage technique for improving soil health by enhancing soil physicochemical quality indicators under wheat mono-cropping system conditions. *Sustainability*, **13**: 8177.

Sagar, L., Singh, S., Sharma, A., Maitra, S., Attri, M., Sahoo, R.K., Ghasil, B.P., Shankar, T., Gaikwad, D.J., Sairam, M., Sahoo, U., Hossain, A. and Roy, S. 2023. Role of soil microbes against abiotic stresses induced oxidative stresses in plants. In *Rhizosphere Biology: Microbial symbionts and plant health: Trends and applications for changing climate,* Mathur, P., Kapoor, R. and Roy, S. (eds.), Springer Nature Singapore, pp.149-77.

Sahoo, U., Maitra, S., Dey, S., Vishnupriya, K.K., Sairam, M. and Sagar, L. 2023a. Unveiling the potential of maize-legume intercropping system for agricultural sustainability: A review. *Farm. Manage.*, **8**(1): 1 - 13.

Sahoo, U., Maitra, S., Sairam, M. and Sagar, L. 2023b. Potential and advantage of pearl millet-legume intercropping system: A review. *Int. J. Bioresour. Sci.*, **10**(01): 99-106.

Sairam, M., Maitra, S., Praharaj, S., Nath, S., Shankar, T., Sahoo, U. and Aftab, T. 2023b. An insight into the consequences of emerging contaminants in soil and water and plant responses. In: *Emerging contaminants and plants: Interactions, adaptations and remediation technologies*, Aftab, T. (eds.), Cham, Springer International Publishing. pp. 1–27.

Sairam, M., Maitra, S., Sagar, L., Gopala Krishna, T. and Sahoo, U. 2023a. Precision nutrient management on the growth and productivity of Rabi maize (*Zea mays* L.) under light textured brown forest soils of Odisha. *Res. Crop.*, **24**(3): 487-495.

Sairam, M., Mondal, T.K., Gaikwad, D.J., Pramanick, B. and Maitra, S. 2023c. Conservation agriculture impacts on soil organic carbon and soil properties, In: *Advances in Agricultural Technology*, Maitra, S., Gaikwad, D.J. and Santosh, D.T. (eds.), Published by Griffon, Canada, 267 - 283.

Sairam, M., Shankar, T., Maitra, S. and Duvvada, S.K. 2020. Effect of integrated nutrient management on growth, yield, nutrient content and economics of summer rice (*Oryza sativa* L.). *Ind. J. Pure Appl.Biosci.*, **8**(3): 421 - 427.

Santosh, D.T. and Maitra, S. 2022. Effect of drip irrigation and plastic mulch on yield and quality of ginger (*Zingiber officinale*). *Res. Crop.*, **23**(1): 211 - 219.

Santosh, D.T., Tiwari, K.N. and Maitra, S. 2021. Influence of drip irrigation and plastic mulch on young cashew (*Anacardium occidentale* L.). *Int. J. Bioresour. Sci.*, **8**(2): 87 - 92.

Sarkar, R.K., Shit, D. and Maitra, S. 2000. Competition functions, productivity and economics of chickpea (*Cicer arietinum*)-based intercropping system under rainfed conditions of Bihar plateau. *Indian J. Agron.*, **45**(4): 681-686.

Sekaran, U., Sagar, K.S. and Kumar, S. 2021. Soil aggregates, aggregate-associated carbon and nitrogen, and water retention as influenced by short and long-term no-till systems. *Soil Tillage Res.*, **208**: 104885.

Shahane, A.A. and Shivay, Y.S. 2021. Soil health and its improvement through novel agronomic and innovative approaches. *Front. Agron.*, **3**: 680456.

Shukla, M.K., Lal, R.B., Owens, L. and Unkefer, P. 2003. Land use management impacts on structure and infiltration characteristics of soils in the north Appalachian region of Ohio. *Soil Sci.*, **168**: 167–177.

Silburn, D.M., Freebairn, D.M. and Rattray, D.J. 2007. Tillage and the environment in sub-tropical Australia—Tradeoffs and challenges. *Soil Tillage Res.*, **97**: 306–317.

Su, Z., Zhang, J., Wu, W., Cai, D., Lv, J. and Jiang, G. 2007. Effects of conservation tillage practices on winter wheat water-use efficiency and crop yield on the Loess Plateau, China. *Agric. Water Manag.*, **87**: 307–314.

Szostek, M., Szpunar-Krok, E., Pawlak, R., Stanek-Tarkowska, J. and Ilek, A. 2022. Effect of different tillage systems on soil organic carbon and enzymatic activity. *Agronomy*, **12**: 208.

Tomar, S., Manepalli, S.B., Gaikwad, D.J. and Maitra, S. 2021. A review on molecular mechanisms of Wheat (*Triticum aestivum* L.) and rice (*Oryza sativa* L.) against abiotic stresses with special reference to drought and heat. *Int. J. Agri., Environ. Biotechnol.*, **14**(2): 215 - 222.

UN 2023. Global issues: Population. Available online: https://www.un.org/en/global-issues/population#:~:text=The%20world%20population%20is%20projected,and%2010.4%20billion%20by%202100, accessed 29 August, 2023.

Ussiri, D.A.N. and Lal, R. 2009. Long-term tillage effects on soil carbon storage and carbon dioxide emissions in continuous corn cropping system from an Alfisol in Ohio. *Soil Till. Res.*, **104**: 39-47.

Ussiri, D.A.N., Lal, R. and Jarecki, M.K. 2009. Nitrous oxide and methane emissions from long term tillage under a continuous corn cropping system in Ohio. *Soil Till. Res.*, **104**: 247-255.

Veiga, M., Reinert, D.J., Reichert, J.M. and Kaiser, D.R. 2008. Short and long-term effects of tillage systems and nutrient sources on soil physical properties of a southern Brazilian hapludox. *R. Bras. Ci. Solo.*, **32**: 1437-1446.

Wang, Z., Liu, L., Chen, Q., Wen, X. and Liao, Y. 2016. Conservation tillage increases soil bacterial diversity in the dryland of northern China. *Agron. Sustain. Dev.*, **36**: 28

Wardak, D.L.R., Padia, F.N., de Heer, M.I., Sturrock, C.J. and Mooney, S.J. 2022. Zero tillage has important consequences for soil pore architecture and hydraulic transport: A review. *Geoderma*, **422**: 115927.

Yuan, J., Sadiq, M., Rahim, N., Tahir, M.M., Liang, Y., Zhuo, M., Yan, L., Shaheen, A., Mahmood, B. and Li, G. 2023. Changes in soil properties and crop yield under sustainable conservation tillage systems in spring wheat agroecosystems. *Land*, **12**(6): 1253.

Zahan, T., Hossain, M.F., Chowdhury, A.K., Ali, M.O., Ali, M.A., Dessoky, E.S., Hassan, M.M., Maitra, S. and Hossain, A. 2021. Herbicide in weed management of wheat (*Triticum aestivum* L.) and rainy season rice (*Oryza sativa* L.) under conservation agricultural system. *Agronomy*, **11**(9): 1704.

Zhang, Y., Dalal, R.C., Bhattacharyya, R., Meyer, G., Wang, P., Menzies, N.W. and Kopittke, P.M. 2021. Effect of long-term no-tillage and nitrogen fertilization on phosphorus distribution in bulk soil and aggregates of a Vertisol. *Soil Till. Res.*, **205**: 104760.