THEORETICAL BIOLOGY FORUM

TBF: 393-399 (2023)
Review Article

Impact of conservation agriculture on soil properties and crop yields: A review

Bhawna Babal[1*], M.K. Sharma[2], Gaytri Hetta[3], Hemali Bijani[1], Bhawna Sheoran[4] and V.K. Phogat[2]

[1]Department of Soil Science, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur-176062, India
[2]Department of Soil Science, CCS Haryana Agricultural University, Hisar-125004, India
[3]Department of Agronomy, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur-176062, India
[4]Regional Centre for Biotechnology (RCB), Faridabad, Haryana-121001, India

ABSTRACT

Yield stagnation and soil degradation is a major concern nowadays that could possibly be overcome by the use of conservation agriculture (CA) which is a set of management practices vitally important for sustaining and increasing productivity and profitability in agriculture. Based on various studies conducted, the effects of CA on soil properties are highly variable in different soil types, locations, and cropping systems. This present review examines the relevant literature on CA to provide better insight and understanding of its effect on soil properties and crop yields. This article discusses on the aspects of soil health by adopting the CA in terms of the amount of organic matter, alteration in pore-sizes and their distribution, facilitating retention and movement of water, ensuring proper aeration, moderating temperature, maintaining biomass and diversity, influencing pH and cation exchange capacity, and reducing sub-surface compaction facilitating plant roots to penetrate deeper in the soil profile. The CA largely improves the yield of different crops under long-term experiments while a decline in yields has been observed during the conversion period or short-term experiments. The review concludes that though there is inadequate knowledge for managing functional CA systems under all conditions, but its underlying principles may provide the basis for developing new practices to sustain productivity while maintaining the quality of both the soil and the environment.

Keywords- *Conservation agriculture, cropping systems, soil microorganisms, soil properties, zero tillage*

ARTICLE HISTORY
08 November 2022: Received
27 February 2023: Revised
15 May 2023: Accepted
02 August 2023: Available Online

DOI:
https://doi.org/10.61739/TBF.2023.12.2.393

CORRESPONDING AUTHOR:
Bhawna Babal

E-MAIL ID: **bhawnababal10@gmail.com**

Introduction

There are sufficient evidences that the persistent use of conventional farming practices through extensive tillage practices, especially, when combined with removal or *in-situ* burning of crop residues is, though, high yielding but costly and environmentally unsustainable. It causes soil erosion losses and steadily declines the soil's organic carbon [1]. In this scenario, instead of conventional agricultural systems, it is necessary to adopt and adapt conservation agriculture (CA), a crop production system that retains crop residues on the soil surface with zero or reduced tillage and follows diversified cropping systems, and in turn, enhances the natural biological processes above and below the ground.

The CA is a set of management principles that assures sustainable production. It emphasizes (i) zero tillage with minimal soil disturbance, (ii) retention of crop residues to protect the soil from erosion, reduce run-off and evaporation, enhance soil physical, chemical, and biological properties, and (iii) diversifying crop rotations to help mitigate weed, disease and pest problems and improve the productivity of subsequent crop [1]. These principles may be applied to a wide range of crop production systems from low-yielding dry and rainfed conditions to high-yielding irrigated situations. The specific and compatible management components, however, need to be identified through adaptive research.

In India, more than half of the dry matter produced annually, particularly, under the rice-wheat cropping system is inedible organic biomass [2] and is burnt in the fields with the sole intention to clear the field for sowing the succeeding crops which causes loss of nutrients as well as pollutes the environment. Under the CA system, the zero-tillage practice is considered as one of the potential ecological approaches [3] for better crop residue management resulting in energy saving, solving weed problems and higher or equal yields [4] while the inclusion of legumes in rotation presumes a greater significance to soil fertility. The CA primarily aims at a saving of resources and resource-conserving technology related to land preparation is called conservation tillage which has been defined in 1984 by the Soil Conservation Service of USA as any tillage and planting system in which at least 30 percent of the soil surface is covered by residue, *viz.* mulch tillage, ridge tillage, and zero tillage.

The impact of CA, however, varies widely across cropping systems, soil types and climatic conditions, therefore, needs to be examined closely. An attempt has been made to review the relevant and recent literature on the impact of conservation agriculture on different soil properties under the following heads:

Influence of conservation agriculture on the physical properties of soil

Soil aggregation: Under CA system, zero tillage with residue retention increases soil aggregation as compared to conventional tillage [5] as tillage breaks the soil aggregates [6] and fragments roots and mycorrhizal hyphae which bind the macroaggregates [7]. Surface residues protect the soil aggregates against raindrop impact [8]. Under zero tillage, higher accumulation of organic matter in surface soil reduces slaking and disintegration of aggregates upon wetting while tillage mixes soil organic matter in the tilled layer leading to the disintegration of soil aggregates [9].

