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Evaluation of soil chemical attributes as indicators of quality in olive groves

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ABSTRACT: Olive cultivation (*Olea europaea L.)* covers approximately 11 million hectares worldwide and has been expanding in Brazil as an alternative for agricultural diversification. The intensification of production systems has increased productivity but has also intensified the extraction of nutrients from the soil. In this context, soil organic matter (SOM) stands out as an essential component for maintaining soil quality. Its most labile fractions are particularly sensitive to changes in management practices and serve as important indicators of soil quality. Despite this, information on the dynamics of organic carbon in olive cultivation systems remains limited, especially in Brazil. Thus, this study aims to evaluate changes in soil organic matter and chemical properties under olive cultivation (CA) and forest cover (FA) in the Serra da Mantiqueira region. Four deformed composite soil samples were collected from 0–5, 5–10, 10–20, and 20–40 cm layers. Soil fertility, including macronutrients and micronutrients, and soil organic carbon (SOC) were evaluated. For macronutrients (K, Ca, Mg), the application of mineral fertilizers resulted in the highest values in the CA profile compared to the FA. However, for the micronutrients (Cu and Fe), the highest values were concentrated in the superficial soil layer in FA. SOM values ranged from 1.38 to 3.49 g kg^{-1}, with the lowest value observed in area CA 5-10 and the highest in area FA 0-5. SOC ranged from 8.97 (CA 20-40) to 26.16 g kg^{-1} (FA 0-5). The conversion of forest land to olive orchards induces changes in soil chemical properties, often enhancing nutrient availability. Nevertheless, declines in soil organic carbon (SOC) can negatively affect soil quality, highlighting the need for conservation practices (e.g., mulching) to support the restoration of soil carbon stocks.

Keywords: conventional tillage; no-tillage; soil management; tropical climate.

Avaliação dos atributos químicos do solo como indicadores de qualidade de em áreas de oliveiras

RESUMO: O cultivo da oliveira (*Olea europaea* L.) ocupa aproximadamente 11 milhões de hectares em todo o mundo e tem se expandido no Brasil como uma alternativa para a diversificação agrícola. A intensificação dos sistemas de produção tem aumentado a produtividade, mas também intensificado a extração de nutrientes do solo. Nesse contexto, a matéria orgânica do solo (MOS) destaca-se como um componente essencial para a manutenção da qualidade do solo. Suas frações mais lábeis são particularmente sensíveis às mudanças nas práticas de manejo e atuam como importantes indicadores da qualidade do solo. Apesar disso, as informações sobre a dinâmica do carbono orgânico em sistemas de cultivo de oliveira ainda são limitadas, especialmente no Brasil. Assim, este estudo teve como objetivo avaliar as alterações na matéria orgânica do solo e nos atributos químicos sob cultivo de oliveira (CA) e cobertura florestal (FA) na região da Serra da Mantiqueira. Foram coletadas quatro amostras compostas deformadas de solo nas camadas de 0–5, 5–10, 10–20 e 20–40 cm. Avaliaram-se a fertilidade do solo, incluindo macro e micronutrientes, e o carbono orgânico do solo (COS). Para os macronutrientes (K, Ca, Mg), a aplicação de fertilizantes minerais resultou em maiores valores no perfil de CA em comparação à FA. Por outro lado, para os micronutrientes (Cu e Fe), os maiores teores concentraram-se na camada superficial do solo em FA. Os valores de MOS variaram de 1,38 a 3,49 g kg^{-1}, sendo o menor valor observado na área CA (5–10 cm) e o maior na área FA (0–5 cm). O COS variou de 8,97 (CA 20–40 cm) a 26,16 g kg^{-1} (FA 0–5 cm). A conversão de áreas florestais em olivais promove alterações nos atributos químicos do solo, frequentemente aumentando a disponibilidade de nutrientes. No entanto, a redução do carbono orgânico do solo pode comprometer a qualidade do solo, evidenciando a necessidade da adoção de práticas conservacionistas (por exemplo, cobertura morta) para auxiliar na recuperação dos estoques de carbono.

