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No-till farming: prospects, challenges – productivity, soil health, and ecosystem services

Somasundaram Jayaraman[A,*] and Ram C. Dalal[B]

For full list of author affiliations and declarations see end of paper

***Correspondence to:**
Somasundaram Jayaraman
ICAR-Indian Institute of Soil Science, Nabibagh, Berasia Road, Bhopal 462038, Madhya Pradesh, India
Emails: somajayaraman@gmail.com; Somasundaram.J@icar.gov.in

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ABSTRACT

Globally, declining soil quality due to soil degradation is of great concern, and directly affects crop production, soil health and sustainability of natural resources. In conventional farming practices, the loss of fertile topsoil via runoff and erosion from arable land is a big concern. In addition, changes in land use and management practices result in loss of soil organic carbon (SOC) stock by −10–59%. The change from conventional till (CT) with residue burning/removal to no-till (NT) farming with residue retention/conservation agriculture (CA) practices have been recognised as important soil management practices for sustaining soil health and reversing land degradation. Worldwide, NT/CA practices are now being adopted on about 180 million ha (i.e. ~14% of arable land). CA practices promote soil health by increasing organic carbon, and soil aggregation, thus improving infiltration and minimising erosion losses. In addition, CA has the potential to increase SOC sequestration, reduce greenhouse gas (GHG) emissions and help to mitigate global climate change. Among sustainable food production systems, CA is often advocated with a view to increase food production while conserving natural resources and SOC. This special issue 'No-till farming: prospects, challenges – productivity, soil health, and ecosystem services' addresses and critically reviews these important issues and aims to foster awareness of NT farming. The collection of 15 papers lucidly covers various facets of NT farming. A summary and salient findings of these papers are provided in this Editorial. NT farming is a promising practice, which not only improves soil physical, chemical and biological health but also enhances carbon sequestration, crop productivity and mitigates GHG emissions through appropriate crop residue and nutrient management strategies. The adage says 'one size won't fit all' or 'a single recipe will not solve all problem/challenges', so we need to adopt site-specific NT systems for higher benefits and productivity and sustaining soil health.

Keywords: carbon sequestration, climate smart agriculture, conservation agriculture, food security, greenhouse gases, GHG, no-till farming, simulation model, soil health, soil properties.

In 2050 the world population is estimated to reach ~10 billion, an increase of 25% despite the Covid-19 mortalities, therefore, there is a continuous need for increasing food production. Soils support directly or indirectly about 98% of our food production (Dalal *et al.* 2018, 2021; Lal 2020; Kopittke *et al.* 2021). It is a precious resource, which needs sustainable management for addressing critical socio-economic and environmental issues (Amundson *et al.* 2015). Humanity is facing various challenges such as malnutrition, soil erosion, land degradation and climate change (Kopittke *et al.* 2019; Lal 2020; Singh *et al.* 2020; Dalal *et al.* 2021). Food and nutritional security is one of the greatest challenges facing humanity. Further, rapid urbanisation along with drastic change in diets, means that soils are becoming increasingly degraded due to over exploitation/utilisation (Gomiero 2018; FAO 2019; Zhang and Zhang 2020) and urban encroachment. There is an urgent need to ensure food security and nutrition; thus, understanding and sustaining soil health is of paramount importance now. In fact, sustainable soil management has become even more important to safeguard soil resource from degradation as well as to enhance agricultural production to feed an increasing population (Dalal and Jayaraman 2021; Dalal *et al.* 2021; Jayaraman *et al.* 2021*a*, 2021*b*, 2021*d*) and address climate change by reducing net CO_2, CH_4 and N_2O emissions (Reeves *et al.* 2019).

According to the UN Sustainable Development Goals (SDGs), soil resource directly and indirectly addresses more than seven of the 17 goals (UN 2015). Moreover, the SDGs identify the need to restore degraded soils as well as improve soil health (Bouma *et al.* 2019; Dalal *et al.* 2021; Jayaraman *et al.* 2021*c*). Since soils are the foundation of food production and deliver many essential ecosystem services (Lal 2015*b*; Kopittke *et al.* 2019), there is a widespread understanding that we must foster and unlock the full potential of soils, so as to not only support food production but also to deliver many ecosystem functions/services such as store and supply clean water, sustain soil biodiversity and conserve gene pool, sequester carbon (C) and increase resilience in a changing climate, and cleaner production (Lal 2013). Thus, there is a greater need now for universal application of sustainable soil management.