Diversifying crop rotations influence soil organic carbon (SOC) content by changing the quantity and quality of organic matter input to the soil and soil aggregation indirectly. Hajabbasi and Hemmat [10] reported a higher mean weight diameter under no-till with continuous wheat in clay-loam soil (Calcic Cambisol). Better soil aggregation under the reduced tillage indicated less soil disturbance coupled with the addition of crop residues on the surface compared with conventional tillage [11]. The rooting system of plants is considered important for the formation of macro-aggregates, significantly higher number of macro-aggregates was observed in soils under wheat than in maize [12] due to higher plant population and horizontal growing root system of wheat [13]. The influence of diversified crop rotation on soil microbial biomass and bacterial diversity further enhances soil aggregation [14].

Bulk density: Soil bulk density is fundamental to soil compaction and related to agricultural management issues [15]. Studies involving the impact of CA systems on soil bulk density have, however, reported contradictory results. In some studies, a greater soil bulk density was observed under CA than in conventional agriculture [16], in some experiments, it was lower [15]; [17] while in some cases no difference was observed under the two agricultural systems [18]; [19]. In general, the effect of CA is mainly confined to plough layer [19] and tillage under certain conditions may however, form a plough pan immediately beneath the usually tilled soil layer [20]. Bulk density in the surface soil layer was reported to be lower under traditional agriculture due to frequent tilling and loosening while it was lower under CA in the sub-surface owing to the addition of crop residues leading to higher SOC and consequently better aggregation [21].

Porosity*:* Porosity varies according to the changes in bulk density values in response to different agricultural systems. Micro and mesopores are, in general, reported to be higher in zero than conventional tillage but in some cases, no effect of tillage was observed [22]. Yoo *et al.* [23] reported no influence of residue management and crop rotation on pore-size distribution whereas, Blanco-Canqui and Lal [18] observed higher volume of mesopores (5-25 μm) in the surface 3 cm soil layer under zero tillage with residue than without residue retention. Macropores increase with the disturbance of soil by tillage. When soils are converted to CA, macroporosity is reduced which is compensated with time by the creation of macropores from roots and faunal activities [24]. Significantly lower macropores in the surface 10 cm soil under short-term CA (5 years) were also reported by Mondal *et al.* [25] although mesopore volume was higher under CA while Yoo *et al.* [23] did not find consistent results in silty clay loam and silt loam soils. In the surface 5 cm soil layer of a 24-year-old experiment on a Paleustalf in Australia, the volume of pores > 60 μm was significantly higher under zero tillage with residue retention than conventional tillage with residue burnt [26].

Hydraulic conductivity and water retention: Studies have largely shown CA as an effective practice to increase hydraulic conductivity of soil due to an increase in a number of bio pores [27]; [28]. The residue mulch was found to increase the soil's capacity to retain water from saturation to permanent wilting point in the surface 0-10 cm of a silt loam soil in Central Ohio (USA) [18]. Such results were also confirmed in some other studies [28], [29] while in some cases inconsistent results were observed [30], [31].

Infiltration: Despite the inconsistent values of hydraulic conductivity in some of the studies on CA, infiltration is generally observed higher than under conventional agriculture as surface residues prevent aggregate breakdown [8], crust formation [32], increases the volume of macro-pores [33] and make the aggregates more stable [5] possibly due to the improved aggregate stability and the greater number and continuity of macropores [15], [34]. In addition, the residues act as a barrier, reducing the runoff velocity and providing the water more time to infiltrate [35]. However, reduced tillage without residue retention led to decreased infiltration due to the sealing of surface soil [36].

Soil temperature*:* Surface residues in CA reflect solar radiation and insulate the soil surface and conserve moisture [37]. As soil particles have a lower heat capacity and greater heat conductivity than water, the dry soil potentially warms and cool faster than moist, usually observed under CA systems. Soil temperatures in surface layers become significantly lower during the day in the summer season and higher during the night due to the insulation effect of the residues, and hence, moderation of soil temperature [38]. However, some studies reported that CA did not have a significant influence on soil temperature [39] while several others emphasized the influence of crop residue and other surface mulches in CA on soil temperature [40] by changing soil thermal properties.

Soil moisture*:* The tillage and cropping systems are reported to significantly affect the soil moisture content. The soil moisture was found to be significantly higher under reduced tillage over conventional in the surface 15 cm soil depth owing to higher evaporation losses and absence of residues in the tilled soil and it was higher under soybean–wheat than soybean + pigeon pea cropping system [39]. Similarly, various other workers also reported higher moisture content under CA in various crops [17], [41] due to greater rates of infiltration and decreased soil water evaporation [34].

