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# Is just considering texture enough to define compaction on the basis of soil density?

# Considerar apenas a textura é suficiente para definir a compactação a patir da densidade do solo?

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## Highlights

Setting compression considering only the texture is error-prone.
We selected 1,521 studies with bulk densities in the literature.
Managements that do not move the soil the bulk density for compaction was 1.43 Mg m$^{-3}$.
Managements that move the soil the bulk density for compaction was 1.35 Mg m$^{-3}$.

## Abstract

The bulk density values indicative of compaction in clayey soils correspond to a wide range of values (1.30-1.47 Mg m$^{-3}$), due to the diverse types of soil management. Our hypothesis is that if we consider bulk density values within similar management groups (those that fall to the ground and those that do not fall), the values will be more accurate within each management group. Our objective in this work was to analyze using the concepts of (Yates & Cochran, 1938; Whitehead, 2002) what is a suitable statistical way of grouping these results to reach a consensus regarding a tested hypothesis, the greatest number of density values surveyed between 1977 and 2021, considered for the study of compaction in clayey Oxisols under different managements, to verify whether our hypothesis will be confirmed. We selected 1,521 studies with bulk densities in the literature, corresponding to 44 years (1977 and 2021), which were analyzed by a statistical technique that integrates the results of two or more independent studies on the same subject and combines them into a summary measure (portion forestry). From the data collected in the literature, it was possible to separate two groups of bulk density and management in clayey soils indicative of compaction: the managements that perform little or no manipulation of the soil, such as pasture and no-tillage, densities between 1.41-1.45 Mg.m$^{-3}$ (average 1.43 Mg m$^{-3}$), and for the others, such as conventional plowing and minimum tillage, soil densities between 1.31-1.38 Mg.m$^{-3}$ (average 1.35 Mg m$^{-3}$). Finally, we conclude that compaction must be analyzed considering the texture and type of soil management.

**Key words:** Compaction. Bulk density. Pasture. No-tillage. Conventional tillage. Minimum tillage.

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## Resumo

Os valores de densidade do solo indicativos de compactação em solos argilosos correspondem a uma ampla faixa de valores (1,30-1,47 Mg $m^{-3}$), devido aos diversos tipos de manejo do solo. Nossa hipótese é que se considerarmos os valores de densidade do solo dentro de grupos de manejo semelhantes (os que caem no chão e os que não caem), os valores serão mais precisos dentro de cada grupo de manejo. Nosso objetivo neste trabalho foi analisar usando os conceitos de (Yates & Cochran, 1938; Whitehead, 2002) qual é uma forma estatística adequada de agrupar esses resultados para chegar a um consenso sobre uma hipótese testada, o maior número dos valores de densidade levantados entre 1977 e 2021, considerados para o estudo da compactação em Latossolos argilosos sob diferentes manejos, para verificar se nossa hipótese será confirmada. Selecionamos 1.521 estudos com densidades do solo na literatura, correspondentes a 44 anos (1977 e 2021), que foram analisados por uma técnica estatística que integra os resultados de dois ou mais estudos independentes sobre o mesmo assunto e os combina em uma medida resumida (forest plot). A partir dos dados levantados na literatura, foi possível separar dois grupos de densidade do solo e manejo em solos argilosos indicativos de compactação: os manejos que realizam pouca ou nenhuma manipulação do solo, como pastagem e plantio direto, densidades entre 1,41 -1,45 Mg.$m^{-3}$ (média 1,43 Mg $m^{-3}$), e para as demais, como aração convencional e preparo mínimo, densidades de solo entre 1,31-1,38 Mg.$m^{-3}$ (média 1,35 Mg $m^{-3}$). Por fim, concluímos que a compactação deve ser analisada considerando a textura e o tipo de manejo do solo.
**Palavras-chave:** Compactação. Densidade do solo. Pastagem. Plantio direto. Preparo convencional. Cultivo mínimo.

## Introduction

Soil preparation aims to provide favorable conditions for plant growth and development. However, it affects the soil's physical, chemical, and biological properties depending on the suitability or the cultivation methods used (Mosaddeghi et al., 2009; Aziz et al., 2013; Kahlon et al., 2013; Bhuyan et al., 2022). In general, soil cultivation methods affect soil aggregation, infiltration rates and soil water holding capacity, soil organic matter incorporation and can promote compaction, with increased soil bulk density and affect plant root growth (Ren et al., 2018; Tavares et al., 2014; Moraes et al., 2016; Macedo et al., 2017, Bhuyan et al., 2022).

