Does conservation tillage, in synergy with liming and fertilization, can affect selected soil properties?

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Abstract

The aim of this study is to determinate effect of different tillage systems, liming and soil fertilization on pH, SOC – soil organic carbon and CEC – cation exchange capacity. Soil samples were taken from 0-15 and 15 -30 cm. At a depth of 0-15 cm, tillage and liming had a significant effect on pH, and tillage and fertilization had a significant effect on CEC. None of the tested treatments had a statistically significant effect on SOC. At a depth of 15-30 cm, soil reaction was significantly affected by tillage, liming, and fertilization, CEC was significantly affected by tillage, fertilization, and liming and SOC content was significantly affected by fertilization and liming.

Keywords: soil tillage systems, mineral fertilization, liming, soil health, soil properties

Introduction

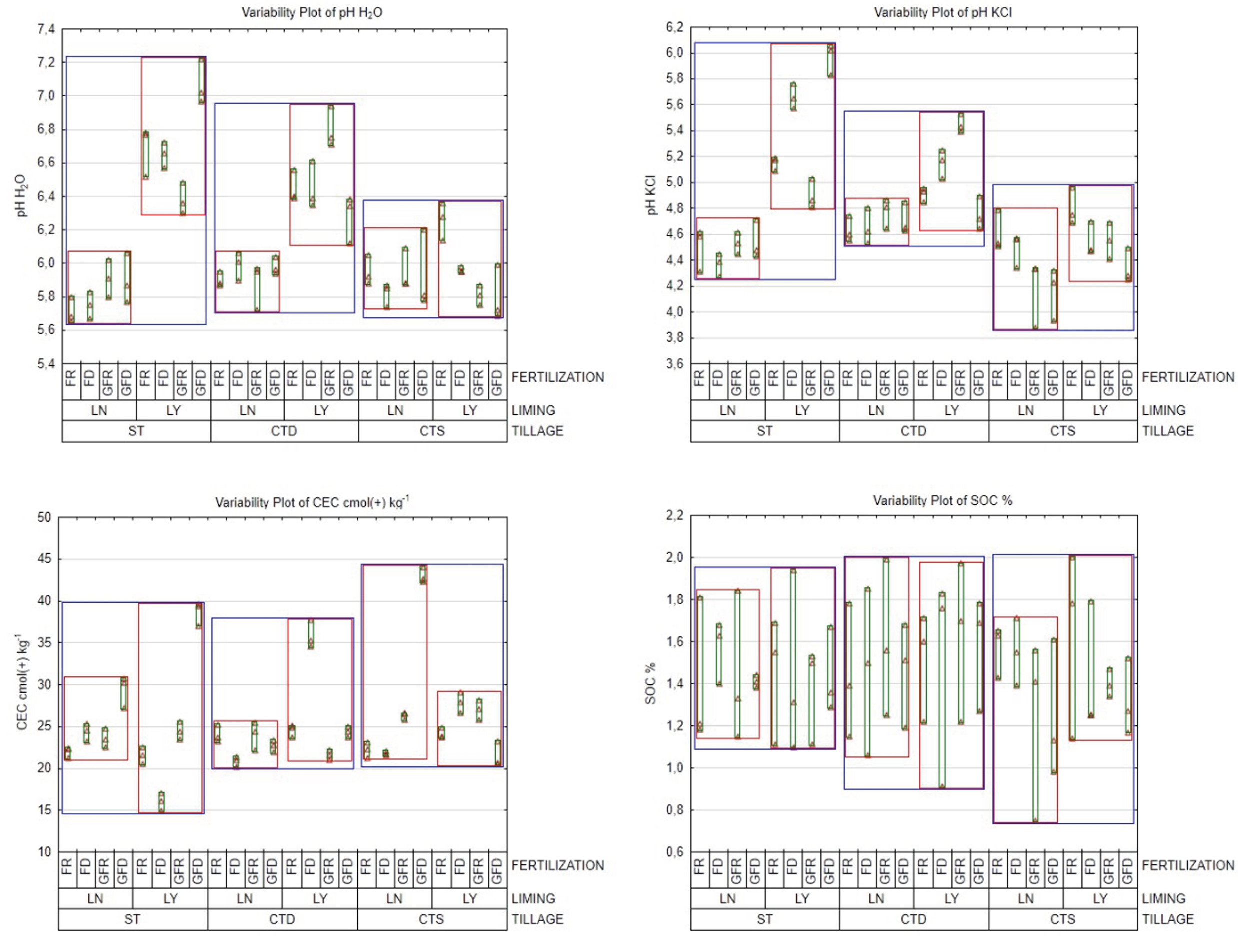
Conservation tillage (CT) represents a critical step towards the sustainable future of agriculture. It promotes soil health, reduces erosion, mitigates climate change, and significantly contributes to soil fertilization (cost savings for farmers) (Jug et al., 2018). There are three primary pillars of conservation tillage: 1) Reduced soil disturbance that represents one of the fundamental principles of conservation tillage. This typically involves a significant reduction in or elimination of traditional tilling or ploughing practices; 2) Retention of crop residues on the soil surface. This includes minimum of 30% of the plant residuals left behind after harvest and 3) Crop rotation and diversification as often seen as complementary practices. By rotating crops and diversifying planting schedules, farmers can further improve soil health, reduce the risk of pests and diseases, and maintain a balanced nutrient cycle (Jug et al., 2022; FAO, 2016). While there are challenges associated with this shift in agricultural practices, the long-term benefits in terms of environmental sustainability and resilience make conservation tillage a compelling choice. Soil health and climate change are intimately linked, and understanding