SOIL HEALTH UNDER CONVENTIONAL AND MINIMUM-TILLAGE PRACTICE: SOIL CARBON STORAGE AND NUTRIENT USE

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Abstract

Tillage is a fundamental soil practice that impacts various soil characteristics. However, the impact of tillage on soil health is complex and context-specific. Our study aimed to evaluate the soil carbon sequestration and nutrient use of two different tillage practices: conventional and minimum-tillage, at various depths ranging from 0 to 30 cm, using a chernozem soil type. The results of our study are consistent with the hypothesis that, over time, minimum-tillage typically boosts soil health in the 0-10 cm soil layer. Compared to the conventional practice (19.36 t C ha^{-1}), there was a significant accumulation of soil organic carbon (0-30 cm) in the minimum-tillage practice (23.21 t C ha^{-1}). Below 10 cm depth, the soil organic carbon stocks are close to those of the conventional layer (0-30 cm). Total nitrogen (TN), available potassium (AK), and phosphorus (AP) content in 0-10 cm depth under minimum-tillage practice were 19.5%, 2%, and 3%, respectively, compared to the conventional treatment. Overall, the values of TN, AP and AK decreased with depth within the soil profiles as a consequence of soil practice and minimum disturbance. The data indicate that minimum tillage is a sustainable and effective management practice that maintains soil health, promotes soil carbon increase, and facilitates efficient nutrient use.

Keywords: soil health, tillage, soil carbon, soil nutrients

The worldwide production of food depends on soil technologies, which can result in the loss of soil organic carbon (SOC) and nutrient availability, crucial indicators of the agroecosystems' sustainability and the general health of the soil. Preserving the soil's moisture content, organic matter content, nutrient availability to plants, and avoiding erosion and pollution are part of soil management. By using the right tillage techniques, these may be controlled efficiently.

Tillage is the process of preparing soil to support plant growth. Conventional tillage involves disturbing the soil, allowing plant roots to establish (Mihu *el al.,* 2025). This decreases the soil's capacity to retain water, increasing its erosion susceptibility. Conversely, conservative tillage is an approach that minimizes energy, equipment, and moisture loss in addition to promoting soil preservation. The three most common types of conservation tillage are min-tillage, mulch-tillage, and no-tillage. The percentage of surface soil covered by crop residue following planting is used to differentiate between various forms of conservative tillage (Amit *et al.,* 2018). Globally, the most widely used conservative tillage practice is min-tillage. By reducing soil erosion and disturbance of soil aggregates, min-tillage systems limit SOC degradation (Corbeels *et al.*, 2019; Miranda *et al.,* 2016). However, accumulating plant residues on the topsoil layer decreases the interaction between crop residues and soil minerals, which could eventually lead to a gradual decline in SOC stabilization. Additionally, it has been noted that long-term min-tillage or no-tillage adoption reduces crop output, compaction of the soil (Nunes, 2015), and the soil's C input (plant biomass and root exudate). The primary goal of conservation tillage is to prevent soil degradation by preserving agricultural residue in soil, promoting soil organic carbon. Conservation tillage preserves the soil's stability and proper pore distribution, compared to conventional tillage methods that break down soil aggregates and produce a hard pan. (Das *et al.,* 2020). Long-term conservation tillage strategies have been shown to improve nutrient cycling, energy transfers, and soil enzymatic activity; enzymatic activity and soil organic carbon are thought to be closely related to soil health (Dick, 1994).

This study aimed to compare soil organic carbon and nutrient content among two tillage systems (conventional and minimum tillage) in

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three depths (0-10 cm, 10-20 and 20-30 cm) under temperate conditions. We hypothesized that, in terms of improving the chemical quality and soil health, minimum tillage is a suitable practice.

MATERIAL AND METHOD

This study was established in 2019 in the Research Station of Iasi University of Life Sciences (IULS), Romania (47°07′ N latitude, 27°30′ E longitude) Soil is a clay-loam, classified as Chernozem (WRB Classification) with 35% clay, 25% silt and 36.9% sand. The region has a temperate humid subtropical climate—Cfa (Köppen classification), with a mean annual temperature and precipitation of 9.4°C and 517.8 mm (*figure 1*).