Palavras-chave: cultivo convencional; plantio direto; manejo do solo; clima tropical.

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INTRODUCTION

The cultivation of olive trees (*Olea europaea* L.) occupies approximately 11 million hectares worldwide, being predominantly concentrated in the Mediterranean region, where it stands out as one of the most widespread perennial crops (Sobreiro et al., 2023). Olive cultivation has been expanding in Brazil, although its production remains small compared to other crops. It is considered an alternative for agricultural diversification, especially in regions with wet winters, dry summers, average temperatures between 25 and 35 °C, with some periods of low temperatures, typically between 0 and 7 °C, and low-fertility soils (Fernández-Rodríguez et al., 2022).

The olive oil market has expanded, driven by the growing demand for healthy and sustainable products. Consequently, in recent decades, there has been a transition from traditional and extensive systems to intensive systems, characterized by higher planting density and greater nutritional demand, resulting in increased productivity (Zipori et al., 2020). In this context, mineral nutrition plays a central role in orchard management, since most nutrients are absorbed from the soil solution and continuously removed through fruit harvest and pruning, which may lead to fertility depletion, especially in intensive systems (Erel et al., 2018). However, inadequate fertilization management can compromise soil quality, productivity, and the sustainability of the agroecosystem, making the adoption of conservation practices necessary (Torrús-Castillo et al., 2022).

Strategies that promote increases in soil organic matter (SOM) levels are noteworthy, as they contribute to improving soil structure and health, enhancing water retention, increasing biodiversity, and reducing erosion processes in olive-growing areas (Torrús-Castillo et al., 2023). The study of soil organic matter (SOM) has emerged as a sensitive tool for assessing the effects of management on soil quality, especially when considering its physical fractions, such as labile carbon, which respond rapidly to changes in land use and management. Understanding the dynamics of organic carbon in maintaining soil quality and mitigating degradation processes, such as erosion and fertility decline, supports the development of effective strategies for soil conservation and sustainable management (Guimarães et al., 2021).

Despite advances in understanding the role of SOM in maintaining soil quality, information on the dynamics of organic carbon in olive cultivation systems remains limited, particularly under conditions different from those traditionally studied in the Mediterranean region. In Brazil, few studies have evaluated how conservation systems, such as no-tillage, influence SOM fractions. Understanding these changes provides a basis for developing management strategies that reconcile productivity, soil conservation, and the sustainability of agricultural systems.

Considering the growth of olive cultivation associated with the scarcity of scientific data on the interaction between this crop and soil quality - especially in the Serra da Mantiqueira region - this study aims to evaluate changes in labile soil organic matter and other chemical attributes, with an emphasis on soil quality under forest-based and conventional cultivation systems.

MATERIALS AND METHODS

Study area and soil sampling

The experimental areas were located at the "Empresa de Pesquisa Agropecuária", in the Minas Gerais State, municipality of Maria da Fé, at 22º18'29" S and 45º22'31" W, altitude of 1278 m (Figure 1). The regional climate is Cwb, according to Köppen's classification (Alvares et al., 2013), with mean rainfall ranging from 1.650 mm to 1.750 mm (during summer), and drier periods during the winter, with a mean annual temperature of 17ºC.

The soil of this study was classified as a Rhodic Ferralsol according to the World Reference Base for Soil Resources (IUSS, 2015). Two locations were selected for the study: a) Antropized Forest area (FA), at 22º18'56" S and 45º22'42" W, with an altitude of 1309 m; and b) Area under conventional cultivation of *Olea europaea* L. (CA) during 11 years, using a conventional management system (22º18'52" S and 45º22'41" W, with an altitude of 1296 m. Four deformed composite soil samples were collected in 2017 from depths of 0–5 cm, 5–10 cm, 10–20 cm and 20–40 cm layers per site in each soil profile and then were air-dried, pounded to break up clods, and sieved (< 2 mm) to obtain the air-dried fine earth fraction, which was used for chemical analyses carried up at the laboratory.

