Journal of Applied and Natural Science
15(3), 1178 - 1187 (2023)
ISSN : 0974-9411 (Print), 2231-5209 (Online)
journals.ansfoundation.org

Research Article

# Sowing carbon solutions: Decoding soil characteristics and carbon fluxes in maize-dominated cropping systems of Tamil Nadu, India

**Libi Robin, P***
Department of Soil Science and Agricultural Chemistry, Tamil Nadu Agricultural University (TNAU), Coimbatore – 641003 (Tamil Nadu), India
**Kaleeswari, R.K.**
Department of Soil Science and Agricultural Chemistry, Tamil Nadu Agricultural University (TNAU), Coimbatore – 641003 (Tamil Nadu), India
**Janaki, P**
Nammazhvar Organic Farming Research Centre, Tamil Nadu Agricultural University (TNAU), Coimbatore – 641003 (Tamil Nadu), India
**Uma. D**
Department of Biochemistry, Tamil Nadu Agricultural University (TNAU), Coimbatore – 641003 (Tamil Nadu), India
**Karthikeyan, S**
Centre for Post Harvest Technology, Tamil Nadu Agricultural University (TNAU), Coimbatore – 641003 (Tamil Nadu), India

*Corresponding author. E-mail: libirobin.p@gmail.com

***Article Info***
https://doi.org/10.31018/jans.v15i3.4760
Received: June 5, 2023
Revised: September 1, 2023
Accepted: September 6, 2023

***How to Cite***

Libi Robin, P *et al.* (2023). Sowing carbon solutions: Decoding soil characteristics and carbon fluxes in maize-dominated cropping systems of Tamil Nadu, India. *Journal of Applied and Natural Science*, 15(3), 1178 - 1187. https://doi.org/10.31018/jans.v15i3.4760

## Abstract
This study on soil carbon dynamics provides valuable insights for sustainable agricultural practices, optimizing crop productivity and environmental sustainability in maize-based cropping systems. The present study aimed to find out the soil characteristics and carbon dynamics in maize-based cropping systems in the Western zone of Tamil Nadu, India. Soil samples from six cropping systems were analyzed for bulk density, sand, silt, clay content, pH, available nutrients (N, P, K, Zn), total organic carbon (TOC), oxidizable organic carbon fractions, microbial biomass carbon (MBC), and carbon pools. The distribution of oxidizable organic carbon fractions varied among cropping systems and soil depths. The easily decomposable and moderately labile fractions were highest in the maize-black gram system, while the recalcitrant fraction showed variations across cropping systems. The active carbon pool ($C_{f1}$ + $C_{f2}$) was highest at 2.53 g kg-1 in the maize-blackgram system, while the passive carbon pool ($C_{f3}$ + $C_{f4}$) was also highest at 3.79 g kg-1 in this system. The study also assessed the carbon stock and microbial biomass carbon. TOC content decreased with depth, with the highest values observed in the topsoil. The maize-black gram system had the highest TOC content at all depths. MBC content followed a similar pattern, with the highest values in the topsoil and the maize-black gram system. These findings provided insights into the soil characteristics and carbon dynamics in maize-based cropping systems in the study area. The long-term integration of maize cultivation with blackgram demonstrated significant enhancements in organic carbon levels, TOC content, microbial biomass carbon (MBC), and both passive and active carbon pools characterized by rapid turnover rates.

**Keywords:** Carbon stocks, Maize-based cropping systems, Microbial biomass carbon, Organic carbon dynamics, Soil carbon dynamics

## INTRODUCTION

Maize (*Zea mays L.*) is one of the most important cereal crops in the world, providing food and feed for millions of people and livestock. However, the long-term effects of maize-based cropping systems on soil organic carbon (SOC) dynamics have received relatively little attention. SOC is essential to soil health and is vital in sustaining agricultural productivity (Lal, 2018). The loss of SOC can lead to reduced soil fertility, decreased crop yields, and increased vulnerability to erosion and other environmental stresses (Kumar *et al.*, 2018).

Therefore, understanding the long-term effects of maize-based cropping systems on SOC dynamics is crucial for sustainable agriculture and environmental management.

Recent studies have shown that maize-based cropping systems can significantly impact SOC dynamics. For example, Li *et al.* (2018) found that the continuous maize cropping system significantly decreased SOC content compared to the crop rotation system. Similarly, a study by Lal (1997) reported that long-term maize monoculture reduced SOC content and soil fertility compared to crop rotation systems. In contrast, other studies have shown that maize-based cropping systems can promote SOC accumulation. For instance, a study by Ding *et al*. (2014) found that applying crop residues and manure increased SOC content in a maize-soybean rotation system. Similarly, a study by Yadav *et al.* (2021) reported that conservation tillage and residue retention practices can increase SOC content in maize-based cropping systems.

Moreover, the effects of management practices such as tillage, crop residue management, and fertilizer application on SOC dynamics in maize-based cropping systems have also been studied. For instance, a study by Mamta *et al.* (2023) and Meena *et al.* (2015) found that reduced tillage and improved residue management practices increased SOC content in maize-based cropping systems. Similarly, a study by Abid *et al.* (2020) and Sarwar *et al.* (2021) reported that applying organic and inorganic fertilizers increased SOC content in maize-based cropping systems. On the other hand, a study by Abid *et al.* (2020) reported that applying mineral fertilizers reduced SOC content in maize-based cropping systems due to increased mineralization rates.

The long-term effects of maize-based cropping systems on SOC dynamics are critical for sustainable agriculture and environmental management. Recent studies have shown that inappropriate management practices can lead to decrease SOC content, adversely impacting soil fertility and crop productivity (Wairiu, 2017; Wiesmeier *et al*., 2019). Therefore, adopting sustainable management practices that promote SOC accumulation in maize-based cropping systems is crucial. The main objective of this study was to collect and assess the existing research on the long-term effects of maize-based cropping systems on soil organic carbon (SOC) changes. The study specifically investigates the impacts of carbon management practices in these systems.

## MATERIALS AND METHODS

### Soil characteristics

The soil samples were collected from maize-based cropping systems located in the Western zone of Tamil Nadu (Fig. 1). The study investigated six different cropping systems, including maize-fallow, maize-blackgram, maize-ragi, maize-tomato, maize-turmeric, and maize-cumbu. These cropping systems have been maintained in the area for over 11 years, and they are typically cultivated twice per year, except for the maize-fallow system.

The bulk density increased with increasing soil depth, ranging from 1.34 to 1.56 g cm-3, and was highest in the maize-cumbu cropping system. The sand content was highest in the maize-cumbu system at all soil depths, while the silt and clay contents were highest in the maize-blackgram and maize-cumbu systems, respectively. The pH of the soil was alkaline and ranged from 7.13 to 8.85, with the highest value observed in the maize-tomato system (Table 1).The availability of nutrients varied significantly among the cropping systems and soil depths.