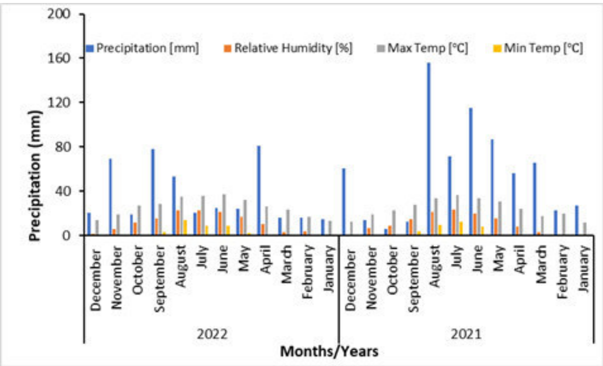

Figure 1 **Temperature, precipitation and humidity data of the study area**

The experiment was performed as a randomized block design with three repetitions, in a winter wheat-soybean-maize rotation system, with the current experiment in wheat. Each plot covered an area of 60 m^2 and was separated by a 1m buffer zone. The experiment was performed with two tillage practices: min-tillage (MT) and conventional tillage (CT) as main plot treatments. In the CT system, straw was chopped between 3-5 cm lengths and placed to a depth of 30 cm using moldboard plowing. For MT, the tillage process involved partial straw removal using a disc harrow treatment at a depth of 25 cm. Winter wheat was planted with the FABIMAG FG01 no-till seeding machine between September 25 and October 5. During the growth season, the recommended dose of 100 kg/ha urea (46% N) is used as base fertilizer before sowing, followed by 180 kg/ha NPK (12:32:16) complex fertilizers during the vegetative stage. The experiment was carried out in rainfed conditions without irrigation. Initially, 3 L/ha of glyphosate was used for weed management, and 0.6 L/ha of 6.25 g/L florasulam + 300 g/L acid 2.4-D EHE were applied to the vegetation.

Following the winter wheat harvest, soil samples of 0-10, 10-20, and 20-30 cm were collected at random from each plot. After removing plant residues, the soil sample was air-dried, mixed completely, sieved through a 2 mm screen, and stored at 4°C for future analysis. Using a Mettler Toledo S210 pH meter, the pH of the soil was measured in a 1:2.5 soil: water ratio. Soil organic carbon was determined using the modified Walkley and Black method, whereas total nitrogen was determined using the conventional Kjeldahl method. Specord Plus UV-Vis Spectrophotometer (Analytikjena, Jena, Germany) was used to measure the amount of accessible potassium and phosphorus at 715 nm after they had been extracted using 1 N NH_4OAc. An Atomic Absorption Spectrometer (ContrAA700, Analytik jena, Jena, Germany) was used to measure the soil's Zn, Cu, Fe, and Mn DTPA extractable micronutrients after they had been agitated for two hours at a 1:2 soil solution ratio and pH 7.3.

RESULTS AND DISCUSSIONS

Influence of tillage practice on soil pH

Our results indicate that the pH of the soil at a depth of 0–30 cm was impacted by the tillage method (*figure 2*). The soil pH levels in all the plots ranged from moderately acidic to neutral, as follows: CT < MT. Surface (0–10 cm depth) soil neutrality was performed with MT (6.87), whereas CT provided an acidified soil layer at 0–30 cm depth. The acidified plowed soil layer (6.29) might be explained by soil disturbance, which increased the rate of straw mineralization and decomposition due to aeration. A further contributor of soil acidity could be fertilizer distribution through the soil at a depth of 0-30 cm; fertilizers include nitrogen in amide form, and releasing protons-H^+ changes ammonium (NH_4-N) to nitrate (NO_3-N), acidifying the soil. These results are comparable with those reported by Dwivedi et al., who found that the tillage methods increased soil acidity in both layers investigated. The neutral pH values under MT might be linked to the soil water diffusion limiting phenomenon, which balanced the pH value by increasing the amount of Na^+, Ca^{2+} and Mg^{2+}, exchangeable cations.