how conservation tillage affects both is crucial in the context of sustainable agriculture and environmental responsibility. It also, helps maintain and improve soil health by preventing erosion, retaining organic matter, and enhancing nutrient cycling (Ligang et al., 2023; Jug et al., 2019). Simultaneously, it acts as a significant player in mitigating climate change by sequestering carbon, reducing energy consumption, and indirectly levering methane emissions (Hatano and Lipiec, 2004). Also, by minimizing soil disturbance, they reduce the disruption of the intricate web of microorganisms, earthworms, and beneficial soil organisms that contribute to soil fertility. This, in turn, maintains the integrity of vital soil properties such as pH, organic matter content, and cation exchange capacity (Ligang et al., 2023). Organic matter, primarily derived from crop residues, is retained in the soil. This, in essence, captures atmospheric carbon dioxide, sequestering it within the soil, thereby reducing the overall carbon footprint of agriculture (Bot and Benites, 2005; Đurđević et al., 2019). In comparison to conventional tillage methods, conservation tillage is more energy-efficient. The reduced need for heavy machinery and fuel consumption is not only economically beneficial but also ecologically responsible, given the associated reduction in carbon emissions. While conservation tillage holds immense promise, its full potential is realized when combine with different fertilization strategies and liming. Fertilization is the practice of adding essential nutrients to the soil to enhance plant growth, and liming represent traditional procedure for amelioration of acid soils (Jug et al., 2022; Đurđević et al., 2011). When these practices are integrated, they influence selected soil properties in a synergistic manner, ultimately fostering a more productive and sustainable agricultural system (Jug et al., 2021). Considering the mentioned importance of conservation tillage practice to soil health the aim of this study is to determinate effect of different tillage systems, liming and soil fertilization practice on three key soil health indicators - pH, soil organic carbon (SOC), cation exchange capacity (CEC).