Globally, declining soil quality due to soil degradation is of great concern, and directly affects crop production, soil health and sustainability of natural resources. In conventional farming practices, the loss of fertile topsoil via runoff and erosion from arable land is a big concern (Blanco-Canqui and Lal 2009). In addition, changes in land use and management practices results in loss of soil organic carbon (SOC) stock by −10–59% (Guo and Gifford 2002; Dalal *et al.* 2021). The change from conventional till (CT) with residue burning/removal to no-till (NT) farming with residue retention/conservation agriculture (CA) practices have been recognised as important soil management practices for sustaining soil health and reversing land degradation (Lal 2013; Hati *et al.* 2021; Jayaraman *et al.* 2021*a*, 2021*b*) (Fig. 1). Worldwide, NT/CA practices are now being adopted on about 180 million ha (i.e. about 14% of the arable land) (Kassam *et al.* 2019). CA practices have greater potential of promoting soil health by increasing organic carbon (Dalal *et al.* 2011; Sarker *et al.* 2018; Mohanty *et al.* 2020), and soil aggregation, thus improving infiltration and minimising erosion losses (Dalal and Bridge 1996; Govaerts *et al.* 2009; Somasundaram *et al.* 2011, 2017, 2018*a*, 2018*b*, 2020; Lal 2015*a*; Page *et al.* 2013, 2019, 2020; Jayaraman *et al.* 2019, 2021*a*, 2021*b*; Dalal *et al.* 2021).

In addition, it has the potential to increase SOC sequestration, reduce greenhouse gas (GHG) emissions and help to mitigate global climate change (Lal 2015*b*). Among sustainable food production systems, CA is often advocated with a view to increase food production while conserving natural resources and soil carbon (Somasundaram *et al.* 2020). This special collection 'No-till farming: prospects, challenges – productivity, soil health, and ecosystem services' addresses and critically reviews these important issues and aims to foster awareness of NT farming and its relationship between soil health, carbon sequestration, GHG emissions, food security and ecosystem services. In this special issue, we received 27 papers, however, only 15 papers were accepted for publication. A summary and the salient findings of these papers is provided below (Fig. 2).

Rao *et al.* (2022) studied the impact of 'Conservation agriculture improves soil physical properties and crop productivity: a long-term study in middle Indo-Gangetic Plains (IGP) of India'. This region is one of the largest rice (*Oryza sativa*)–wheat (*Triticum aestivum*) production systems in south Asia, occupying ~13 million ha and accounts for 30% of rice–wheat area in the region, producing staple food for 1 billion people (Ladha *et al.* 2003). Conservation agriculture can potentially stop deterioration of soil fertility and improve crop production in the middle IGP of India. Soil health management with changing climate is important to cope-up with the increasing production demand by adoption of CA

Fig. 1. Crop residue retention in NT plots under a soybean–wheat system.

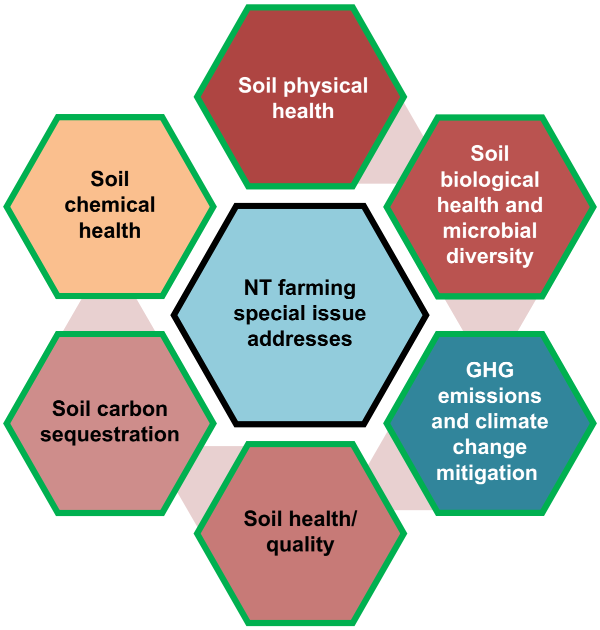

Fig. 2. Thematic concepts of different papers published in this no-till (NT) special issue.

practices. Moreover, cropping systems, which received full CA or partial CA with best management practices (BMPs) not only showed significantly higher amount of water stable aggregates, and aggregate associated carbon but also improved economic returns. Research findings suggest that NT and retention of crop residues have potential for not only improving soil health but also economic returns. The results of this study also confirmed BMPs and compatible NT residue retention and crop diversification practices as possible technological interventions to maximise resource use efficiency and productivity in rice-based cropping systems. The authors concluded that the relative importance of soil aggregation, NT and residue management practices vis-à-vis soil C sequestration needs to be studied in a holistic manner.