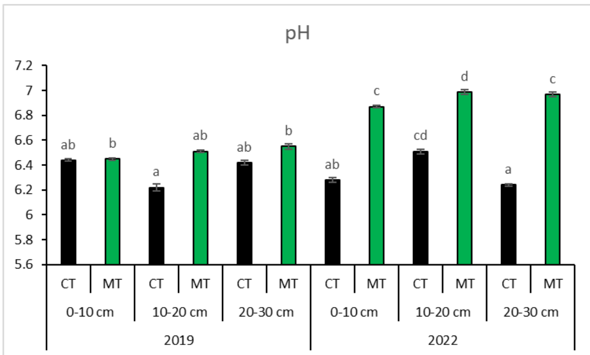

Figure 2 **Dynamics of soil pH at 0–30 cm depths under different tillage, MT: minimum tillage; CT: conventional tillage. Error bars represent the corresponding standard error of mean values. Different letters indicate significant differences between treatments during this period at the 0.05 level.**

Influence of tillage practice on soil SOC and total Nitrogen

Based on tillage practices, conservation tillage treatments can increase agricultural yields by protecting soil structure and enhancing its quality. Because of straw burying and/or mulching, as well as less physical disturbance, MT may improve the fraction of macro-aggregates with higher organic carbon content.

This study found that, compared with CT, MT considerably increased the amount of organic carbon in the 0–10 cm soil layer, from 24.26 t C/ha to 19.36 t C/ha (*figure 3*). MT increased surface soil organic content (0-10 cm), whereas at 10-30 cm depth, soil organic stocks are comparable to those of the plow layer (0-30 cm). Overall, using conservation tillage for two years (2021–2022) performed an increase in surface soil fertility compared to conventional tillage; minimum tillage combined with straw burying is beneficial for improving soil organic carbon because the straw area interacts with soil microorganisms and enzymes, which provide organic matter/humus buildup (Topa *et al.,* 2021).

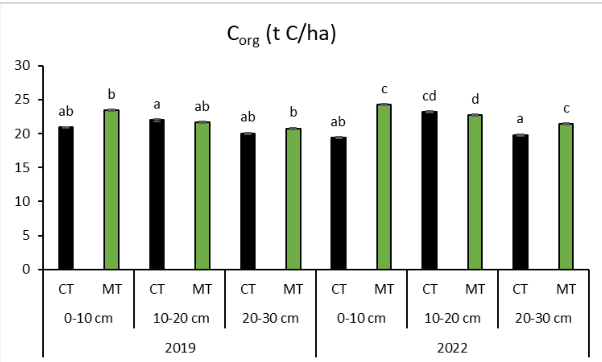

Figure 3 **Dynamics of soil organic carbon at 0–30 cm depths under different tillage, MT: minimum tillage; CT: conventional tillage. Error bars represent the corresponding standard error of mean values. Different letters indicate significant differences between treatments during this period at the 0.05 level**

A significant source of organic nitrogen is soil organic matter, and the dynamics and storage of this element are often linked to those of organic carbon/matter (Das *et al.,* 2020). The influence of the conservation tillage system on the total nitrogen content of the soil was only observed in the 0–10 cm layer, where it increased by 19.5 % in comparison to the CT. MT increased by 15.3 and 21.9%, respectively, in the 10–20 and 20–30 cm layers of total nitrogen. These findings are in line with earlier research showing that the adoption of conservation tillage increases the soil's overall nitrogen concentration. According to (Topa *et al.,*2021) soil total nitrogen buildup was higher under NT and MT after long-term experience.

Influence of Tillage Practice on Soil Available P and K

To ensure optimal crop productivity, phosphorus, a crucial plant nutrient, is required in constant amounts. *Figure 4* shows that under MT as compared to CT, the amount of phosphorus accessible in the 0–30 cm soil increased by 2%. This pattern may be explained by the mineralization and decomposition of soil organic matter driven by tillage practices, which alter the microbial population and soil enzyme diversity and activity, as well as the amount and stoichiometry of soil phosphorus. Increased P content in MT may be connected to higher soil organic carbon content because organic matter can adsorb P while also obstructing de-adsorption centers from clay surfaces, aluminum, and iron oxides. According to the conclusions of (Tiecher *et al.,2018)* the values of accessible P are assigned to higher soil organic matter, chelating the inorganic P linked with the enhancement of organic-inorganic P pool stability.