Soil penetration resistance: Soil penetration resistance is a relatively credible and useful indicator for rapid evaluation of soil strength and structural changes [42]. The adoption of CA significantly reduced the penetration resistance for 5-35 cm soil depth [39]. The decrease in penetration resistance may be due to higher moisture retention under CA. Therefore, adoption of CA may reduce soil compaction subsequently improving aeration, root growth and availability of moisture and nutrients [43], [86].

Influence of conservation agriculture on chemical properties of soil

Soil organic carbon*:* Soil organic carbon content (SOC) is sensitive to tillage practices, crop residue return, and nitrogen management [44]. Because of less soil disturbance under CA, the plant residues, fertilizers and other soil amendments do not get mixed into the soil, and plant roots tend to proliferate in top few centimeters resulting in a higher accumulation of SOC in surface layers. Intensive tillage in conventional agriculture redistributes SOC in the soil profile leading to higher SOC in the subsurface [87]. Consequently, SOC contents under CA compared with that under conventional may be overstated if the entire plow depth is not considered [45]. Baker *et al.* [46] also suggested sampling of the entire soil profile for accounting differences in SOC between management practices. Govaerts *et al.* [47] reviewed the literature to assess the influence of the different components of conservation agriculture (reduced tillage, crop residue retention, and crop rotation) on SOC. They found that out of 78 cases, the SOC content was lower in 7, higher in 40 and similar in 31 cases. The mechanisms governing the balance among lower, similar and higher SOC after conversion to CA are still not very clear, therefore, these results emphasize the need for further research on CA, especially, in tropical areas where good quantitative information is lacking in literature.

Ogle *et al.* [48] found management impacts sensitive to climate. The changes in SOC were greater in tropical moist > tropical dry > temperate moist and least in a temperate dry climate. They reported that the biochemical kinetics of the processes involved with the breakdown of soil organic matter following cultivation, formation of soil aggregates after a change in tillage, and increased productivity and carbon input with a new cropping system are likely to occur at a more favorable rate under the temperature regimes of tropical regions and in humid climatic conditions. As crop residues are precursors of SOC pool, therefore, returning more crop residues to soil is associated with an increase in SOC [49]. In Canada, replacement of fallow lands with legume (green manuring) found an effective practice for enhancing SOC contents [50]. Legume crops were also found to enhance soil fertility and crop productivity by providing additional N to the system [51]. The CA system may also increase the possibility for crop intensification due to a faster turnaround time between harvesting and planting of next crop. In some situations, it may be possible to take an extra crop in the system after the main crop, inter-cropping or relay cropping with the main crop [52].

From a database of 67 long-term experiments, West and Post [53] found that enhancing rotation complexity did not increase SOC much as compared to the increase with a shift to zero tillage but crop rotation was more effective in retaining C and N in soil than monoculture. Legume-based cropping systems increased C and N contents due to the higher residue input in 17 years long experiments [54]. Introducing legumes in rotation enhances the N by symbiotically fixed N [55] but changing from continuous maize to maize–soybean rotation did not increase SOC due to the production of more residues and C input with continuous maize [53]. Gregorich *et al.* [56] reported higher SOC content below the plough layer in legume-based rotations than under monoculture maize. Thus, the zero tillage with residue retention (CA) enhances SOC in surface layers and legumes in crop rotation enhance this entity to deeper layers in the soil profile.

pH*:* Decomposition processes of a large number of crop residues by soil microbes under CA systems were found to lower the pH of the surface 5 cm soil as compared to conventional tillage systems [57], although some authors observed this decline upto a depth of 60 cm [58]. In contrast, Duiker and Beegle [59], however, suggested that the higher soil organic matter content under CA buffers the soil pH and proposed that greater leaching under CA systems removes bases leading to a lower pH.

Cation exchange capacity: Although CEC is largely considered to be an inherent soil property it may be influenced by changes to SOM and pH [60]. Contradictory results have been reported on the influence of CA on CEC. It was found to be higher in some studies due to an increase in negative charge associated with increased SOC [61]. In some experiments, a decrease in CEC was reported possibly due to decreased pH-dependent charge upon a decrease in pH under CA [62] while some studies reported no change in CEC under CA [63], [64].