The highest available N, P, K, and Zn were observed in the topsoil (0-15 cm), with decreasing values in deeper soil layers. The maize-fallow and maize-blackgram systems had the highest available N content, while the maize-cumbu system had the highest available P, K, and Zn content. Prior to sowing maize seeds, the fields were prepared by creating ridges and furrows. Maize seeds were then sowed with a spacing of 60 cm × 25 cm. Recommended doses of NPK, specifically 135:62.5:50, were applied to the maize in the form of urea, single super phosphate, and muriate of potash, respectively. Full doses of P (62.5 kg $ha^{-1}$) and K (50 kg $ha^{-1}$) were applied during land preparation. The application of N was divided into three equal splits, with the first being applied during land preparation, the second on the 25th day after sowing, and the third on the 45th day after sowing. The farmers followed all other practices for maize cultivation, such as irrigation and weeding, as required.

After harvesting the maize, the land was prepared for sowing the succeeding crop with appropriate spacings, except for the maize-fallow cropping system, where the land remained empty after the maize harvest until the next season. For the succeeding crops, only half of the full recommended doses of NPK were applied in the form of urea, SSP, and MOP due to the residual effect of the maize fertilizer. Apart from fertilization, the farmers followed various other practices for each crop, including providing irrigation at field capacity and conducting timely weeding during the critical period of crop-weed competition.

### Soil sampling, sample preparation and analysis of soil properties

The soil samples were dried in ambient temperature conditions and then sieved through a 2-mm mesh before being sent for laboratory analysis. To determine soil microbial biomass carbon (SMBC), fresh undisturbed sub-samples were collected and stored in

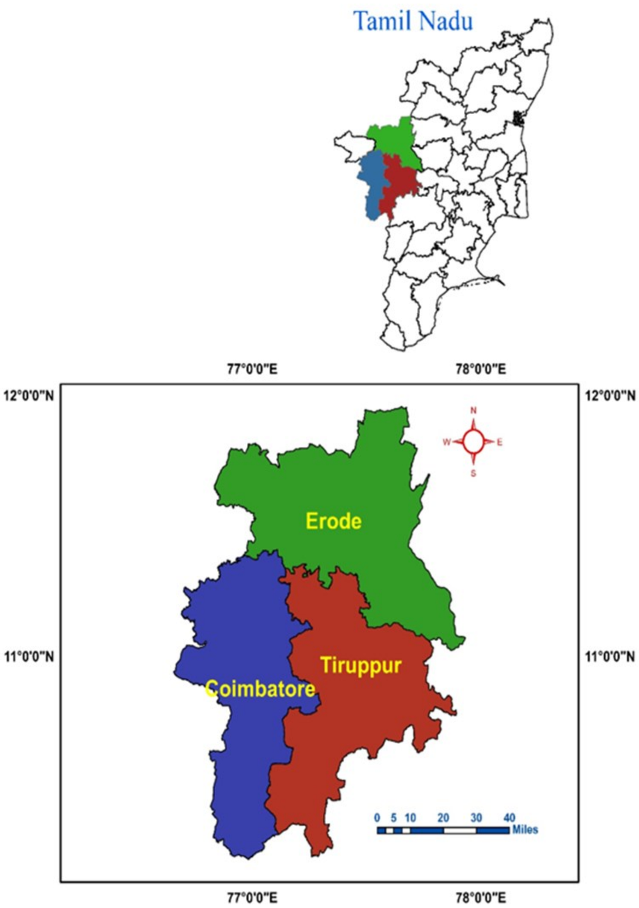


**Fig. 1.** *Location of the study areas of the Western zone of Tamil Nadu*

sealed plastic bags in a refrigerator until further analysis. Various soil properties were analyzed using the following methods: pH was measured in a soil water suspension with a ratio of 1:2.5 (Jackson 1973), available nitrogen was estimated by alkaline permanganate method (Subbiah and Asija 1956), available phosphorus was measured using the Modified Olsen's extractant method (Olsen 1954), available potassium was extracted with neutral normal ammonium acetate and analyzed using flame photometry (Stanford and English 1949), DTPA extractable zinc was determined using the method described by Lindsay and Norvell (1978), soil separates (sand, silt, and clay) was measured using the international pipette method (Piper 1966), and bulk density was determined using the core sampler method (Dakshinamurthi and Gupta 1968).

### Carbon pools and carbon stock

Total organic carbon (TOC) was analyzed using a TOC analyzer, while SMBC was determined using the chloroform fumigation extraction method as described by Vance *et al.* (1987). The oxidizable organic carbon was determined by the Wet digestion method described by Walkley and Black (1934). Carbon stock was estimated using the method outlined by Sisti *et al.* (2004).

### Fractions of oxidizable organic carbon

A modified Walkley and Black method was employed to estimate the different fractions of oxidizable organic carbon, as outlined by Chan *et al.* (2001). This approach used concentrated sulphuric acid ($H_2SO_4$) of different concentrations (12 N, 18 N, and 24 N), with 5 ml, 10 ml, and 20 ml, respectively. By comparing the amount of SOC determined using 5 ml, 10 ml, and 20 ml of concentrated $H_2SO_4$ with TOC, the TOC was separated into four different fractions with decreasing oxidizability.

### Lability index

To determine the SOC's lability index (LI), the very labile, labile, and less labile pools of $C_{f1}$, $C_{f2}$, and $C_{f3}$, respectively, were assigned weights of 3, 2, and 1. Subsequently, their values were transformed into a proportional amount of TOC and multiplied by their respective weighting factors to obtain an LI for the SOC content in the cropping systems under study. The computation of the index followed the method proposed by Hazra *et al.* (2018).

$$\text{Lability index} = [C_{f1}/TOC\times3+ C_{f2}/TOC\times2+ C_{f3}/TOC\times1] \quad \text{Eq.1}$$

### Statistical analysis

The statistical analysis of the laboratory data was conducted using both Microsoft Excel 2021 and the SPSS v. 22 statistical software packages. The mean values and standard errors were calculated for each measurement and presented in the analysis. In order to compare the means of the treatments, a one-way analysis (one-way ANOVA) was performed. The Duncan's multiple range test (DMRT) was used at a 5% significance level to examine the differences between the means.