Material and methods

The research was conducted in the eastern part of Croatia (location Čačinci - 17° 86' 36" E, 45° 61' 32" N) on Stagnosol. Results in this paper include research of the second year 2022 where the impact of different tillage systems, liming and soil fertilization practice on key soil health indicators was investigated. First factor was the soil tillage treatments: conventional tillage (ST) - ploughing up to 30 cm depth, deep conservation tillage (CTD) - loosening up to 30 cm depth with a minimum of 30% soil coverage with crop residues and shallow conservation tillage (CTS) - loosening up to 10 cm depth with a minimum of 50% soil surface coverage with crop residues. Second factor included liming (LY) 4375 kg ha^{-1} CaO (according to the recommendation for neutralizing the acid soil reaction, calculated with ALRxp computer program) (Đurđević et al., 2011) and treatment without liming (LN). Third factor was soil fertilization (FR - N_40 kg : P_2O_5_150 kg : K_2O_94 kg; FD - N_20 kg : P_2O_5_75 kg : K_2O_47 kg; GFR - N_40 kg : P_2O_5_150 kg : K_2O_94 kg + 150 kg Geo2_ soil microbial biomass activator; GFD - N_20 kg : P_2O_5_75 kg : K_2O_47 kg + 150 kg Geo2_soil microbial biomass activator). The experiment was carried out on 24 plots (4 fertilisation treatments x 2 liming treatments x 3 tillage treatments) x 3 repetitions. The basic plot size was 320 m^2 (tillage treatment) and the size of the fertilization and liming plots was 80 m^2. One composite sample consists of 20 cores collected within a plot, with the sample recovery depth of 0-15 cm and 15-30 cm. Soil samples were taken after the harvest of soybean, before application of any kind of fertilization and prior to soil preparation for next crop (Đurđević, 2014.). Soil samples were stored in plastic bags, homogenized, dried, milled and analysed in a laboratory - pH - using a glass electrode in a 1:5 (volume fraction) suspension of soil, (in H_2O and KCl) (ISO, 2021); SOC - determination of organic and total carbon after dry combustion (elementary analysis) (ISO, 1995); CEC - determination of effective cation exchange capacity and base saturation level using barium chloride solution (ISO, 2018). ANOVA design with soil tillage and fertilization as given factors was used to test the influence of different soil tillage systems, liming and different fertilization levels on pH, soil organic carbon (SOC), cation exchange capacity (CEC). Mean values that were significant according to the performed F- test were compared using the LSD test at $p < 0.05$ level of significance for the investigated factors. Statistica software package, version 14.0.0. (TIBCO Software Inc., Palo Alto, CA, USA) was used to conduct the ANOVA analysis and graphic designs.