Influence of conservation agriculture on soil microorganisms

Shifting to CA systems induces major shifts in the number and composition of soil fauna and flora including both pests and beneficial organisms [65] and, in turn, has an impact on physico-chemical conditions of soil, *i.e.*, soil structure, nutrient cycling, and organic matter decomposition. Bacteria, fungi, actinomycetes, and algae are included in the microflora and the remaining groups of interest are usually referred to as soil fauna. Microfauna is small (< 0.2 mm), and live in the water-filled pore space comprising mainly of protozoa and nematodes. Mesofauna includes microarthropods (mites and springtails) and small Oligochaeta (0.2-2 mm) living in air-filled pore spaces of soil and litter. Macrofauna (>2 mm) include termites, earthworms, and large arthropods having the ability to dig soil, sometimes called 'ecosystem engineers' because of their large impact on soil structure. CA has been found to increase both population and diversity of microflora [83] may be due to more diversified cropping rotations.

Soil management influences microorganisms and the associated processes through changes in the quantity and quality of plant residues entering the soil, their seasonal and spatial distribution, and changes in nutrient inputs [85]. The soil microbial biomass (SMB) reflects the changes in soil management practices and the organic carbon input from plant biomass. In CA systems, the SMB is, generally larger than in conventional agriculture systems [39] and decreases as the degree of tillage in the agricultural system is increased [82] but it remains strongly dependent on soil conditions. Under CA, higher levels of C substrates are available in the soil for growth of the microorganisms along with better soil aeration, temperature, and moisture [65]. While examining the effects of several rotations (a component of CA system) under dryland on Vertisols in cotton-based systems in Australia, Bell *et al.* [66] found microbial activity related to the length of fallow rather than the rotation *per se*, and restricted to the surface layers. Monoculture of maize under CA resulted in increased SMB compared to the conventional tillage but no such differences in this entity were observed under maize-wheat rotation because of the buffering tendency of wheat in the rotation against C depletion in soil [67].

Influence of conservation agriculture on crop yields

There are contradictory results regarding the effect of CA on the yields of different crops. Some workers reported higher yields under CA [68], [41], others showed no significant difference [36], [69] while others showed a significant reduction in yield of different crops upon adoption of CA [70], [71].

Zero tillage was reported to have a grain and biomass yield advantage of 6% and 10%, respectively, over conventional tillage in maize [72]. Similarly, a higher yield of garlic bulbs was reported under zero than conventional tillage in Bangladesh [73]. The higher yields under CA have mainly been attributed to better moisture storage in drier areas [74]; improved soil fertility and nutrient cycling [75]; better soil physical conditions [33] timely sowing of crops (due to omission of land preparation) leading to better crop growth and yields [76]. Adimassu *et al.* [77] showed that significantly lower grain and biomass yield of wheat crops was recorded under zero tillage without residue retention over conventional tillage with residue retention in the humid highlands of Ethiopia. Similar results were reported in teff (*Eragrostis tef, Zucc.*) by Fufa *et al.* [78]. The lower yields under CA may be due to higher disease and pest infestation [79]; waterlogging in higher rainfall areas with poorly drained soils [80], and lack of access to effective seeding equipment and required inputs in adequate quantities [81].

Conclusion

The literature reviewed suggests that shifting to CA systems increases organic matter and improves aggregation in soils under different agroecological regions. These systems may affect the bulk density and porosity of soils, particularly, in surface layers. Infiltration remains higher, evaporation reduces, moisture is conserved, penetration resistance decreases, temperature moderates, and interconnectivity of bio pores and channels created by the roots remains maintained. The effect of CA on the yield of different crops is highly location/site- specific and governed by the climatic and soil conditions, and management practices in addition to tillage practices and crop rotations. The CA provides micro-organisms with enough substrates for their multiplication. It may be concluded that, though there is inadequate knowledge for managing functional CA systems under all conditions but its underlying principles may provide the basis for developing new practices to sustain productivity while maintaining the quality of both the soil and the environment.

References

1. Ramnarine R, VoroneyRP, Dunfield KE, ClaudiaWR(2018) Characterization of the heavy, hydrolysable and non-hydrolyzable fractions of soil organic carbon in conventional and no-tillage soils. *Soil Till Res*181: 144-151.

2. Singh A, Kaushal M, Singh H (2012) Improvement in productivity of wheat with crop residue and nitrogen- a review.Asian J Biol Sci1: 139-146.

3. Sanaullah M, Usman M, Wakeel A, Cheema SA, Ashraf I, Farooq M (2020) Terrestrial ecosystem functioning affected by agricultural management systems: a review. Soil Till Res196: 104464.

4. Kumar V, Gathala MK, Saharawat YS, Parihar CM, Kumar R, Kumar R, Jat ML, Jat AS, Mahala DM, and Kumar *et al.* (2019) Impact of tillage and crop establishment methods on crop yields, profitability, and soil physical properties in rice-wheat system of Indo- Gangetic Plains of India. Soil Use Manage35: 303-313.