## RESULTS

The present study showed that the percent distribution of the three fractions of oxidizable organic carbon (easily decomposable, moderately labile, and recalcitrant) varied among the different cropping systems and soil depths. In the 0-15 cm soil depth, the easily decomposable fraction ranged from 14.00% (maize-fallow) to 21.07% (maize-blackgram), while the moderately labile fraction ranged from 13.19% (maize-fallow) to 22.05% (maize-blackgram). The recalcitrant fraction ranged from 14.55% (maize-ragi) to 46.62% (maize-ragi). In the 15-30 cm soil depth, the easily decomposable fraction ranged from 12.41% (maize-fallow) to 19.48% (maize-blackgram), while the moderately labile fraction ranged from 12.50% (maize-fallow) to 20.14% (maize-blackgram). The recalcitrant fraction ranged from 37.79% (maize-fallow) to 46.46% (maize-ragi). In the 30-45 cm soil depth, the easily decomposable fraction ranged from 11.26% (maize-fallow) to 18.47% (maize-blackgram), while the moderately labile fraction ranged from 11.28% (maize-fallow) to 18.75% (maize-blackgram). The recalcitrant fraction ranged from 38.53% (maize-fallow) to 44.76% (maize-ragi) (Fig. 2).

The results showed that the active carbon pool ($C_{f1}$ + $C_{f2}$) was highest in the Maize-blackgram cropping system across all three depth intervals, ranging from 2.51 to 2.81 g/kg. The lowest active carbon pool was found in the Maize-fallow system, ranging from 1.43 to 1.83 g/kg (Fig. 3). For passive carbon pools ($C_{f3}$ + $C_{f4}$), the Maize-blackgram system also had the highest values ranging from 3.62 to 3.94 g/kg, while the Maize-fallow system had the lowest values ranging from 2.72 to 3.02 g/kg. The active and passive carbon pools generally decreased with increasing depth, with the highest values found in the topsoil (0-15 cm) and the lowest values in the subsoil (30-45 cm) (Fig. 4).

The present results showed that the cropping system significantly impacts SOC levels. Maize-blackgram cropping system had the highest TOC levels, ranging from 0.67% to 0.87% across all three soil depths, followed by maize-tomato system which had TOC levels ranging from 0.72% to 0.86% (Table 2). The lowest TOC levels were found in the maize-ragi system, with values ranging from 0.25% to 0.35%. The highest levels of oxidizable organic carbon were found in the maize-fallow system, with values ranging from 0.18% to 0.35%. Maize-blackgram and maize-tomato systems had the second highest oxidizable organic carbon levels, while maize-ragi, maize-turmeric, and maize-cumbu systems had the lowest levels. Soil microbial biomass carbon was highest in the maize-fallow system, with values ranging from 0.17 g/kg soil to 0.47 g/kg soil. Maize-tomato and maize-blackgram systems had the second highest levels of microbial biomass carbon, while maize-ragi, maize-turmeric, and maize-cumbu systems had the lowest levels.

Regarding total organic carbon (TOC), maize-blackgram reigns supreme, with values ranging from 0.87% to 0.67% in the top 30 cm of soil. Meanwhile, maize-fallow may have the lowest TOC values overall, but it still manages to hold on to a respectable 0.38% to 0.31%. However, when we look at oxidizable organic carbon (OC), maize-blackgram falls behind and maize-tomato takes the lead with values ranging from 0.45% to 0.29% (Table 3). Maize-turmeric follows closely behind, showcasing its own unique blend of organic carbon pools. The microbial biomass carbon (MBC) tells us another intriguing story about the soil microbial communities. Maize-fallow may have low TOC values, but its MBC values are anything but low, reaching up to 0.47 g/kg of soil. On the other hand, maize-tomato seems to be the darling of the microbial world, with MBC values ranging from 0.62 to 0.25 g/kg of soil across the different soil depths. However, when we dive deeper into the soil, we uncover even more hidden gems - the soil organic carbon pools in the 15-30 cm and 30-45 cm soil depths. Maize-blackgram continues to shine in the 15-30 cm depth, with the highest $C_{f2}$ values ranging from 1.35 to 1.16 g/kg of soil. Maize-fallow, on the other hand, surprises us with its high $C_{f4}$ values ranging from 1.86 to 2.01 g/kg of soil. In the 30-45 cm depth, maize-tomato takes the lead with high $C_{f3}$ values ranging from 1.07 to 0.89 g/kg of soil, showcasing its ability to delve deep into the soil

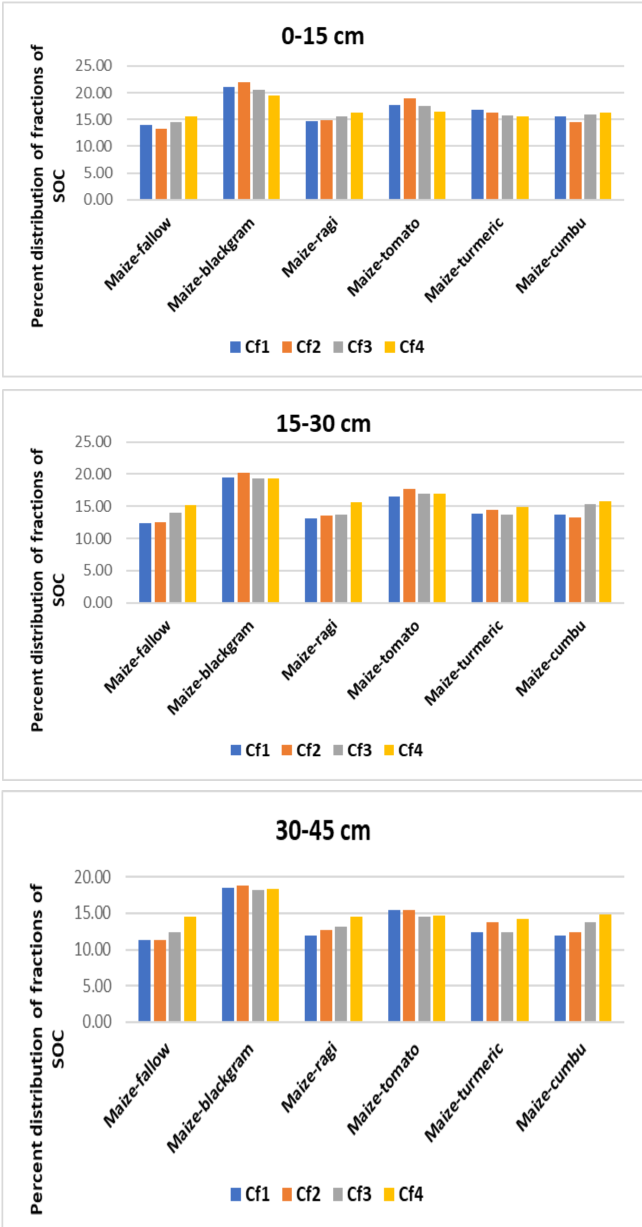


**Fig. 2.** *Percentage distribution of diverse oxidizable organic carbon fractions with varying lability in the different depth like (0-15 cm), (15-30) and (30-45) of different maize-based cropping systems*