Soil chemical analyses

For the chemical characterization, the following parameters were determined: pH in water 1:2.5 soil: solution ratio (v/v), exchangeable bases (Ca^{+2}, Mg^{+2}, K^{+}, and Na^{+}), exchangeable Al^{+3}, potential acidity (H+ Al), micronutrients (Cu, Mn, and Fe), and available P (Teixeira et al., 2017). Soil organic carbon (SOC) content was determined by wet oxidation using potassium dichromate solution ($K_2Cr_2O_7$), H_2SO_4, and with external heating (Yeomans & Bremner, 1988), and the labile portion of the soil organic matter (SOM) was carried out using 0–5 and 5–10 cm layer samples according to the method of Anderson & Ingram (1989).

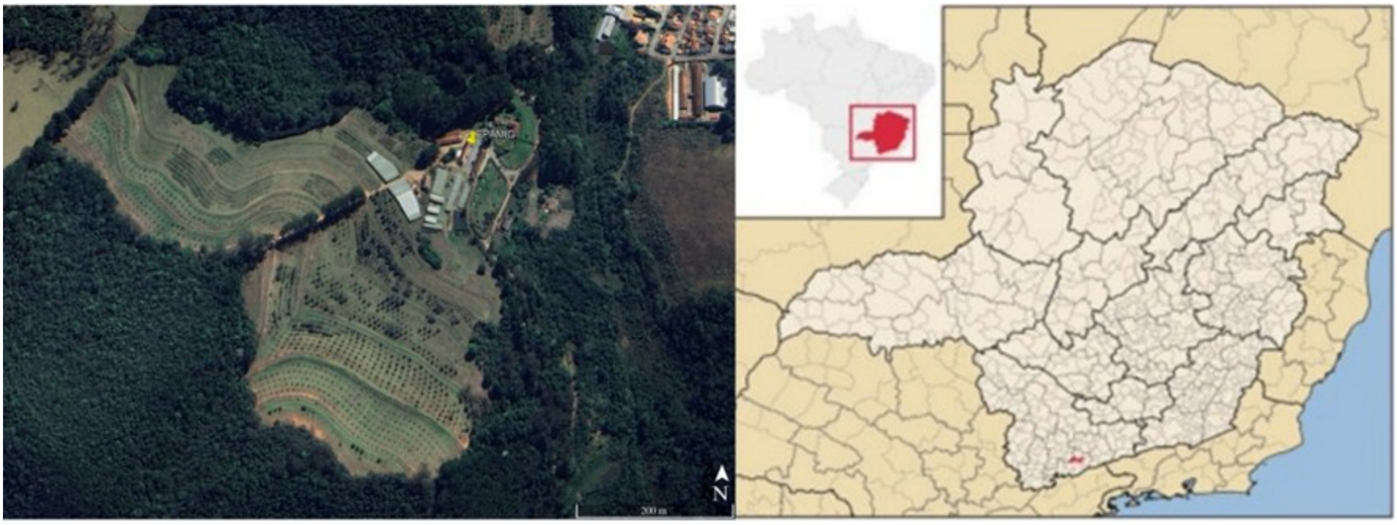

Figure 1 - Localization of the study area in Maria da Fé, Minas Gerais State, Brazil.

Statistical Analysis

In this study, we determined the main effects of the two soil management types (M) in the four soil profile depths (D), and also the effects of the M × D interaction. We used a factorial analysis of variance (ANOVA two-way), with M and D as fixed factors. We checked the dataset for normality using a Shapiro-Wilk test, having initially assessed the homogeneity of variance. Mean values were compared using Tukey's test ($p < 0.05$). For soil organic carbon data, a polynomial regression analysis was applied, using Agroestat statistical software (Barbosa & Maldonado Júnior, 2015).