Such changes are more pronounced in conventional tillage systems than in conservation systems. Conventional tillage (moldboard plowing (inversion of the soil) followed by a secondary tillage operation such as disking and/ or harrowing) produces a looser structure, breaks up aggregates, increases pore volume, and accelerates the decomposition of organic matter but facilitates plant root growth on the soil surface (Braunack & Dexter, 1989), although below this, there is an inverse behavior due to the increase in soil density (Bhuyan et al., 2022). No-tillage farming (zero tillage) is a soil conservation system with the objective of minimal soil manipulation necessary for successful agricultural production. It is a tillage method that does not turn the soil, unlike intensive tillage, which alters the structure with plows and therefore allows for less decomposition of organic matter, a reduction in the apparent density of the soil, and an increase in total porosity.

On the other hand, the intense machine traffic associated with the lack of soil disturbance in soil conservation preparations, such as no-till, leaves the soil structure intact but causes an increase in soil density both on the surface and the subsurface (Tavares et al., 2014; Moraes et al., 2016; Bhuyan et al., 2022). However, no-tillage has emerged as a technology for more rational use of the soil, capable of protecting it against erosion and compaction (Fuentes-Llanillo et al., 2021). Not tilling the soil keeps plant residues on the surface and continuously supplies organic matter, which is responsible for maintaining and improving its physical properties (increased stability of aggregates and continuity of pores, water infiltration, and reduction of surface runoff) about conventional tillage.

It is common to consider bulk density values according to their texture to compare the effect of different soil preparations on soil compaction and root development. For example, for clayey soils, the most common values cited in the literature are 1.40 Mg $m^{-3}$ (Arshad et al., 1996), 1.30 to 1.40 Mg $m^{-3}$ (Reichert et al., 2009), 1.30 to 1.43 Mg $m^{-3}$ (Bhuyan et al., 2022) and 1.47 Mg $m^{-3}$ (USDA Department of Agriculture, 2014). However, research that used the cultural profile methodology (Tavares et al., 1999; Boizard et al., 2017), in clay soils under diverse cultures and management (Neves et al., 2003; Portella et al., 2012; Tavares & Tessier, 2009; Tavares et al., 2010, 2012, 2014; Macedo et al., 2017; Watanabe et al., 2018) found different bulk density values for the same structural classification within the same soil profile analyzed according to the considered management.

It can be seen from the above that the bulk density values indicative of compaction in clayey soils correspond to a wide range of values (1.30-1.47 Mg $m^{-3}$), due to the diverse types of soil management. Our hypothesis is that if we consider bulk density values within similar management groups (those that fall to the ground and those that do not fall), the values will be more accurate within each management group. Our objective in this work was to analyze using the concepts of (Yates & Cochran, 1938; Whitehead, 2002) what is a suitable statistical way of grouping these results to reach a consensus regarding a tested hypothesis, the greatest number of density values surveyed between 1977 and 2021, considered for the study of compaction in clayey Oxisols under different managements, to verify whether our hypothesis will be confirmed.

## Material and Methods

Since 1938, there has been a combination of different estimates for agricultural experiments conducted by Yates and Cochran (1938). Since then, the meta-analytic study has been growing in the most diverse areas (Whitehead, 2002) as it is an adequate statistical study to group studies that may diverge and reach a consensus (Rodrigues & Ziegelmann, 2010).

Science, Scopus, and Scielo databases from 1977 to 2021 in the option of all indexes ("All indexes"). Specific keywords of interest to the study were used in the field "type one or more words." The keywords and their respective combinations for research were: (1) bulk density, (2) compaction (3) soil management. All articles that agreed with the subject and presented the study's density values and dispersion measures were analyzed. Without adopting the selection criteria and performing only the search with word combinations, 3,605 publications were found. Next, for the classification of these articles, we considered some parameters such as the number of entries, treatments, and the number of repetitions (N), type of soil management, bulk density, presence, or absence of compaction, analyzed depth, and measures of dispersal. As selection criteria, it was considered: soil density value, dispersion measure (standard deviation or coefficient of variation), studies between 0 - 30 cm, studies in clayey soils and managements such as pasture (P), no-tillage (NT), conventional tillage (CT) and minimal tillage (use only the scarifier) (MT).