**Table 1.** Variations in soil properties across different soil layers under different maize-based cropping systems

| Soil Properties | Soil depth (cm) | Maize-fallow | Maize-blackgram | Maize-ragi | Maize-tomato | Maize-turmeric | Maize-cumbu |
|---|---|---|---|---|---|---|---|
| Bulk density ($g\ cm^{-3}$) | 0-15 | 1.34 | 1.27 | 1.35 | 1.34 | 1.24 | 1.16 |
| | 15-30 | 1.44 | 1.36 | 1.42 | 1.43 | 1.36 | 1.23 |
| | 30-45 | 1.56 | 1.44 | 1.51 | 1.52 | 1.47 | 1.46 |
| Sand (%) | 0-15 | 47.30 | 43.65 | 42.60 | 43.50 | 44.50 | 58.60 |
| | 15-30 | 43.20 | 41.10 | 39.20 | 41.25 | 43.50 | 55.60 |
| | 30-45 | 41.10 | 37.40 | 37.20 | 38.64 | 40.50 | 54.70 |
| Silt (%) | 0-15 | 22.20 | 27.10 | 24.60 | 25.30 | 22.90 | 12.70 |
| | 15-30 | 23.10 | 29.20 | 25.30 | 26.40 | 24.10 | 13.30 |
| | 30-45 | 25.10 | 31.70 | 25.60 | 27.90 | 26.20 | 17.30 |
| Clay (%) | 0-15 | 30.10 | 28.00 | 32.40 | 30.20 | 31.60 | 28.30 |
| | 15-30 | 32.56 | 29.20 | 35.20 | 32.10 | 32.30 | 27.30 |
| | 30-45 | 33.10 | 30.30 | 36.40 | 32.50 | 33.10 | 27.20 |
| pH | 0-15 | 7.74 | 8.62 | 6.48 | 8.22 | 8.59 | 7.13 |
| | 15-30 | 8.14 | 8.85 | 6.72 | 8.65 | 8.81 | 7.46 |
| | 30-45 | 8.11 | 8.73 | 6.67 | 8.66 | 8.78 | 7.48 |
| Available N ($kg\ ha^{-1}$) | 0-15 | 183.30 | 243.10 | 192.20 | 231.40 | 220.70 | 228.70 |
| | 15-30 | 102.20 | 158.30 | 115.30 | 148.60 | 137.50 | 129.60 |
| | 30-45 | 68.40 | 124.30 | 82.40 | 112.50 | 86.30 | 92.50 |
| Available P ($kg\ ha^{-1}$) | 0-15 | 12.00 | 26.90 | 21.80 | 25.40 | 21.50 | 25.70 |
| | 15-30 | 10.50 | 19.60 | 15.60 | 18.70 | 14.60 | 22.58 |
| | 30-45 | 9.60 | 16.50 | 13.70 | 16.80 | 11.50 | 18.40 |
| Available K ($kg\ ha^{-1}$) | 0-15 | 561.20 | 753.40 | 659.50 | 706.50 | 673.40 | 688.30 |
| | 15-30 | 486.40 | 672.20 | 558.40 | 623.40 | 574.30 | 602.50 |
| | 30-45 | 442.60 | 625.80 | 515.30 | 584.30 | 531.40 | 562.80 |
| Available Zn ($mg\ kg^{-1}$) | 0-15 | 0.62 | 0.82 | 0.72 | 0.76 | 0.69 | 0.77 |
| | 15-30 | 0.51 | 0.68 | 0.57 | 0.56 | 0.48 | 0.59 |
| | 30-45 | 0.39 | 0.46 | 0.43 | 0.44 | 0.37 | 0.41 |

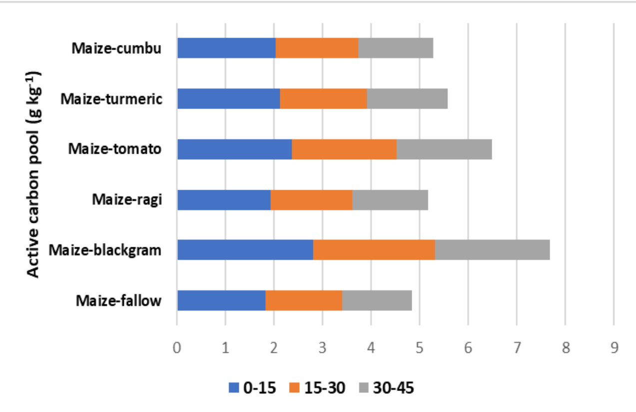


**Fig. 3.** *Active carbon pools ($C_{f1}$ + $C_{f2}$) of different depth like (0-15), (15-30) and (30-45) of different maize based cropping systems*

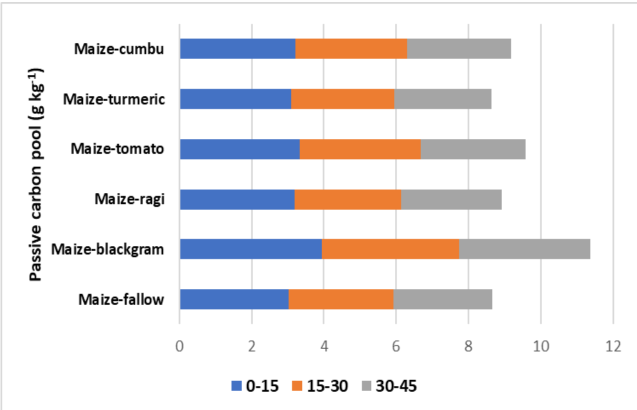


**Fig. 4.** *Passive carbon pools ($C_{f3}$ + $C_{f4}$) of different depth like (0-15), (15-30) and (30-45) of different maize based cropping systems*

This study showed the effects of different cropping systems on soil organic carbon (SOC) stocks and lability indices (LI) in three soil depths (0-15, 15-30, and 30-45 cm) (Table 4). The cropping systems evaluated were Maize-fallow, Maize-blackgram, Maize-ragi, Maize-tomato, Maize-turmeric, and Maize-cumbu. Our results showed that Maize-blackgram had the highest SOC stock in all soil depths, followed by Maize-tomato and Maize-cumbu. On the other hand, Maize-fallow had the lowest SOC stock in all soil depths. Interestingly, the highest LI was observed in Maize-blackgram, which suggests that this cropping system has the potential to cycle organic matter and improve soil fertility rapidly. Regarding soil depth, the highest SOC stock was found in the topsoil (0-15 cm), consistent with previous studies. However, we observed a decrease in SOC stock with increasing soil depth, which is likely due to reduced plant root biomass and microbial activity in deeper soil layers.