RESULTS AND DISCUSSION

ANOVA analysis revealed significant M × D interaction effects, and soil pH was lower in FA compared to CA at all depths (Figure 2a). This result is attributed to the parent material, which is predominantly acidic in Brazilian territory, and to intense weathering and nutrient leaching processes, particularly of basic cations, leading to low pH values and increased soil acidity (Van Breemen et al., 1983; Hue, 2022). Due to soil acidity correction (liming) at the beginning of establishment, the pH values observed in CA (ranging from 5.5 to 6.0) are considered suitable for optimal olive tree development (López-Escudero & Mercado-Blanco, 2011; Bizos et al., 2020), as they promote greater nutrient availability in the soil and facilitate plant uptake.

Soil pH values close to 6 reduce the solubility of Al^{3+} and do not cause toxic effects on the roots. Conventional management of the olive grove (CA) can be attributed to the liming of the soil at the time of planting.

The highest levels of Ca^{2+} (3.65 cmolc dm^{-3}) and Mg^{2+} (2.30 cmolc dm^{-3}) were observed in the CA (Figure 2b and 2c). An effect similar to that of pH was observed in the Ca^{2+} and Mg^{2+} content, which decreased with depth in the CA. The same was observed for soil CTC, with the highest value (9.41) observed in the CA 0–5 cm layer, decreasing with depth to 7.02 in the 20–40 cm layer, while for FA, values ranged from 8.23 (0–5) to 6.48 (20–40). There were no differences in FA at any depth.

In contrast, when analyzing the aluminum (Al^{3+}) content from the surface to a depth of 40 cm, it was observed that in FA soils, this content was significantly higher compared to CA soils (Figure 2d). It is worth noting that in FA soils, the Al^{3+} content decreased with depth, while the opposite trend was observed in CA soils.

It is also important to highlight that lower levels of Ca^{2+} and Mg^{2+} were found in FA, which is likely associated with liming practices that not only precipitate exchangeable Al at soil pH values close to 6, but also increase nutrient availability, particularly Ca and Mg. Maintaining soil pH above 5.5 is essential to minimize aluminum toxicity, which can restrict plant growth and nutrient uptake (MacLean et al., 1972; Deressa et al., 2020).