5. Govaerts B, Sayre KD, Goudeseune B, De Corte P, Lichter K, Dendooven L,Deckers J (2009) Conservation agriculture as a sustainable option for the central Mexican highlands. *Soil Till Res* 103: 222-230.

6. Ashagrie Y,Zech W, Guggenberger G, Mamo T (2007). Soil aggregation, and total and particulate organic matter following conversion of native forests to continuous cultivation in Ethiopia. Soil Till Res94:101-108.

7. Helgason B, Walley F,Germida J (2009) Fungal and Bacterial Abundance in Long-Term No-Till and Intensive-Till Soils of the Northern Great Plains. Soil Sci Soc Am J73: 120-127.

8. Six J, Elliott ET,Paustian K (2000) Soil macroaggregate turnover and micro aggregate formation: a mechanism for C sequestration under no-tillage agriculture.Soil BiolBiochem32: 2099-2103.

9. Morlue B, Kamau S, Ayuke FO, Kironchi G (2021) Land use change, but not soil macrofauna, affects soil aggregates and aggregate-associated C content in central highlands of Kenya. J Soils Sediments21:1360-1370.

10. Hajabbasi MA, Hemmat A (2000) Tillage impacts on aggregate stability and crop productivity in a clay-loam soil in central Iran. Soil Till Res56: 205-212.

11. Somasundaram J, Reeves S, Wang W, Heenan M,Dalal R (2017) Impact of 47 years of no-tillage and stubble retention on soil aggregation and carbon distribution in a Vertisol. Land Degrad Dev28: 1589-1602.

12. Lichter K, Govaerts B, Six J, Sayre KD, Deckers J, Dendooven L (2008) Aggregation and C and N contents of soil organic matter fractions in a permanent raised-bed planting system in the Highlands of Central Mexico. Plant Soil305: 237-252.

13. Denef K, Six J (2005) Clay mineralogy determines importance of biological and abiotic processes for macroaggregate formation and stabilization.*Eur J Soil Sci*56: 469-79.

14. Six J, Bossuyt H, Degryze S, Denef K (2004) A history of research on the link between (micro)aggregates, soil biota, and soil organic matter dynamics. Soil Till Res79:7-31.

15. Blanco-Canqui H, Ruis SJ (2018) No-tillage and soil physical environment. Geoderma326: 164-200.

16. Moraes, MT, Debiasi H, Carlesso R,Franchini JC, da Silva VR, Da Luz FB (2016) Soil physical quality on tillage and cropping systems after two decades in the subtropical region of Brazil. Soil Till Res155: 351-362.

17. Babal B, Phogat VK, Sharma MK, Ahlawat S (2020) Impact of long-term conservation agriculture induced changes in soil properties on persistence of pendimethalin under different cropping systems. Soil Res59: 299-308.

18. Blanco-Canqui H, Lal R (2007) Impacts of long-term wheat straw management on soil hydraulic properties under no-tillage.Soil Sci Soc Am J71: 1166-1173.

19. D'Haene K, Vermang J, Cornelis WM, Leroy BLM, Schiettecatte W, De Neve S, Gabriels D,Hofman G (2008) Reduced tillage effects on physical properties of silt loam soils growing rootcrops.Soil Till Res99: 279-290.

20. Pal D, Phogat VK (2005) Effect of deep tillage and gypsum application on yield, and N, P, K and S uptake by mustard. J Indian Soc Soil Sci53:134-136.

21. Verhulst N, Govaerts B, Verachtert E, Castellanos-Navarrete A, Mezzalama M, Wall P, Decker J, Sayre KD (2010) Conservation agriculture, improving soil quality for sustainable production systems? In 'Advances in soil science: food security and soil quality'. (Eds R Lal, BA Stewart) pp. 137-208. (CRC Press: Boca Raton, FL, USA)

22. Azooz RH, Arshad MA (1996) Soil infiltration and hydraulic conductivity under long-term no-tillage and conventional tillage systems. *Can J Soil Sci*76:143-152.

23. Yoo GY, Nissen TM, Wander MM (2006) Use of physical properties to predict the effects of tillage practices on organic matter dynamics in three Illinois soils.J Environ Qual35: 1576-1583.

24. Kay BD,VandenBygaart AJ (2002) Conservation tillage and depth stratification of porosity and soil organic matter. Soil Till Res66: 107-118.

25. Mondal S, Poonia SP, Mishra JS, Bhatt BP, Karnena KR, Saurabh K, Kumar R, Chakraborty D (2020) Short-term (5 years) impact of conservation agriculture on soil physical properties and organic carbon in a rice-wheat rotation in the Indo-Gangetic plains of Bihar.Eur J Soil Sci71:1076-1089.