Results and discussion

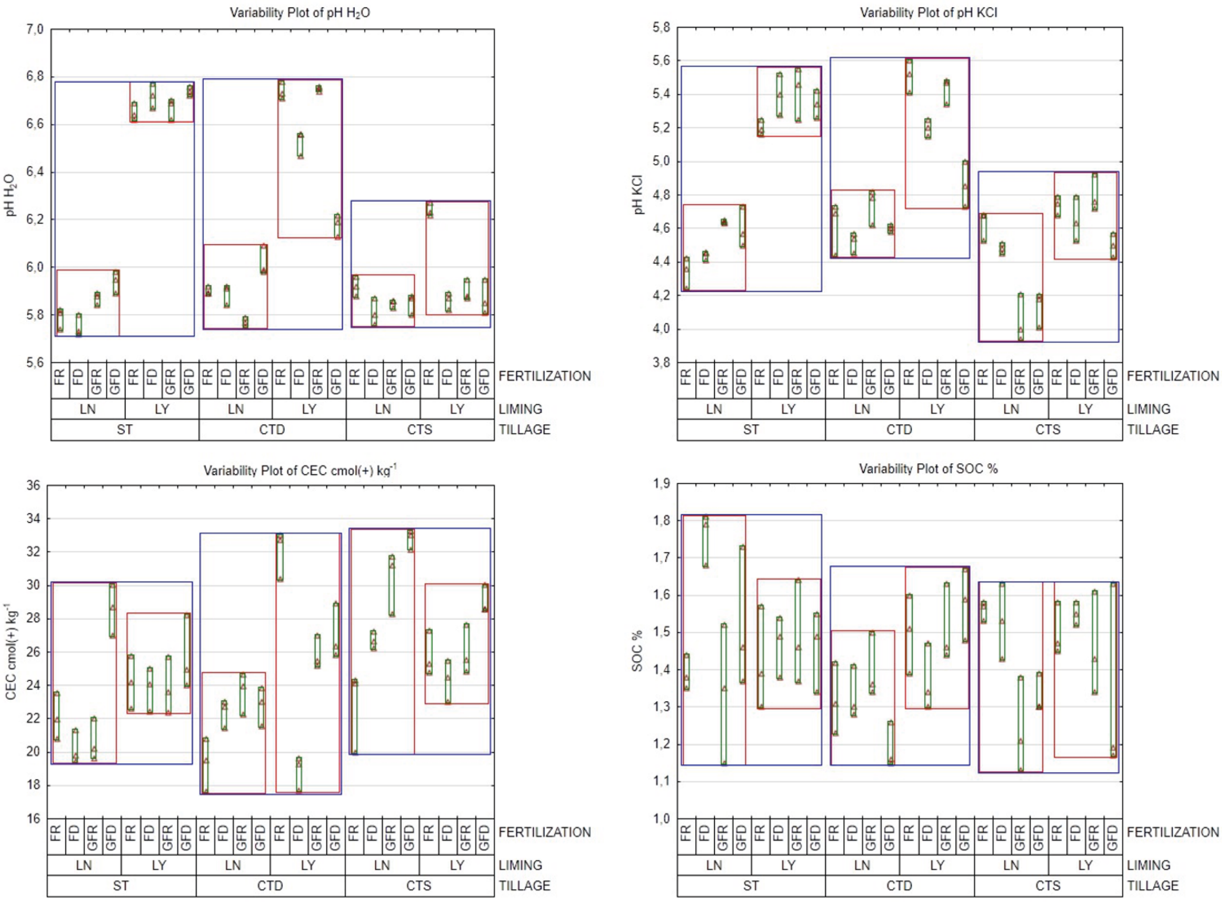
The soil chemical health indicators under different tillage measures were analysed. The results show that active and exchangeable acidity were significantly affected by soil tillage and liming (p value <0.001), with average values of 6.13 (pH-H_2O) and 4.76 (pH-KCl). Significant interactions were observed between the tested factors. The highest measured values of active (7.07) and exchangeable acitity (5.97) were observed on conventional tillage with liming on the GFD fertilization, while the lowest value of active acidity was observed on conventional tillage without liming on the FR fertilization (5.71). The exchangeable acidity was lowest on CTS tillage without liming and on the GFD fertilization (4.16) (Graph 1). Conservation tillage can lower the soil pH due to decreased aeration. According to Yuan et al. (2022) conventional tillage disrupts the soil structure, reduces soil fertility, and increases soil porosity, leading to nutrient loss and a decrease in soil organic matter. On the other hand, conservation tillage can reduce wind and water erosion, provide shade, and improve soil moisture, and also reduce soil pH. However, it is important to note that the effect of conservation tillage on pH can vary depending on a number of factors, such as soil type, climate, and cropping system (Busari et al., 2015). The average CEC was 25.48 $cmol^{(+)}$ kg^{-1}, and its variation was significantly affected by soil tillage and fertilization (p value <0.001). The highest CEC value was measured on CTS tillage, without liming on the GFD fertilization (42.99 $cmol^{(+)}$ kg^{-1}), while the lowest CEC value was measured on conventional tillage, with liming on the FD fertilization (16 $cmol^{(+)}$ kg^{-1}). None of the tested treatments had a statistically significant effect (p value >0.5) on the value of soil organic carbon, which averaged 1.46% (Graph 1). Conservation tillage can increase cation exchange capacity (CEC), especially in arid and semi-arid regions, primarily due to improved surface properties of soil particles. It promotes the formation of soil aggregates, which are clusters of soil particles that are held together by organic matter. Also, it can reduce the loss of soil organic matter (SOM), which is a major source of CEC in soil. Soil aggregates have a higher surface area than individual soil particles, which gives them a greater capacity to hold and exchange cations. A number of studies have shown that conservation tillage can improve CEC (Cooper et al., 2020). For example, according to Ligang et al. (2023) when applying conservation tillage practice, CEC was significantly higher in the top 15 cm of soil than in conventionally tilled soil. Another study by Busari et al., (2015) reported that effective cation exchange capacity (ECEC) were significantly higher at the end of the two years of study under CT in compare to conventional tillage.