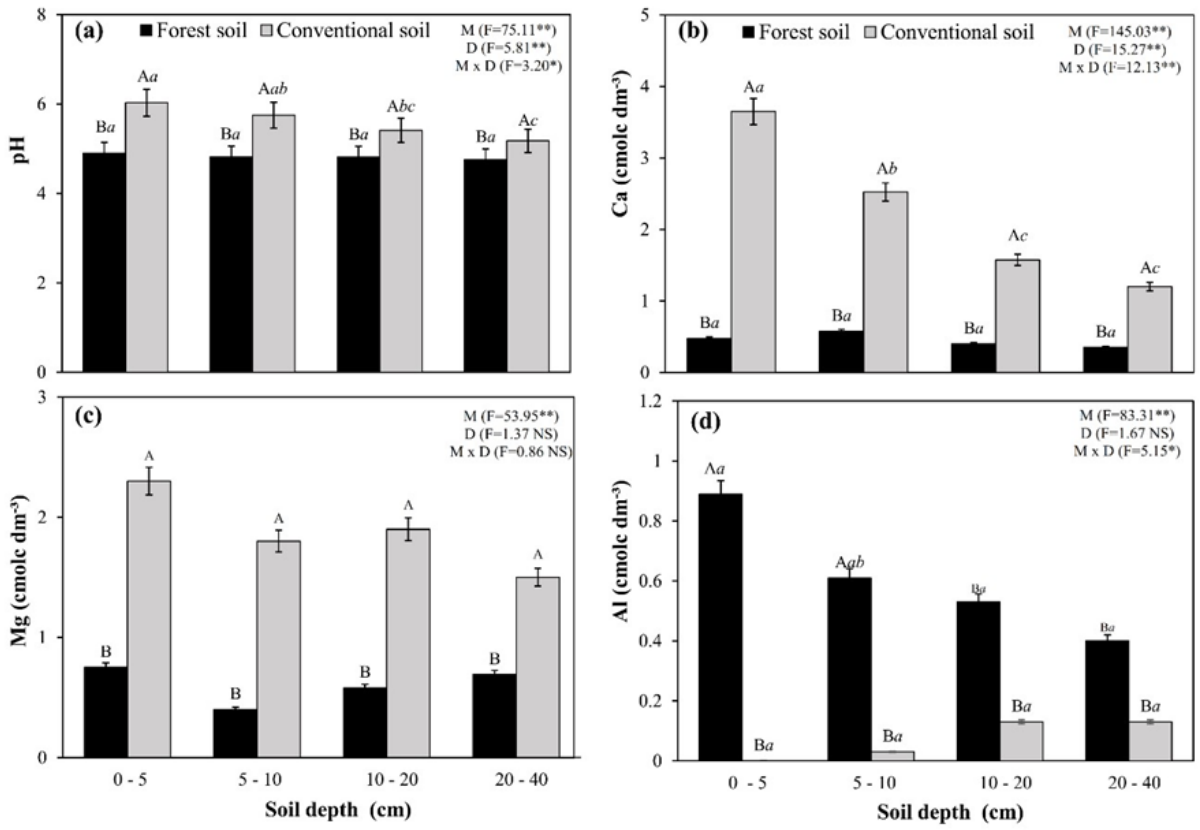

Figure 2 - Effect of soil management and depth on (a) pH, (b) Ca+2, (c) Mg+2, and (d) Al+3. Different uppercase letters indicate significant differences within the same soil depth at the different soil managements, while different italic lowercase letters indicate significant differences between different soil depth at the same soil management, according to the F test. *p ≤ 0.05; **p ≤ 0.01; NS, not significant; M × D, soil management–depth interaction. Vertical bars represent the mean ± standard error (n = 4).

The K^+ values were low in all soil layers, with the highest values observed in the superficial horizons under CA, with a decrease in subsurface (Figure 3a). Meanwhile, Na^+ content was not affected by individual factors or the interaction M × D, with a tendency to decrease in subsurface (Figure 3b).

P content showed significant differences for each factor, but no M × D interaction was observed. As indicated in Figure 3c, P levels were higher under the CA treatment at all depths compared to FA; however, a statistically significant increase was only observed in the surface layer (0–5 cm). The increase in the levels of basic cations, such as Ca^{2+}, Mg^{2+}, and K^+ (Figures 2b, 2c, and 3a), as well as P (Figure 3c), in the surface horizons under CA compared to the forest soil is likely associated with liming and fertilization practices adopted to meet the nutritional requirements of olive orchards.