26. Zhang SL, Simelton E, Lovdahl L, Grip H, Chen DL (2007) Simulated long-term effects of different soil management regimes on the water balance in the Loess Plateau, China. Field Crop Res100:311-319.

27. Schwen A, Bodner G, Scholl P, Buchan GD,Loiskandl W (2011) Temporal dynamics of soil hydraulic properties and the water-conducting porosity under different tillage. *Soil Till Res*113: 89-98.

28. Castellini M, Ventrella D (2012) Impact of conventional and minimum tillage on soil hydraulic conductivity in typical cropping system in southern Italy. Soil Till Res124: 47-56.

29. Azimzadeh SM (2012) Conservation tillage in Mediterranean climate (a review). Adv Environ Biol6:1880-1890.

30. Liebig MA, Tanaka DL,Wienhold BJ (2004) Tillage and cropping effects on soil quality indicators in the northern Great Plains. Soil Till Res78: 131-141.

31. Sharratt B, Zhang MC, Sparrow S (2006) Twenty years of conservation tillage research in subarctic Alaska - II. Impact on soil hydraulic properties. Soil Till Res91: 82-88.

32. Lal R, Shukla MJ (2004) Principles of Soil Physics. New York: Marcel Dekker

33. Mondal, S, Das TK, Thomas P, Mishra AK (2019) Effect of conservation agriculture on soil hydro-physical properties, total and particulate organic carbon and root morphology in wheat (*Triticum aestivum*) under long-term tillage management practices.Indian J Agric Sci89: 46-55.

34. Li Y, Li Z, Cui S, Jagadamma S, Zhang QP (2019) Residue retention and minimum tillage improve physical environment of the soil in croplands: a global meta-analysis. Soil Till Res 194:104292.

35. Lampurlanés J, Cantero-Martínez C (2006) Hydraulic conductivity, residue cover and soil surface roughness under different tillage systems in semiarid conditions. Soil Till Res85: 13-26.

36. Baudron F, Tittonell P, Corbeels M, Letourmy P, Giller KE (2012) Comparative performance of conservation agriculture and current smallholder farming practices in semi-arid Zimbabwe. Field Crops Res132:117-128.

37. Hillel D (1998) Environmental Soil Physics. San Diego, CA, USA: Academic Press.

38. Oliveira JCM, TimmLC, Tominaga TT, Cassaro FAM, Reichardt K, Bacchi OOS, Dourado-Neto D, Camara GMD (2001) Soil temperature in a sugarcane crop as a function of the management system. Plant Soil230: 61-66.

39. Somasundaram J, Salikram M, Sinha NK, Mohanty M, Chaudhary RS, Dalal RC, *et al.* (2019) Conservation agriculture effects on soil properties and crop productivity in a semiarid region of India. Soil Res57: 187-199.

40. Shen Y, McLaughlin N, Zhang X, Xu M, Liang A (2018) Effect of tillage and crop residue on soil temperature following planting for Black soil in Northeast China. Sci Rep8: 1-9.

41. Page KL, Dang YP, Dalal RC, Reeves, S, Thomas G, Wang W,Tompson, JP (2019) Changes in soil water storage with no-tillage and crop residue retention on a Vertisol: impact on productivity and profitability over 50 years. Soil Till Res194: 104319.

42. Lowery B, Morrison JE (2002) Soil penetrometers and penetrability. In 'Methods of soil analysis. Part 4. Physical methods'. (Eds JH Dane, GC Topp) pp. 363-388. (Soil Science Society of America: Madison, WI, USA).

43. Busaria MA, Kukal SS, Kaur A, Bhatt R,Dulazi, AA (2015) Conservation tillage impacts on soil, crop and the environment.Int Soil Water Consrv Res3: 119-129.

44. Clapp CE, Allmaras RR, Layese MF, Linden DR, Dowdy RH (2000) Soil organic carbon and ^{13}C abundance as related to tillage, crop residue, and nitrogen fertilisation under continuous corn management in Minnesota. Soil Till Res55: 127-142.

45. Vanden Bygaart AJ, Angers DA (2006) Towards accurate measurements of soil organic carbon stock change in agroecosystems.CanJ Soil Sci86: 465-471.

46. Baker JM, Ochsner TE, Venterea RT, Griffis TJ (2007) Tillage and soil carbon sequestration -What do we really know? *Agric Ecosyst Environ*118: 1-5.