After selecting the works, the concepts of the meta-analysis statistical technique that uses the effect measure were used. Variability was also used, integrating, and combining the results of two or more independent studies on the same research question in a summary bar ("forest plot") (Yates & Cochran 1938; Whitehead, 2002). As the objective of this work was to analyze and statistically compare the densities in clayey soil under different preparations and soil managements considered compact and that could limit root development, we considered 1.39 Mg m$^{-3}$ as the control (average densities between 1.30 and 1.47 Mg m$^{-3}$ which can limit root development in clayey soils according to Arshad et al. (1996), Reichert et al. (2009), USDA Department of Agriculture (2014) and (Bhuyan et al., 2022). In situations where there is no standardization of the explanatory measurement unit, Borenstein et al. (2009) suggest the calculation of the measure of effect through the "standardized mean difference" (g), calculated as:

$$\hat{g}_k = \left(1 - \frac{3}{4n_k - 9}\right) \frac{\mu_{ek} - \mu_{ck}}{\sqrt{((n_{ek} - 1)s^2_{ek} + (nck - 1)s^2_{ck})/(n_k - 2)}}$$

Where S$^2$ek and S$^2$ck are the sample variance, $n_{ek}$ and $n_{ck}$ represent the number of repetitions, and $\mu_{ek}$ and $\mu_{ck}$ are the means of treatment.

The meta-analyses compared the control (BD = 1.39 Mg m$^{-3}$) with each of the bulk densities of the managements (P, CT, MT, and NT) for a depth of 0-30 cm. Data on variability and "forest plot" graphs that summarize the main results of the meta-analysis in a single figure and facilitate the understanding of the results obtained (Whitehead, 2002; Borenstein et al., 2009).

The scatter plot analyzes if there is variability in the papers due to the heterogeneity between different studies. Therefore, it is possible to analyze each point on the graph and verify its diagnostic odds ratio and sample size. Inaccurate studies, generally performed with small samples, may find positive or negative results statistically significant or not due to the influence of chance and would be symmetrically distributed in the parge part of the funnel. Higher precision studies and smaller numbers would be closer to the value located in the narrowest part of the funnel (Pereira & Galvão, 2014).

We opted for the approach of random effects as the management effect (treatment) is not identical between the studies. Studies combined with the same objective of studying soil density but not conducted in the same way can cause high heterogeneity. This random-effects approach allows study results to vary in a normal distribution across studies (Rodrigues & Ziegelmann, 2010). The software R was used for the analysis, the "metaphor" package (Viechtbauer, 2010), and the "ggplot2" (Wickham, 2009).

## Results and Discussion

Figure 1 shows the tillage and management studies in clayey soils selected for this study. The symmetrical shape of the figure with the points symmetrically distributed between the X (results obtained) and Y (precision of the studies) axes indicates that the published results are homogeneous, suggesting the absence of publication bias. Otherwise, from the published results being heterogeneous, we would have an asymmetric figure with a concentration of studies on one side of it indicating publication bias. Therefore, the studies selected for this research did not present publication bias, i.e., we did not choose only scientific publications with positive evidence and discarded those with contrary evidence, according to the objective and hypothesis of the work (Pereira & Galvão, 2014; Wheelan, 2016). Therefore, it is likely that the variation in results between studies is not due to chance, sampling error, or methodological differences (Pereira & Galvão, 2014).

Forest plot (Figures 2, 3, 4, and 5) indicates with the confidence intervals for each study are large in all management considered, which reflected in a large overall effect. For comparison of bulk density in (P) and (NT) management for a depth of 0-30 cm with the control (1.39 Mg $m^{-3}$) (Figures 2 and 3), showed a value greater than 1.39 Mg $m^{-3}$ for P ("overall effect" = 0.04 ± 0.02, indicating an interval of values between 1,41-1,45 Mg $m^{-3}$) and for NT ("overall effect" = 0.03 ± 0.00, indicating a value equal 1,42 Mg $m^{-3}$). These results are in accord with Possamai et al. (2022), Silva et al. (1997), Neves et al. (2003), Whalley et al. (2008), Portella et al. (2012), Cherubin et al. (2018), Tavares and Tessier (2009), Tavares et al. (2010), Vizzotto et al. (2000), Paulo and Almeida (2016), Pulido et al. (2018), Moraes et al. (2016), Watanabe et al. (2018), S. Zhang et al. (2012a), X. Zhang et al. (2012b) and Bonetti et al. (2019).