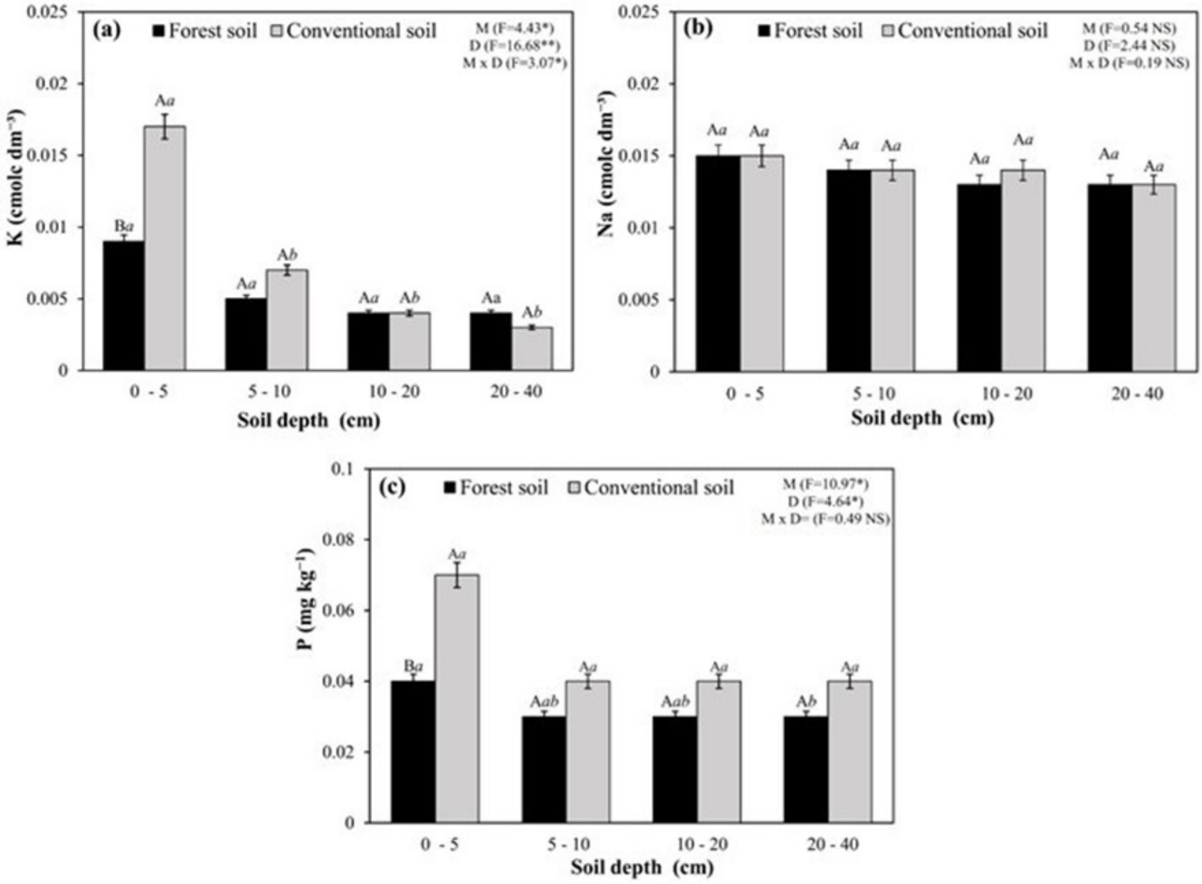

Figure 3 - Effect of soil management and depth on (a) K+, (b) Na+, (c) P. Different uppercase letters indicate significant differences within the same soil depth at the different soil managements, while different italic lowercase letters indicate significant differences between different soil depth at the same soil management, according to the F test. *p ≤ 0.05; **p ≤ 0.01; NS, not significant; M × D, soil management–depth interaction. Vertical bars represent the mean ± standard error (n = 4).

The highest soil Cu concentrations were 2.32 mg kg^{-1} for the CA agricultural system (0–5 cm) and 2.33 mg kg^{-1} for the FA area (5–10 cm) (Figure 4a). At the same time, an interaction effect (p <0.001) was obtained as a function of soil depths, with a decreasing slope as depth increased, with the most representative effect in the CA area. Soil Mn content ranged from 7.12 to 12.93 mg kg^{-1} in CA, which were detected at soil depths of 20-40 and 0-5 cm, respectively (Figure 4b). In FA, no significant differences were found in relation to the different depths, but there were significant differences in relation to the type of soil management, especially in the superficial horizons (first 10 cm), and there were no interaction effects between the M x D factors. In contrast, Fe content was higher in FA (Figure 4c) when compared to CA for all depths and soil management types, presenting an interaction effect (p < 0.001). In this study the micronutrients (Cu, Mn, and Fe) presented the highest contents in the surface layers (0-5 cm, and 05-10cm), likely caused by the application of fertilizers and pesticides conducted in the olive tree area, CA; and the cycling of micronutrients, in forest area (Lopes & Guimarães Guilherme, 2016; Andrade et al., 2021).