47. Govaerts B, Verhulst N, Sayre KD, Dixon J, Dendooven L (2009) Conservation agriculture and soil carbon sequestration; Between myth and farmer reality.CRC Crit Rev Plant Sci28: 97-122.

48. Ogle SM, Breidt FJ, Paustian K (2005) Agricultural management impacts on soil organic carbon storage under moist and dry climatic conditions of temperate and tropical regions. Biogeochemistry72: 87-121.

49. Conceição PC, Dieckow J, Bayer C (2013) Combined role of no-tillage and cropping systems in soil carbon stocks and stabilization. *Soil Till Res*129: 40-47.

50. VandenBygaart AJ, Gregorich EG, Angers DA (2003) Influence of agricultural management on soil organic carbon: A compendium and assessment of Canadian studies. Can J Soil Sci83: 363-380.

51. Veloso MG, Angers DA, Tiecher T, Giacomini S, Dieckow J, Bayer C (2018) High carbon storage in a previously degraded subtropical soil under no-tillage with legume cover crops. Agric Ecosyst Environ268:15-23.

52. Jat ML, Gupta RK, Erenstein O, Ortiz R (2006) Diversifying the Intensive Cereal Cropping Systems of the Indo-Ganges through Horticulture.Chron Horticult46:16-20.

53. WestTO, Post WM (2002) Soil organic carbon sequestration rates by tillage and crop rotation: A global data analysis.Soil Sci Soc Am J66: 1930-1946.

54. Diekow J, Mielniczuk J, Knicker H, Bayer C, Dick DP,Kogel-Knabner I (2005) Soil C and N stocks as affected by cropping systems and nitrogen fertilisation in a southern Brazil Acrisol managed under no-tillage for 17 years. Soil Till Res81: 87-95.

55. Jarecki MK, Lal R (2003) Crop management for soil carbon sequestration.CRC Crit Rev Plant Sci22: 471-502.

56. Gregorich EG, Drury CF, Baldock JA (2001) Changes in soil carbon under long-term maize in monoculture and legume-based rotation. Can J Soil Sci81: 21-31.

57. Arshad MA, Franzluebbers AJ,Azooz, RH (2004) Surface-soil structural properties under grass and cereal production on a MollicCyroboralf in Canada. Soil Till Res77:15-23.

58. Roldan A, Salinas-Garcia JR, Alguacil MM, Caravaca F (2007) Soil sustainability indicators following conservation tillage practices under subtropical maize and bean crops. *Soil Till Res*93: 273-282.

59. Duiker SW, Beegle DB (2006) Soil fertility distributions in long-term no-till, chisel/disk and moldboardplow/disk systems. Soil Till Res88: 30-41.

60. McBride MB (1994) Environmental Chemistry of Soils. New York, NY: Oxford University Press.

61. Sa JCD, Cerri CC, Lal R, Dick WA, Piccolo MD, Feigl BE (2009) Soil organic carbon and fertility interactions affected by a tillage chronosequence in a Brazilian Oxisol. Soil Till Res104: 56-64.

62. Thomas GA, Dalal RC, Standley J (2007) No-till effects on organic matter, pH, cation exchange capacity and nutrient distribution in a Luvisol in the semi-arid subtropics. Soil Till Res94: 295-304.

63. Qin SP, He XH, HuCS, Zhang YM, Dong WX (2010) Responses of soil chemical and microbial indicators to conservational tillage versus traditional tillage in the North China Plain. Eur J Soil Biol46:243-247.

64. Williams A, Jordan NR, Smith RG, Hunter MC, Kammerer M, Kane DA, *et al.* (2018) A regionally-adapted implementation of conservation agriculture delivers rapid improvements to soil properties associated with crop yield stability. Sci Rep8: 1-8.

65. Zhang X, Xin X, Zhu A, Yang W, Zhang J, Ding S, *et al.* (2018) Linking macro-aggregation to soil microbial community and organic carbon accumulation under different tillage and residue managements. Soil Till Res178: 99-107.

66. Bell M, Seymour N, Stirling GR, Stirling AM, Van Zwieten L, Vancov T, Sutton G, Moody P (2006) Impacts of management on soil biota in Vertisols supporting the broadacre grains industry in northern Australia.Aust J Soil Res44: 433-451.

67. Govaerts B, Mezzalama M, Unno Y, Sayre KD, Luna-Guido M, Vanherck K, Dendooven L,Deckers J (2007) Influence of tillage, residue management, and crop rotation on soil microbial biomass and catabolic diversity.Appl Soil Ecol37: 18-30.

68. Ngwira AR, Aune JB,Mkwinda S (2012) On-farm evaluation of yield and economic benefit of short-term maize legume intercropping systems under conservation agriculture in Malawi. Field Crops Res132: 149-157.