These findings suggest that the choice of cropping system can significantly impact SOC stocks and lability indices. Therefore, careful consideration should be given to selecting cropping systems that promote SOC sequestration and cycling, such as Maize-blackgram, to maintain soil fertility and productivity.

## DISCUSSION

The findings of this study provide valuable insights into the influence of agricultural practices on soil health and carbon sequestration potential in maize-dominated cropping systems of Tamil Nadu. The differences in soil properties observed in present study are consistent with earlier research conducted in a similar agro-climatic region (Western zone of Tamil Nadu). A previous study by Hema *et al.* (2019) has also reported similar patterns in soil properties, including bulk density, texture, and pH, in this specific geographical area. These findings highlight how agricultural practices can influence the soil's structure, composition, and nutrient availability in the region. Additionally, Meetei *et al.* (2020) found differences in nutrient availability among rice-based cropping systems in Manipur. This emphasizes the importance of using customized fertilization methods and crop rotation to improve how efficiently nutrients are used.

In terms of carbon dynamics, the present study aligns with the findings of Prabha *et al.* (2019), who investigated different land use systems in a North Eastern zone of Tamil Nadu. They observed variations in carbon pools across different land use systems and soil depths, indicating differences in organic matter inputs, decomposition rates, and stabilization mechanisms. These observations highlight the significance of carbon sequestration and soil organic matter enhancement in

**Table 2.** Variations in TOC, OC, and MBC content across soil layers of different maize-based cropping systems

| Cropping systems | Soil organic carbon | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Total organic carbon (TOC) (%) | | | Oxidizable organic carbon (%) | | | Soil microbial biomass carbon (g/kg soil) | | |
| | 0-15 (cm) | 15-30 (cm) | 30-45 (cm) | 0-15 (cm) | 15-30 (cm) | 30-45 (cm) | 0-15 (cm) | 15-30 (cm) | 30-45 (cm) |
| Maize-fallow | 0.38a | 0.31b | 0.31b | 0.35a | 0.24a | 0.18a | 0.47b | 0.39b | 0.17b |
| Maize-blackgram | 0.87c | 0.74d | 0.67d | 0.54f | 0.42d | 0.33f | 0.65e | 0.54d | 0.30e |
| Maize-ragi | 0.35a | 0.25a | 0.28a | 0.43c | 0.37c | 0.22b | 0.43a | 0.32a | 0.11a |
| Maize-tomato | 0.86c | 0.73d | 0.72e | 0.45d | 0.35b | 0.29d | 0.62d | 0.51c | 0.25d |
| Maize-turmeric | 0.85c | 0.63c | 0.56c | 0.48e | 0.41d | 0.31e | 0.63de | 0.49c | 0.24d |
| Maize-cumbu | 0.46b | 0.32b | 0.30ab | 0.41b | 0.34b | 0.24c | 0.53c | 0.41b | 0.21c |
| Mean | 0.63 | 0.50 | 0.47 | 0.44 | 0.36 | 0.26 | 0.56 | 0.44 | 0.21 |

Presence of different letters following the values in the column indicates significant differences between treatments at a significance level of 5%, as determined by the Duncan's Multiple Range Test (DMRT) for mean separation

**Table 3.** Variations in oxidizable organic carbon pools across soil layers in diverse maize-based cropping systems

| Cropping systems | Soil organic carbon pools (g $kg^{-1}$ soil) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $C_{f1}$ | | | $C_{f2}$ | | | $C_{f3}$ | | | $C_{f4}$ | | |
| | 0-15 (cm) | 15-30 (cm) | 30-45 (cm) | 0-15 (cm) | 15-30 (cm) | 30-45 (cm) | 0-15 (cm) | 15-30 (cm) | 30-45 (cm) | 0-15 (cm) | 15-30 (cm) | 30-45 (cm) |
| Maize-fallow | 0.97a | 0.86a | 0.78a | 0.76a | 0.72a | 0.65a | 1.01a | 0.97a | 0.86a | 2.01a | 1.94a | 1.86a |
| Maize-blackgram | 1.46d | 1.35d | 1.28d | 1.27e | 1.16e | 1.08e | 1.43d | 1.34d | 1.26d | 2.51b | 2.47c | 2.36b |
| Maize-ragi | 1.02a | 0.91a | 0.83ab | 0.86b | 0.78bc | 0.73b | 1.08a | 0.95a | 0.91ab | 2.10a | 2.01ab | 1.86a |
| Maize-tomato | 1.23c | 1.14c | 1.07c | 1.09d | 1.02d | 0.89d | 1.22c | 1.18c | 1.01c | 2.11a | 2.17b | 1.89a |
| Maize-turmeric | 1.17bc | 0.96b | 0.86b | 0.94c | 0.83c | 0.79c | 1.09ab | 0.95a | 0.86a | 2.00a | 1.91a | 1.83a |
| Maize-cumbu | 1.08b | 0.95ab | 0.83ab | 0.84b | 0.76ab | 0.71b | 1.11b | 1.06b | 0.96bc | 2.10a | 2.03ab | 1.91a |
| Mean | 1.16 | 1.03 | 0.94 | 0.96 | 0.88 | 0.81 | 1.16 | 1.08 | 0.98 | 2.14 | 2.09 | 1.95 |

The presence of different letters following the values in the column indicates significant differences between treatments at a significance level of 5%, as determined by the Duncan's Multiple Range Test (DMRT) for mean separation.

**Table 4.** Variations in lability index (LI) and soil organic carbon (SOC) stock (Mg $ha^{-1}$) at different soil depths in distinct maize-based cropping systems

| Cropping systems | Lability index (LI) | | | SOC stock (Mg $ha^{-1}$) | | |
|---|---|---|---|---|---|---|
| | 0-15 (cm) | 15-30 (cm) | 30-45(cm) | 0-15 (cm) | 15-30 (cm) | 30-45 (cm) |
| Maize-fallow | 0.80a | 0.79ab | 0.77b | 7.11a | 5.11a | 4.08a |
| Maize-blackgram | 0.96c | 0.94d | 0.91d | 10.85c | 9.01e | 7.52d |
| Maize-ragi | 0.82a | 0.80b | 0.77b | 7.13a | 6.27b | 5.26b |
| Maize-tomato | 0.88b | 0.84c | 0.82c | 8.61b | 7.04c | 6.26c |
| Maize-turmeric | 0.81a | 0.76a | 0.74a | 8.89b | 8.36d | 7.28d |
| Maize-cumbu | 0.82a | 0.79ab | 0.78b | 8.64b | 7.99d | 5.15b |
| Mean | 0.85 | 0.82 | 0.80 | 8.54 | 7.30 | 5.93 |

Presence of different letters following the values in the column indicates significant differences between treatments at a significance level of 5%, as determined by the Duncan's Multiple Range Test (DMRT) for mean separation

improving soil fertility and climate resilience.