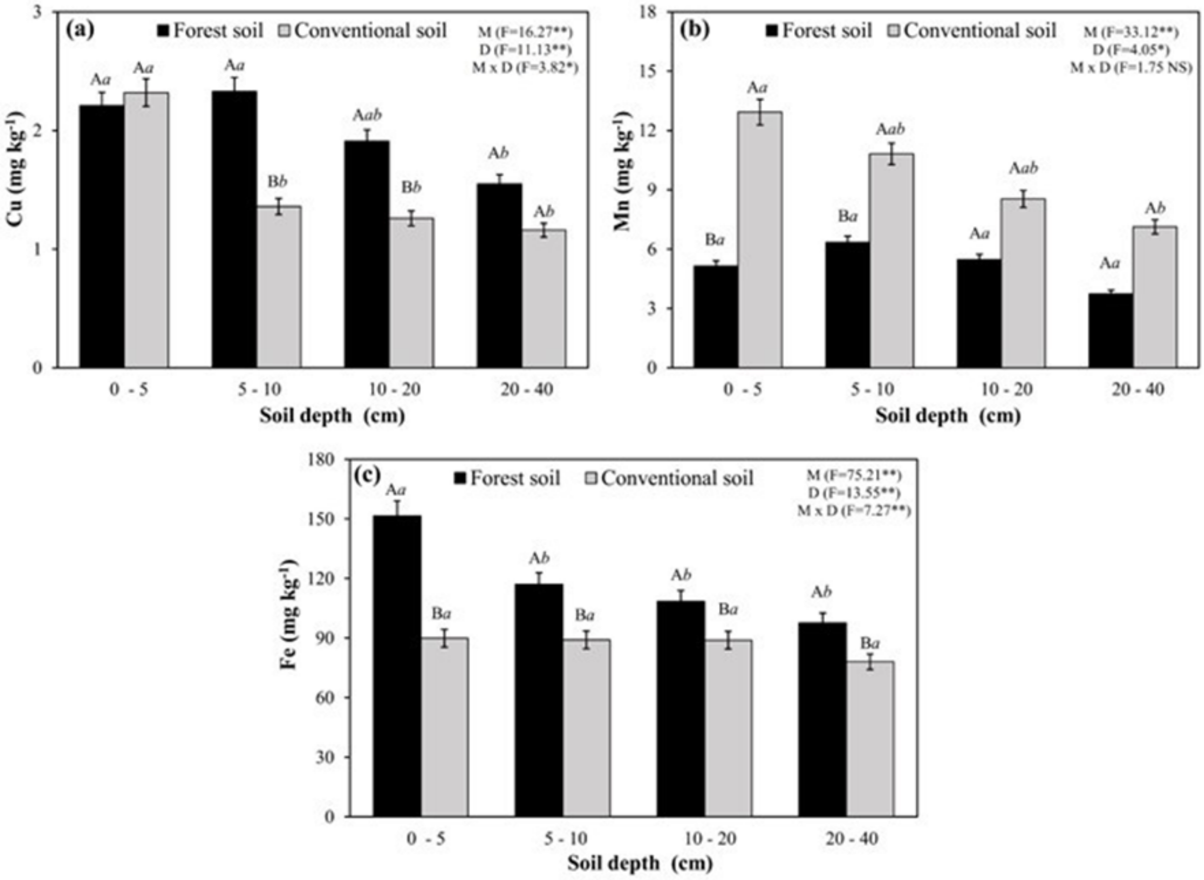

Figure 4 - Effect of soil management and depth on (a) Cu, (b) Mn, (c) Fe. Different uppercase letters indicate significant differences within the same soil depth at the different soil managements, while different italic lowercase letters indicate significant differences between different soil depth at the same soil management, according to the F test. *p ≤ 0.05; **p ≤ 0.01; NS, not significant; M × D, soil management–depth interaction. Vertical bars represent the mean ± standard error (n = 4).

The labile fraction of soil organic matter (SOM) showed no significant M × D interaction effects; however, under both soil management systems, its content was higher in the surface layer, i.e., within the top 5 cm (Figure 5a). Similarly, soil organic carbon (SOC) decreased with depth, with this effect being more pronounced under CA, as indicated by the regression analysis (Figure 5b). The delta analysis between SOC under FA and CA management confirmed the same trend observed in the individual regression analyses, namely, a decrease with depth.