69. Bravo CA, Giraldez JV, OrdonezR, Gonzalez P, Torres FP (2007) Long-term influence of conservation tillage on chemical properties of surface horizon and legume crops yield in a vertisol of southern Spain. *Soil Sci*172: 141-148.

70. Känkänen H, Alakukku L, Salo Y,Pitkänen T (2011) Growth and yield of spring cereals during transition to zero tillage on clay soils. Eur J Agron34: 35-45.

71. Pittelkow CM, Liang X, Linquist BA, van Groenigen KJ, Lee J, Lundy ME, *et al.* (2015) Productivity limits and potentials of the principles of conservation agriculture. *Nature*517: 365-368.

72. Molla GA, Dananto M, Desta G (2021) Effect of Tillage Practices and Cropping Pattern on Soil Properties and Crop Yield in the Humid Lowlands of Beles Sub-Basin, Ethiopia. Am J Plant Biol 6:101-113.

73. Rahman MM, Hossain M, Rahman MH, Rahim MA, Islam MT (2020) Growth and yield performance of garlic varieties under zero-tillage and tillage system. Int J Hortic Sci 26:46-54.

74. Garcia-Palacios P, Alarcon MR, Tenorio JL, Moreno SS (2019) Ecological intensification of agriculture in drylands. J Arid Environ167: 101-105.

75. Kaye JP, Quemada M (2017) Using cover crops to mitigate and adapt to climate change. A review. Agron Sustain Dev37: 1-17.

76. Devkota M, Devkota KP, Acharya S, McDonald AJ (2019) Increasing profitability, yields and yield stability through sustainable crop establishment practices in the rice-wheat systems of Nepal. Agric Syst173: 414-423.

77. Adimassu Z, Alemu G,Tamene L (2019) Effects of tillage and crop residue management on runoff, soil loss and crop yield in the Humid Highlands of Ethiopia. Agric Syst 168:11-18.

78. Fufa H, Tesfa B, Hailu T, Kebebew A, Tiruneh K, Aberra D, Seyfu K (2001) Agronomy research in tef. In: Hailu, T., Getachew, B., Mark, S. (Eds.), Narrowing the Rift: Tef Research and Development. Proceedings of the International Workshop on Teff Genetics and Improvement, pp. 167-176 (DebreZeit, Ethiopia).

79. Dang YP, Seymour NP, Walker SR, Bell MJ,Freebairn DM (2015) Strategic tillage in no-till farming systems in Australia's northern grains-growing regions: I. Drivers and implementation. *Soil Till Res*152: 104-114.

80. Steward PR, Dougill AJ, Thierfelder C, Pittelkow CM, Stringer LC, Kudzala M *et al.* (2018) The adaptive capacity of maize-based conservation agriculture systems to climate stress in tropical and subtropical environments: a meta-regression of yields. Agric Ecosyst Environ251:194-202.

81. Thierfelder C, Matemba-Mutasa R, Rusinamhodzi L (2015) Yield response of maize (*Zea mays* L.) to conservation agriculture cropping system in Southern Africa. Soil Till Res146: 230-242.

82. Kabir Z (2005) Till or no-till: Impact on mycorrhizae. Can J Plant Sci85: 23-29.

83. Wang Z, Chen Q, Liu L, Wen X, Liao Y (2016) Responses of soil fungi to 5-year conservation tillage treatments in the drylands of northern China. Appl Soil Ecol101: 132-140.

84. Choudhary M, Sharma PC, Jat HS, McDonald A, Jat ML, Choudhary S, Garg N (2018) Soil biological properties and fungal diversity under conservation agriculture in Indo-Gangetic Plains of India. J Soil Sci Plant Nutr18: 1142-1156.

85. Choudhary M, Sharma PC, Jat HS, McDonald A, Jat ML, Choudhary S,Garg N (2018) Soil biological properties and fungal diversity under conservation agriculture in Indo-Gangetic Plains of India. J Soil Sci Plant Nutr18: 1142-1156.

86. Nouri A, Yoder DC, Raji M, Ceylan S, Jagadamma S, Lee J, Walker FR, Yin X, Fitzpatrick J, Trexler B, Arelli P, Saxton AM (2021) Conservation agriculture increases the soil resilience and cotton yield stability in climate extremes of the southeast US. CommunEarthEnviron 2: 1-12.

87. Jantalia CP, Resck DVS, Alves BJR, Zotarelli L, Urquiaga S,BoddeyRM (2007) Tillage effect on C stocks of a clayey Oxisol under a soybean-based crop rotation in the Brazilian Cerrado region. Soil Till Res95: 97-109.