Similarly, Datta *et al.* (2022) studied the impact of 'Climate smart agricultural practices improve soil quality through organic carbon enrichment and lower greenhouse gas emissions in farms of bread bowl of India'. Climate change can adversely impact on poorer and vulnerable communities, increasing the risk of natural disasters, and affecting agricultural production. This study explored the potential impacts of climate smart agricultural practices (CSAPs) on working farms in Karnal, Haryana, India. Globally, CSAPs such as NT, crop residue management, and crop rotations are quite popular among farmers. The authors studied the influence of CSAPs on soil quality, wheat grain yield and GHG emissions on 70 farms of Climate Smart villages (12) of Karnal district, Haryana, India. They concluded that CSAPs improve soil quality and wheat yield. Higher SOC content and lower GHG emissions were observed under CSAPs than from CT practices. These CSAP provide an excellent alternative to CT practices in north-west India for adaptation to climate change irrespective of farm type and size. Moreover, CSAPs not only improve SOC stocks, but also help to improve other soil properties and the overall quality of the soil. Therefore, CSAPs should be promoted among the farmers of north-west India for sustainability of the cropping system and future posterity in the context of climate change.

The study conducted by Biswas *et al.* (2022) titled 'Biological soil quality and seasonal variation on enzyme activities under conservation agriculture-based rice–mustard system in the Indo-Gangetic Plains of India' studied the effect of seasonal variation on enzyme activity and biological soil quality under a CA-based rice–mustard system. The results highlighted that CA-based triple zero-till (ZT) system with three crop residue treatments (ZT direct-seeded rice (DSR) with mung bean residue; ZT mustard (ZTM) with rice residue; and ZT summer mung bean (SMB) with mustard residue [~ZTDSR–ZTM–ZTSMB (+R)] resulted in the highest values of microbial biomass C (MBC), Walkley–Black C (WBC) and total organic C (TOC) at the 0–5 cm soil depth. Enzyme activities were the highest during summer. Principal component analysis (PCA) indicated that arylsulphatase activity and TOC were sensitive indicators of the Best Soil Quality. The authors also highlighted that CA-based triple NT with residue retention practice [ZTDSR–ZTM–ZTSMB (+R)] is recommended for rice–mustard cropping for maintaining higher biological quality of soil in this region of India.

Amami *et al.* (2022) studied the 'Effects of conservation and standard tillage on soil physico-chemical properties and overall quality in a semi-arid agrosystem'. Conventional intensive agriculture has degraded the quality of environmental and natural resources in the region. Shifting agricultural operations to more sustainable management practices are needed in the scenario of changing climate. They evaluated the impacts of tillage systems on soil quality indices, which were based on the total set of properties selected through principal component analysis. The findings indicated that compared to CT after 1 year of application, NT and/or minimum tillage treatments affected the soil physico-chemical attributes, saturation percentage, bulk density, penetration resistance, EC, and pH. The authors concluded that farmers in the study region should be encouraged to consider minimum tillage during the early years of transition from standard to NT systems to avoid rapid decline in soil quality and consequent yield loss.

Silva *et al.* (2022) studied the 'Long-term effects of tillage systems on liming efficiency, soil chemical properties and wheat yield in Southern Brazil'. Sustainable management of the soil is one of the key components of CA. However, one of the biggest concerns when adopting CA in tropical and subtropical Oxisols is the management of soil acidity in subsurface layers, which can be overcome by adopting a NT system. The authors evaluated the long-term effects of soil management systems (SMS) including NT, on liming efficiency, soil chemical properties and wheat yield. The NT system was the least detrimental to SOC, an important indicator of soil quality. The NT system had a considerable advantage over other SMS, due to the highest wheat yield (18%), and thus, it was the most viable SMS for subtropical spring wheat production.