The adoption of no-tillage practices in the FA management system contributed to greater SOC accumulation across all soil layers, particularly in the upper layer (0–5 cm), compared to CA management. This phenomenon is related to the greater contribution of biomass at the soil surface, along with the fact that SOM mineralization in natural ecosystems is offset by the continuous accumulation of plant litter on the soil surface. This organic material undergoes decomposition facilitated by microbial agents, which simultaneously synthesize organic compounds that are subsequently incorporated into the soil matrix through precipitation processes. This mechanism promotes the replenishment of the carbon pool, contributing to the concept of a "dynamic soil carbon balance," whereas agricultural practices have the potential to disrupt this equilibrium, compromising both the quality and quantity of SOM (Assunção et al., 2019; Guimarães et al., 2021).

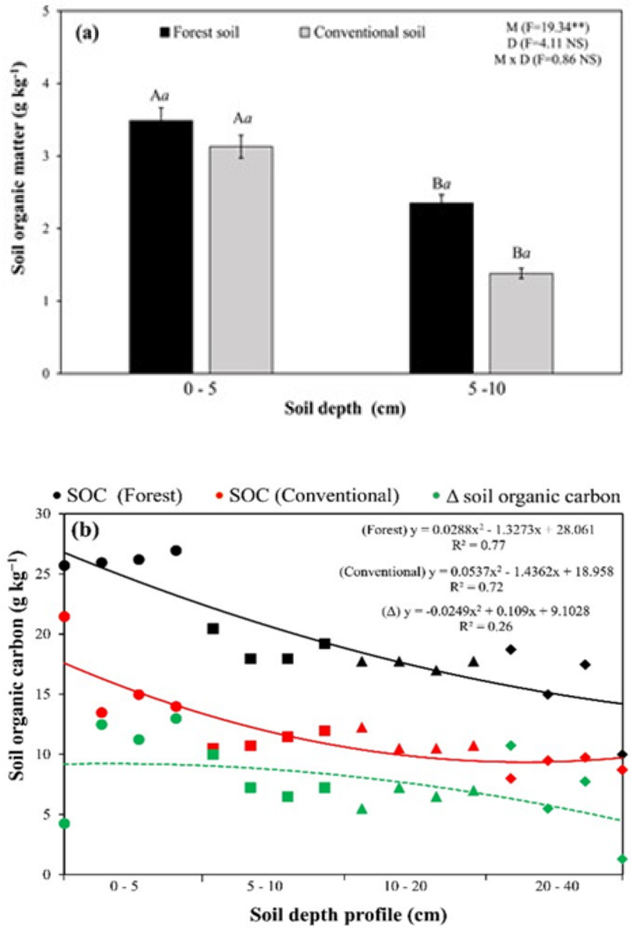

Figure 5 - Effect of soil management and depth on (a) soil organic matter, (b) soil organic carbon. Different uppercase letters indicate significant differences within the same soil depth at the different soil managements, while different italic lowercase letters indicate significant differences between different soil depth at the same soil management, according to the F test. Soil organic carbon (SOC): ● Forest; ● Conventional; ▲ Delta SOC.*p ≤ .05; **p ≤ .01; NS, not significant; M × D, soil management–depth interaction. Vertical bars represent the mean ± standard error (n = 4).

CONCLUSION

The conversion of forest land to olive orchards induces changes in soil chemical properties, often enhancing nutrient availability. Nevertheless, declines in soil organic carbon (SOC) can negatively affect soil quality, highlighting the need for conservation practices (e.g., mulching) to support the restoration of soil carbon stocks.

COMPLIANCE WITH ETHICAL STANDARDS

Authors' contributions: Conceptualization: YVFGD, JCR, OAQS, MGP; Data curation: YVFGD, JCR, DOV; Formal analysis: JCR, DOV; OAQS, Funding acquisition: YVFGD, JCR, MGP; Investigation: DOV, OAQS, HSF; Methodology: JCR, MGP; Project administration: JCR, MGP; Resources: YVFGD, JCR, DOV, OAQS, HSF; Software: YVFGD, DOV; Supervision: MGP; Validation – JCR, DOV, MGP; Visualization: DOV; Writing – original draft: YVFGD, JCR, DOV, OAQS, HSF, MGP; Writing – review & editing: DOV, MGP.

Conflict of interest: The authors declare that there is no conflict of interest (professional or financial) that can influence the article.

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