The study found that the Maize-blackgram cropping system has the highest total organic carbon (TOC) levels compared to the other cropping systems studied. This matches what previous research has suggested, adding root and shoot materials to the soil over a long time, along with regular fertilizer use, probably leads to higher TOC levels (Merante *et al.,* 2017). The comparison between surface soil and sub-surface soil indicated that the sub-surface soil has lower soil microbial biomass carbon (SMBC). This finding is in line with previous research, which has also shown that as soil depth increases, the optimal soil characteristics (such as soil organic carbon, water holding capacity, and bulk density) that influence microbial activities in the soil tend to decrease, leading to a decline in SMBC (Choudhary and Gill, 2013).

Furthermore, the Maize-blackgram cropping system exhibited the highest levels of soil organic carbon (SOC), total organic carbon (TOC), and soil microbial biomass carbon (SMBC). This finding aligns with previous research, which suggests that blackgram, a leguminous crop, can fix nitrogen in the soil (Porpavai *et al*., 2011). Additionally, its taproot nature enables efficient absorption of plant nutrients and water from various soil layers (Das *et al*., 2017 and; Majumder *et al*., 2008). These factors contribute to the observed higher levels of SOC, TOC, and SMBC in the Maize-blackgram cropping system.

In this study, the surface soil exhibited the highest carbon fractions $C_{f1}$ and $C_{f2}$ levels. This finding aligns with previous research, which indicates that the surface soil receives a higher input of crop residues and fine roots, providing more substrate for microbial activity. Consequently, this leads to an increase in both $C_{f1}$ and $C_{f2}$ in the soil (Carpenter-Baggs *et al*., 2003). On the other hand, in the sub-surface soil, the lack of crop residues results in decreased microbial activities, leading to a reduction in Cf1 and $C_{f2}$. However, $C_{f3}$ and $C_{f4}$ increase in the sub-surface soil (Nath *et al.,* 2016).

The lability index of both surface and subsurface soil was found to be highest in the Maize-blackgram cropping system when compared to other cropping systems such as Maize-fallow, Maize-ragi, Maize-tomato, Maize-turmeric, and Maize-cumbu. This outcome aligns with previous studies that have demonstrated legumes' beneficial effects due to their low C/N ratio, which contributes high-quality organic matter to the soil. As a result, the microbial activity increases, leading to a higher lability index in cropping systems that include legumes (Hazra *et al*., 2018)

The present study revealed a decrease in the lability index (LI) in the surface soil as the depth of the soil layer increased. This finding aligns with previous research that indicates the significant decrease in soil LI from the surface soil may be attributed to higher bulk density and the non-availability of easily decomposable substrate (Jat *et al*., 2018). Out of all the cropping systems studied, Maize-blackgram showed the highest SOC stock in both surface and subsurface soil compared to others. This matches previous studies that found legumes can fix atmospheric nitrogen, reducing the need for nitrogen fertilizer and benefiting soil fertility (Benbi *et al*., 2015).

Smith *et al.* (2016) discussed soil carbon sequestration and biochar as negative emission technologies, emphasizing the importance of carbon management strategies to mitigate climate change. Lal (2013) highlighted the critical role of soil health and carbon management in global agriculture, stressing the need for sustainable practices to enhance soil productivity and ecosystem services. Valkama *et al.* (2020) conducted a meta-analysis in Italy, examining the effects of conservation agriculture on soil organic carbon accumulation and crop yield, emphasizing the potential of such practices in enhancing carbon sequestration and maintaining crop productivity.

Additionally, specific studies focusing on agricultural systems and regions provide valuable insights. Pittelkow *et al.* (2015) conducted a study exploring the boundaries and possibilities of conservation agriculture principles, underscoring the significance of sustainable techniques in enhancing soil health and crop productivity. Their findings align with the broader implications of this study, emphasizing the importance of sustainable practices in agricultural systems.

Furthermore, Rumpel *et al.* (2020) examined the topic of carbon sequestration in Indian soils, specifically focusing on the current state and potential for soil carbon storage within the framework of agricultural practices in India. Their research provides additional context to this study, highlighting the relevance of investigating carbon fluxes and soil characteristics in maize-dominated cropping systems.

Additionally, studies focusing on specific management practices provide insights into their impact on soil characteristics and carbon dynamics. Liu *et al.* (2021) investigated the effects of soil tillage and straw incorporation on soil organic carbon, total nitrogen, and grain yield in the North China Plain. Their findings underscored the role of conservation practices in enhancing soil carbon sequestration and nutrient cycling.

## Conclusion

The present study showed variations in soil properties among various cropping systems, namely Maize-fallow, Maize-blackgram, Maize-ragi, Maize-tomato, Maize-turmeric, and Maize-cumbu, in the Western zone of Tamil Nadu. Moreover, these variations were observed across different soil depths. Among these systems, bulk density and sand content were highest in the maize-cumbu system, while silt and clay contents were highest in maize-blackgram and maize-cumbu. Soil pH was alkaline, with maize-tomato having the highest value. Available nutrient levels varied, with maize-fallow and maize-blackgram having the highest nitrogen content, and maize-cumbu having the highest phosphorus, potassium, and zinc content. Carbon fractions and pools differed among systems and depths, with maize-blackgram exhibiting the highest labile and passive carbon pools. Total organic carbon and microbial biomass carbon decreased with depth, with maize-blackgram having the highest values. Based on the observed improvements in soil quality and carbon reserves, the integration of maize with blackgram emerged as a highly recommended cropping system for the study area. This combination exhibited the potential to enhance the overall soil quality and carbon storage capacity, highlighting its importance for sustainable agricultural practices in the region. These findings contribute to understanding soil dynamics in maize cropping systems, aiding sustainable practices and soil management.

## ACKNOWLEDGEMENTS

I am immensely grateful to the Department of Soil Science and Agricultural Chemistry at Tamil Nadu Agricultural University in Coimbatore for their invaluable support and provision of essential resources, which have been instrumental in conducting this research. Their unwavering commitment to excellence and state-of-the-art facilities have significantly contributed to the success of this study. I express my sincere appreciation for their assistance and collaboration throughout this journey.

## Conflict of interest

The authors declare that they have no conflict of interest.