Dhaliwal *et al.* (2022) studied the 'Labile soil carbon and nitrogen fractions under short and long-term integrated crop–livestock agroecosystems'. Labile soil C and N fractions are strongly influenced by agricultural management practices. The authors evaluated the impact of three long-term (≥30 years) on-farm sites (sites 1–3), and one short-term (3 years) field site (site 4) of integrated crop–livestock system (ICLS) on labile C and N fractions and β-glucosidase enzyme activity in 0–5 cm soil depth. The authors found that long-term management systems (ICLS, corn (*Zea mays* L.)/grazing–soybean (*Glycine max* (L.) Merr.)/grazing–cover crop/grazing) had greater hot water extractable organic carbon (HWC), cold water extractable organic carbon (CWC), MBC, microbial biomass nitrogen (MBN), potential carbon mineralisation (PCM) and potassium permanganate oxidisable carbon (POXC) than the control under long-term management system. Long-term ICLS also enhanced β-glucosidase activity compared to the control. However, the C and N fractions and β-glucosidase activity were not affected by short-term ICLS (site 4). Grazed pasture (GP) always had higher C and N fractions than ICLS and the control. The results indicated that there was a significantly positive relationship between SOC and labile C and N fractions, except POXC. The authors concluded that long-term inclusion of cover crops and livestock grazing in corn–soybean system was effective in enhancing labile soil C and N fractions.

Rai *et al.* (2022) studied the 'Simulation of maize and soybean yield using DSSAT under long-term conventional and no-till systems'. In this study, process-based models have been used to simulate the potential impact and benefits of various management practices on crop yield and soil properties under different environmental conditions. The authors evaluated the Cropping System Model (CSM)-CERES-Maize and CSM-CROPGRO-Soybean model for NT and CT systems, and compared the long-term impacts of NT and CT on crop yield and SOC. Two crop models, available in the Decision Support System for Agrotechnology Transfer (DSSAT), were calibrated and evaluated using maize (*Zea mays* L.) and soybean (*Glycine max* L.) yield data from 2006 through 2011 under CT and NT treatments. From the long-term (30-year) simulations, the NT system enhanced SOC over time and, hence, crop yield and biomass production compared to CT. The authors concluded that the application of NT can be beneficial for enhancing the soils and crop production in the long-term as compared to the CT system.

Singh and Kumar (2022) studied the 'Evaluation of the DNDCv.CAN model for simulating greenhouse gas emissions under crop rotations that include winter cover crops'. Process-based modelling studies can help inform conservation practices for mitigating soil CO_2 and N_2O fluxes. The authors evaluated the ability of the DeNitrification–DeComposition (DNDC) model to predict field-measured soil surface CO_2 and N_2O emissions in crop rotations managed with cover crop (CC) and without cover crop (NC) under the 27-year NT field experiment in South Dakota, USA. In this study, CO_2 and N_2O emissions were measured in a 2-year corn–soybean and a 4-year corn–soybean–oat–winter wheat rotation. The model was calibrated with 2-year NC treatment and evaluated against three treatments (2-year CC, 4-year NC and 4-year CC) during the growing season of corn (2017) and soybean (2018). Cumulative CO_2 and N_2O emissions and crop yields were well estimated by the model. The authors concluded that nitrogen transformation processes and effect of rainfall interception on soil water content need further investigation to address the variations in daily N_2O emissions.

Salem *et al.* (2022) studied the 'Initial effect of shifting from traditional to no-tillage on runoff retention and sediment reduction under rainfall simulation'. The authors reported that under various rainfall intensities, the contour tillage (CT) treatment significantly reduced surface runoff compared with the traditional tillage (TT) and NT treatments. For the 30 mm h^{-1} rainfall intensity, the CT treatment decreased sediment yield rate by 58.7% and 49.4% compared with NT and TT treatments, respectively. Furthermore, the CT treatment significantly increased precipitation use efficiency by 11.8% and 19.9% compared with TT and NT treatments, respectively. Additionally, the CT increased grain yield by 12.3% more than TT and 21% more than NT. Consequently, it is preferable to encourage farmers to use CT practices when transitioning from traditional tillage to conservation tillage when crop residue is not retained. Moreover, soil compaction and smoothing may contribute to enhance the generated runoff on the micro-catchment area. The results of the study also suggest for sustainable intensification in the long run, the effectiveness of NT can be improved by using mulching of previous crop residues.

Lai *et al.* (2022) studied 'Influences of grassland to cropland conversion on select soil properties, microbiome and agricultural emissions'. The grassland conversion to cropland could lose soil nitrogen and increase soil compaction, acidity, and salinity, and decrease the diversity of abundant genera of microbiomes, and have an increasing trend in soil CO_2 fluxes over time, and thus increase global warming. The findings showed that the grassland conversion significantly increased soil bulk density and electrical conductivity but reduced pH and total nitrogen (TN). The land use conversion impacted soil biome community grassland and tilled croplands. The landscape position significantly impacted soil pH (footslope < upslope) and TN (footslope > upslope). The grassland conversion significantly decreased soil CO_2 fluxes, but increased soil CH_4 and N_2O fluxes. The landscape position significantly impacted soil CO_2 (footslope > upslope and backslope) and CH_4 fluxes (upslope > footslope and backslope) for some periods. Soil CO_2 fluxes generally followed upward and N_2O fluxes downward trends over time. Therefore, grassland conversion lost soil N, increased soil compaction, acidity, salinity, and soil N_2O and CH_4 fluxes, and decreased the diversity of abundant genera and CO_2 fluxes.