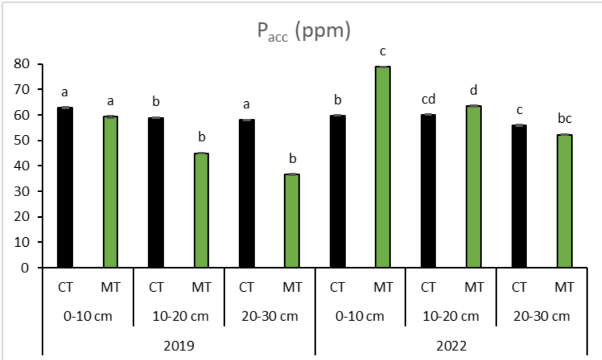

Figure 4 **Dynamics of soil available phosphorus at 0–30 cm depths under different tillage, MT: minimum tillage; CT: conventional tillage. Error bars represent the corresponding standard error of mean values. Different letters indicate significant differences between treatments during this period at the 0.05 level**

A similar trend to that of accessible phosphorus was observed in the distribution of soil-available potassium concentration in a 0–30 cm soil profile. Compared to conventional tillage (186 ppm), the min-tillage practice had more soil accessible K in the 0–10 cm depth (223 ppm). Additionally, the 0–30 cm soil profile was 2.3% higher in MT, which may be due to mineralization and organic matter breakdown. The residues from straw include large amounts of total potassium, which is rapidly transformed into forms that plants can absorb. These findings are following recent research that, in a no-tillage system, showed higher amounts of plant-available potassium at surfaces 0–20 cm, but found no differences at higher soil depths.

Influence of Tillage System on Soil Available and Total Zn, Cu, Fe and Mn

Zn, Cu, Fe, and Mn are micronutrients that are crucial to plant metabolism (Rusu *et. al,* 2023).

A general distribution pattern that followed the order CT > MT suggests that the content of accessible micronutrients is affected by tillage techniques. Table 1 shows a higher concentration and consistent pattern of the 0-30 cm soil accessible microelements under conventional tillage compared to the conservative tillage system MT. These microelements vary in concentration from 1.19 to 4.55 mg kg^{-1} (Zn), 1.09 to 2.10 mg kg^{-1} (Cu), 15.55 to 23.1 mg kg^{-1} (Fe), and 38.98 to 43.10 mg kg^{-1} (Mn), respectively.

Table 1

Effect of tillage and straw practices on soil available micronutrients.

Tillage 0-30 cm	Zn	Cu	Fe	Mn
CT	4.1 ± 0.08 a	1.9 ± 0.02 a	21.2 ± 0.26 a	42.3 ± 0.57 a
MT	1.2 ± 0.01 b	1.1 ± 0.07 b	15.7 ± 0.17 b	39.7 ± 0.54 a

MT: min-tillage; CT: conventional tillage. The date represents means ± SD. Different letters indicate significant differences at the 0.05 level.

In contrast, the stratification pattern/trend for the accessible Zn, Fe, and Mn content was noted, demonstrating the impact of tillage on these microelements. These results contrasted with those of other studies that found that conservation tillage had a greater impact on the soil's accessible micronutrients than CT techniques. Numerous studies indicate that the effects of conservation tillage on the availability, solubility, and mobility of soil micronutrients are extensive, unpredictable, and dependent on a variety of factors, including environmental conditions, soil features (such as soil reactivity and organic carbon concentration), and other factors.

CONCLUSIONS

The impact of conservative tillage on soil qualities and traits, as well as crop quality and quantity, was better understood due to our research conducted over an extended field experiment. The findings suggest that conservation tillage could potentially be used as a practical management option in the conventional farming system of Europe, given the beneficial effects on soil productivity. While maintaining the organic carbon and total nitrogen in a 0–30 cm soil profile, MT changes the chemical characteristics of the soil by reducing soil acidity and increasing the availability of macronutrients. The available micronutrient content (Zn, Cu, Fe, and Mn) showed a stratification tendency in conservative management practice compared to CT.

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