## REFERENCES

1. Abid, M., Batool, T., Siddique, G., Ali, S., Binyamin, R., Shahid, M. J., Rizwan, M., Alsahli, A. A. & Alyemeni, M. N. (2020). Integrated nutrient management enhances soil quality and crop productivity in maize-based cropping system. *Sustainability*, *12*(23), 10214. https://doi.org/10.3390/su122310214
2. Benbi, D. K., Kiranvir, B. R. A. R. & Sharama, S. (2015). Sensitivity of labile soil organic carbon pools to long-term fertilizer, straw and manure management in rice-wheat system. *Pedosphere*, *25*(4), 534-545. https://doi.org/10.1016/S1002-0160(15)30034-5
3. Carpenter-Boggs, L., Stahl, P. D., Lindstrom, M. J. & Schumacher, T. E. (2003). Soil microbial properties under permanent grass, conventional tillage, and no-till management in South Dakota. *Soil and Tillage Research*, *71*(1), 15-23. https://doi.org/10.1016/S0167-1987(02)00158-7
4. Chan, K. Y. (2001). Soil particulate organic carbon under different land use and management. *Soil use and management*, *17*(4), 217-221. https://doi.org/10.1111/j.1475-2743.2001.tb00030.x
5. Choudhary, O. P. & Gill, J. K. (2013). Water-extractable carbon pools and microbial biomass carbon in sodic water -irrigated soils amended with gypsum and organic manures. *Pedosphere*, *23*(1), 88-97. https://doi.org/10.1016/S1002-0160(12)60083-6
6. Dakshinamurthi, C. & Gupta, R. P. (1968). Practicals in soil physics. *IARI, New Delhi*.
7. Das, A., Patel, D. P., Kumar, M., Ramkrushna, G. I., Mukherjee, A., Layek, J., Ngachan, S. V. & Buragohain, J. (2017). Impact of seven years of organic farming on soil and produce quality and crop yields in eastern Himalayas, India. *Agriculture, ecosystems & environment*, *236*, 142-153. https://doi.org/10.1016/j.agee.2016.09.007
8. Ding, X., Yuan, Y., Liang, Y., Li, L. & Han, X. (2014). Impact of long-term application of manure, crop residue, and mineral fertilizer on organic carbon pools and crop yields in a Mollisol. *Journal of Soils and Sediments*, *14*, 854-859. https://doi.org/10.1007/s11368-013-0840-x
9. Hazra, K. K., Ghosh, P. K., Venkatesh, M. S., Nath, C. P., Kumar, N., Singh, M., Singh, J. & Nadarajan, N. (2018). Improving soil organic carbon pools through inclusion of

summer mungbean in cereal-cereal cropping systems in Indo-Gangetic plain. *Archives of Agronomy and Soil Science*, *64*(12), 1690-1704. https://doi.org/10.1080/03650340.2018.1451638
10. Hema, R., Santhy, P., Somasundaram, E. & Patil, S. G. (2019). Impact of different cropping and different nutrient management practices on soil carbon pools and soil carbon stock in vertic ustropept. *Journal of Pharmacognosy and Phytochemistry*, *8*(3), 3424-3428.
11. Jackson, M. L. (1973). Soil chemical analysis, pentice hall of India Pvt. *Ltd., New Delhi, India*, *498*, 151-154.
12. Jat, H. S., Datta, A., Sharma, P. C., Kumar, V., Yadav, A. K., Choudhary, M., Choudhary, V., Gathala, M. K., Sharma, D. K., Jat, M. L. & Yaduvanshi, N. P. S. (2018). Assessing soil properties and nutrient availability under conservation agriculture practices in a reclaimed sodic soil in cereal-based systems of North-West India. *Archives of Agronomy and Soil Science*, *64*(4), 531-545. https://doi.org/10.1080/03650340.2017.1359415
13. Kumar, V., Jat, H. S., Sharma, P. C., Gathala, M. K., Malik, R. K., Kamboj, B. R., Yadav, A. K., Ladha, J. K., Raman, A., Sharma, D. K. & McDonald, A. (2018). Can productivity and profitability be enhanced in intensively managed cereal systems while reducing the environmental footprint of production? Assessing sustainable intensification options in the breadbasket of India. *Agriculture, Ecosystems and Environment*, *252*, 132-147. https://doi.org/10.1016/j.agee.2017.10.006
14. Lal, R. (1997). Long-term tillage and maize monoculture effects on a tropical Alfisol in western Nigeria. I. Crop yield and soil physical properties. *Soil and tillage research*, *42* (3), 145-160. https://doi.org/10.1016/S0167-1987(97)00006-8
15. Lal, R. (2013). Soil carbon management and climate change. *Carbon Management*, *4*(4), 439-462. https://doi.orgE10.4155/cmt.13.31
16. Lal, R. (2018). Digging deeper: A holistic perspective of factors affecting soil organic carbon sequestration in agroecosystems. *Global change biology*, *24*(8), 3285-3301. https://doi.org/10.1111/gcb.14054
17. Li, Z., Yang, X., Cui, S., Yang, Q., Yang, X., Li, J. & Shen, Y. (2018). Developing sustainable cropping systems by integrating crop rotation with conservation tillage practices on the Loess Plateau, a long-term imperative. *Field Crops Research*, *222*, 164-179. https://doi.org/10.1016/j.fcr.2018.03.027
18. Lindsay, W. L. & Norvell, W. (1978). Development of a DTPA soil test for zinc, iron, manganese, and copper. *Soil science society of America journal*, *42*(3), 421-428.https://doi.org/10.2136/sssaj1978.03615995004200030009x
19. Liu, N., Li, Y., Cong, P., Wang, J., Guo, W., Pang, H. & Zhang, L. (2021). Depth of straw incorporation significantly alters crop yield, soil organic carbon and total nitrogen in the North China Plain. *Soil and Tillage Research*, *205*, 104772. https://doi.org/10.1016/j.still.2020.104772
20. Majumder, B. (2006). Soil organic Carbon Pools and Biomass Productivity Under Agroecosystems of Subtropical India [PhD thesis]. *Environmental Engineering Division, Department of Civil Engineering, Jadavpur University, Kolkata, India*, 183.
21. Majumder, B., Mandal, B., Bandyopadhyay, P. K., Gangopadhyay, A., Mani, P. K., Kundu, A. L. & Mazumdar, D. (2008). Organic amendments influence soil organic carbon pools and rice–wheat productivity. *Soil science society of America journal*, *72*(3), 775-785. https://doi.org/10.2136/sssaj2006.0378
22. Mamta, S., Kumar, R., Bairwa, R., Meena, P. & Meena, M. C. (2023). Assessment of carbon pools and stability of soil aggregates in inceptisols of Indo-Gangetic plains as influenced by seven-year continuous tillage practices under maize-based cropping system. *Communications in Soil Science and Plant Analysis*, *54*(4), 544-558. https://doi.org/10.1080/00103624.2022.2118298
23. Meena, J. R., Behera, U. K., Chakraborty, D. & Sharma, A. R. (2015). Tillage and residue management effect on soil properties, crop performance and energy relations in greengram (Vigna radiata L.) under maize-based cropping systems. *International Soil and Water Conservation Research*, *3*(4), 261-272. https://doi.org/10.1016/j.iswcr.2015.11.001
24. Meetei, T. T., Kundu, M. C. & Devi, Y. B. (2020). Long-term effect of rice-based cropping systems on pools of soil organic carbon in farmer's field in hilly agroecosystem of Manipur, India. *Environmental monitoring and assessment*, *192*, 1-17. https://doi.org/10.1007/s10661-020-8165-x
25. Merante, P., Dibari, C., Ferrise, R., Sanchez, B., Iglesias, A., Lesschen, J. P., Kuikman, P., Yeluripati, J., Smith, P. & Bindi, M. (2017). Adopting soil organic carbon management practices in soils of varying quality: Implications and perspectives in Europe. *Soil and Tillage Research*, *165*, 95-106. https://doi.org/10.1016/j.still.2016.08.001
26. Nath, A. J., Bhattacharyya, T., Deka, J., Das, A. K. & Ray, S. K. (2016). Management effect on soil organic carbon pools in lowland rain-fed paddy growing soil. *Journal of Tropical Agriculture*, *53*(2), 131-138.
27. Nelson, D. A. & Sommers, L. (1983). Total carbon, organic carbon, and organic matter. *Methods of soil analysis: Part 2 chemical and microbiological properties*, *9*, 539-579. https://doi.org/10.2134/agronmonogr9.2.2ed.c29
28. Olsen, S. R. (1954). *Estimation of available phosphorus in soils by extraction with sodium bicarbonate* (No. 939). US Department of Agriculture.
29. Piper, C. S. (1966). Mechanical analysis of soil by International Robinson' s Pipette method. *Soil and plant analysis*.
30. Pittelkow, C. M., Liang, X., Linquist, B. A., Van Groenigen, K. J., Lee, J., Lundy, M. E., Van Gestel, N., Six, J., Venterea, R. T. & Van Kessel, C. (2015). Productivity limits and potentials of the principles of conservation agriculture. *Nature*, *517*(7534), 365-368. https://doi.org/10.1038/nature13809
31. Porpavai, S., Devasenapathy, P., Siddeswaran, K. & Jayaraj, T. (2011). Impact of various rice based cropping systems on soil fertility. *Journal of cereals and oilseeds*, *2* (3), 43-46.
32. Prabha, A. S., Arulmani, K., Senthivelu, M., Velumani, R. & Rathnam, K. S. (2019). Carbon Sequestration in Dominant Soil Series under Different Land Uses of Tamil Nadu, India. *Int. J. Curr. Microbiol. App. Sci*, *8*(8), 2666-2674. https://doi.org/10.20546/ijcmas.2019.808.309
33. Rumpel, C., Amiraslani, F., Chenu, C., Garcia Cardenas, M., Kaonga, M., Koutika, L. S., Ladha, J., Madari, B., Shirato, Y., Smith, P. & Soudi, B. (2020). The 4p1000