Graph 1. Variability plots of pH (H_2O), pH (KCl), CEC and SOC (0-15 cm)
(Conventional tillage (ST), deep conservation tillage (CTD), shallow conservation tillage (CTS); liming (LY), without liming (LN); FR - recommended fertilization FD - reduced fertilization by 50%, GFR - recommended fertilization + soil microbial biomass activator, GFD - reduced fertilization by 50% + soil microbial biomass activator)

At a depth of 15-30 cm, all the parameters tested were significantly affected by the treatments. Statistically significant interactions were observed between all treatments. The average active acidity was 6.13 and was significantly affected by soil tillage, liming, and fertilization. The highest value of active acidity was measured on the CTD, LY, GFR treatment and was 6.75, while the lowest value was measured in soil samples on the ST, LN, FD treatments and was 5.75. The average exchangeable acidity was 4.86 and the highest value (5.51) was measured in soil on the CTD, LY, FR treatments, while the lowest value (4.05) was measured on the CTS, LN, GFR. Cation exchange capacity was significantly affected by tillage, liming and fertilization (p value <0.001) and averaged 20.64 $cmol^{(+)}$ kg^{-1}. The highest CEC was measured on the CTS, LN, GFD treatment (32.81 $cmol^{(+)}$ kg^{-1}), and the lowest (18.87 $cmol^{(+)}$ kg^{-1}) on the CTD, LY, FD treatment. The average organic carbon content in the soil was 1.44% and was significantly affected by fertilization and liming (p value <0.005). All interactions of the investigated treatments were statistically significant.

The highest organic carbon content was measured in soil samples on the ST, LN, FD (1.76%), and the lowest on the CTD, LN, GFD (1.19%) (Graph 2). One of the main benefits of CT is that it can increase SOC content in the top layers of the soil. However, there is some evidence that CT may lead to lower measured values of SOC in deeper layers of the soil. CT may reduce the incorporation of organic matter into deeper layers of the soil. This is because CT practices such as no-till and reduced tillage disturb the soil less than conventional tillage (ploughing), which can make it more difficult for organic matter to be mixed into the soil profile. Also, CT may promote the decomposition of SOM in deeper layers of the soil. This is because CT practices can increase soil moisture and aeration, which can create more favourable conditions for the microbes that break down SOM (Li et al., 2020). Blanco-Canqui et al. (2018) reported that soil organic C mainly accumulates near the surface.



Graph 2. Variability plots of pH (H_2O), pH (KCl), CEC and SOC (15-30 cm)
(conventional tillage (ST), deep conservation tillage (CTD),shallow conservation tillage (CTS); liming (LY), without liming (LN); FR - recommended fertilization FD - reduced fertilization by 50%, GFR - recommended fertilization + soil microbial biomass activator, GFD - reduced fertilization by 50% + soil microbial biomass activator)

Conclusions

The effect of tillage, liming, and fertilization on selected soil properties varied depending on the soil depth. At a depth of 0-15 cm, tillage and liming had a significant effect on pH, with the highest pH measured in conventional tillage with liming and the lowest pH measured in conservation tillage without liming. Tillage and fertilization had a significant effect on CEC, with the highest CEC measured in conservation tillage. At a depth of 15-30 cm, all of the parameters tested were significantly affected by the treatments. Soil reaction was significantly affected by tillage, liming, and fertilization, with the highest active acidity measured in conventional tillage and the lowest active acidity measured in conservation tillage. CEC was significantly affected by tillage, fertilization, and liming, with the highest CEC measured in conservation tillage. Soil organic carbon content was significantly affected by fertilization and liming, with the highest organic carbon content measured in conservation tillage. It is important to note that the effectiveness of conservation tillage practices in synergy with liming and fertilization may vary depending on the specific soil type, climate, crop type, and local conditions. Therefore, further research, especially long-term trials, is needed.

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