Haruna and Anderson (2022) evaluated the 'Influence of no-till cover crop management on soil thermal properties'. The authors have highlighted the importance of heat transport within the soil for seed germination, microbial activity, and water and nutrient availability. This study investigated if cover crops (CCs) can influence heat transport parameters within the soil. They observed that NT and CC management reduced rapid heat movement and increased the ability of the soil to resist extreme heat change within the soil. In a more variable atmospheric temperature, CCs might be able to improve crop productivity by keeping the soil temperature more stable. The findings highlight that CCs with NT management may be able to resist extreme soil temperature changes which could improve soil health and crop productivity in these systems. The authors emphasised that NT and CC could improve crop productivity in the future but more *in situ* studies of soil thermal properties under these systems are needed.

Veloso *et al.* (2022) studied 'Mineral–organic associations are enriched in both microbial metabolites and plant residues in a subtropical soil profile under no-tillage and legume cover cropping'. The authors have reported that the implementation of NT coupled with legume cover cropping results in high carbon sequestration rates in highly weathered soils of Southern Brazil. The results of the study highlighted that this effect is observed in the whole-soil profile (100 cm) and is due to the formation of mineral-organic associations through the enrichment in plant and microbial residues, arising from the absence of tillage and the presence of high-quality legume residues.

Carlos *et al.* (2022) studied 'No-tillage promotes C accumulation in soil and a slight increase in yield stability and profitability of rice in subtropical lowland ecosystems'. The authors have evaluated long-term impact (24-years) of NT on SOC and rice yield in a subtropical lowland ecosystem in southern Brazil. NT increased SOC at an annual rate of 0.41 Mg ha^{-1} in relation to the traditional CT soil. Despite the lower rice yield in the NT system, a slightly higher yield stability and profitability were observed. The authors have indicated that NT is a C-friendly management system in lowland ecosystems, but its effect on the yield stability and profitability of rice crop is less prominent and only occurs in the long term.

Kumar *et al.* (2022*a*) studied 'Assessing soil quality and their indicators for long-term rice-based cropping systems in hot sub-humid eco-region of India'. The authors have emphasised that the sustainability of the long-term rice-based cropping systems practiced in hot sub-humid eco-region regions of India is vulnerable to decline in soil organic C, soil erosion, intensive agriculture, and various climatic aberrations. The authors have assessed soil quality by integrating physical, chemical, and biological properties of the soils under major rice-based cropping systems of the region. The results highlighted that rice-legume cropping systems were found to be the most sustainable alternative in terms of productivity, economic profitability, and soil quality.

Kumar *et al.* (2022*b*) studied 'Conservation agriculture influences crop yield, soil carbon content and nutrient availability in rice–wheat system of north-west India'. The authors have reported that CA utilising the principles of zero tillage and crop residue management has emerged as an excellent alternative to conventional tillage-based agriculture. Moreover, intensive tillage and crop residue burning possess severe challenges in securing sustainable food production, soil health and environmental safeguard in north-west India. The authors have highlighted that direct-seeded rice (DSR) in rice and ZT in wheat with full residue retention improved SOC and nutrient availability, enhancing crop production and reduced global warming potential (GWP) by 43% compared to the farmers' practice.

Conclusions

This special issue lucidly covers several facets of NT farming through 15 papers. NT farming is a promising practice, which not only improves soil physical, chemical and biological health but also enhances carbon sequestration, crop productivity and mitigates GHG emissions through appropriate crop residue and nutrient management strategies. The adage says 'one size won't fit all' or 'a single recipe will not solve all problem/challenges', so we need to adopt site-specific NT systems for higher benefits and productivity and sustaining soil health. We hope that readers will immensely benefit from this special issue on 'No-till farming'.

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Author affiliations

[A]ICAR-Indian Institute of Soil Science, Nabibagh, Berasia Road, Bhopal 462038, Madhya Pradesh, India.

[B]School of Agriculture and Food Sciences, Faculty of Science, The University of Queensland, St Lucia, Qld 4072, Australia.