initiative: Opportunities, limitations and challenges for implementing soil organic carbon sequestration as a sustainable development strategy. *Ambio*, *49*, 350-360. https://doi.org/10.1007/s13280-019-01165-2

34. Sarwar, N., Farooq, O., Wasaya, A., Hussain, M., El-Shehawi, A. M., Ahmad, S., Brestic, M., Mahmoud, S. F., Zivcak, M. & Farooq, S. (2021). Integrated nitrogen management improves productivity and economic returns of wheat-maize cropping system. *Journal of King Saud University-Science*, *33*(5), 101475. https://doi.org/10.1016/j.jksus.2021.101475
35. Sisti, C. P., dos Santos, H. P., Kohhann, R., Alves, B. J., Urquiaga, S. & Boddey, R. M. (2004). Change in carbon and nitrogen stocks in soil under 13 years of conventional or zero tillage in southern Brazil. *Soil and tillage research*, *76*(1), 39-58. https://doi.org/10.1016/j.still.2003.08.007
36. Smith, P. (2016). Soil carbon sequestration and biochar as negative emission technologies. *Global change biology*, *22*(3), 1315-1324. https://doi.org/10.1111/gcb.13178
37. Stanford, G. & English, L. (1949). Use of the flame photometer in rapid soil tests for K and Ca.
38. Subbiah, B. W. & Asija, G. L. (1956). A rapid procedure for the estimation of available micronutrient in soils. *Current Science*, *25*, 259-260.
39. Valkama, E., Kunypiyaeva, G., Zhapayev, R., Karabayev, M., Zhusupbekov, E., Perego, A., Schillaci, C., Sacco, D., Moretti, B., Grignani, C. & Acutis, M. (2020). Can conservation agriculture increase soil carbon sequestration? A modelling approach. *Geoderma*, *369*, 114298. https://doi.org/10.1016/j.geoderma.2020.114298
40. Vance, E. D., Brookes, P. C. & Jenkinson, D. S. (1987). An extraction method for measuring soil microbial biomass C. *Soil biology and Biochemistry*, *19*(6), 703-707. https://doi.org/10.1016/0038-0717(87)90052-6
41. Wairiu, M. (2017). Land degradation and sustainable land management practices in Pacific Island Countries. *Regional Environmental Change*, *17*,1053-1064. https://doi.org/10.1007/s10113-016-1041-0
42. Walkley, A. & Black, I. A. (1934). An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil science*, *37*(1), 29-38.
43. Wiesmeier, M., Urbanski, L., Hobley, E., Lang, B., von Lutzow, M., Marin-Spiotta, E., Wesemael, B., Rabot, E., Lie, M., Garcia-Franco, N. & Wollschläger, U. (2019). Soil organic carbon storage as a key function of soils-A review of drivers and indicators at variousscales. *Geoderma*, *333*, 149-162. https://doi.org/10.1016/j.geoderma.2018.07.026
44. Yadav, G. S., Das, A., Babu, S., Mohapatra, K. P., Lal, R. & Rajkhowa, D. (2021). Potential of conservation tillage and altered land configuration to improve soil properties, carbon sequestration and productivity of maize based cropping system in eastern Himalayas, India. *International Soil and Water Conservation Research*, *9*(2), 279-290. https://doi.org/10.1016/j.iswcr.2020.12.003