For comparison of bulk density in (CT) and (MT) management, Figures 4 and 5 showed a value lower than 1.39 Mg $m^{-3}$ for CT, the "overall effect" is -0.02 ± 0.01, indicating an interval of values between 1,36-1,38 Mg $m^{-3}$ and MT the "overall effect" is equal to -0.07 ± 0.01, indicating an interval of values between 1,31-1,33 Mg $m^{-3}$. These results are in accord with, Reichert et al. (2009), Portella et al. (2012), Giarola et al. (2013), Guimarães et al. (2013), Tavares et al. (2014), Moncada et al. (2014), Carducci et al. (2017), Boizard et al. (2017), Macedo et al. (2017), Watanabe et al. (2018), Inagaki et al. (2021).

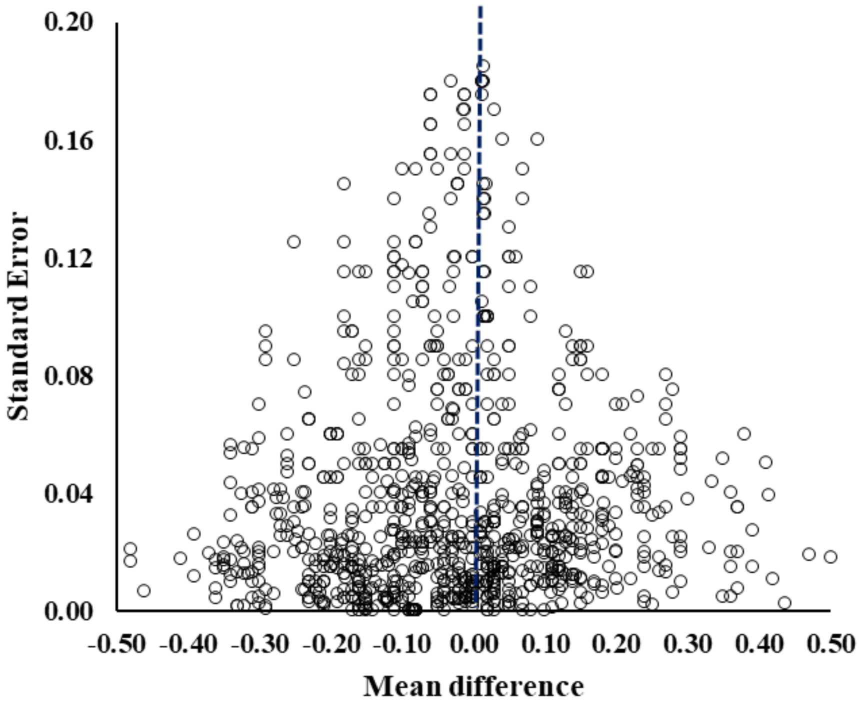


**Figure 1.** Scatter plot representing the dispersion of studies developed in clayey Oxisols, different managements (pasture (P), no-tillage management (NT), conventional tillage (CT), and minimum tillage (MT)) at 0 - 20 cm.

These results indicate that soil density is a dynamic property that varies with the structural conditions of the crop soil (Bauder et al., 1981; Jones, 1983), according to soil texture and the type of management adopted. For the considered management in clayey Oxisol, it is then possible to defining bulk density indicating compaction in these soils, in management that minimizes soil manipulation (P and NT), bulk densities between 1.41-1.45 $Mg.m^{-3}$ (average 1, 43 Mg $m^{-3}$), and for management no that minimizes soil manipulation (CT and MT), bulk densities between 1.31-1.38 $Mg.m^{-3}$ (average 1, 35 Mg $m^{-3}$).

For NT management, the density values showed that the lack of preparation added to the traffic of seeding machines increases its density. This is probably, due to inadequate management practices such as overloading due to machine traffic in wet soil and lack of crop rotation, which were associated with no-tillage, favored soil compaction, and increased soil density (Silva et al., 1997; Neves et al., 2003; Portella et al., 2012; Giarola et al., 2013; Guimarães et al., 2013; Tavares & Tessier, 2009; Tavares et al., 2010, 2014; Moncada et al., 2014; Carducci et al., 2017; Boizard et al., 2017; Macedo et al., 2017; Watanabe et al., 2018; Inagaki et al., 2021; Possamai et al., 2022). But it is important to remember that no-tillage is a technology for more rational use of the soil, capable of protecting against erosion and improving the physical properties of soils for root growth and reducing the cost of soil management operations (Fuentes-Llanillo et al., 2021; Possamai et al., 2022).

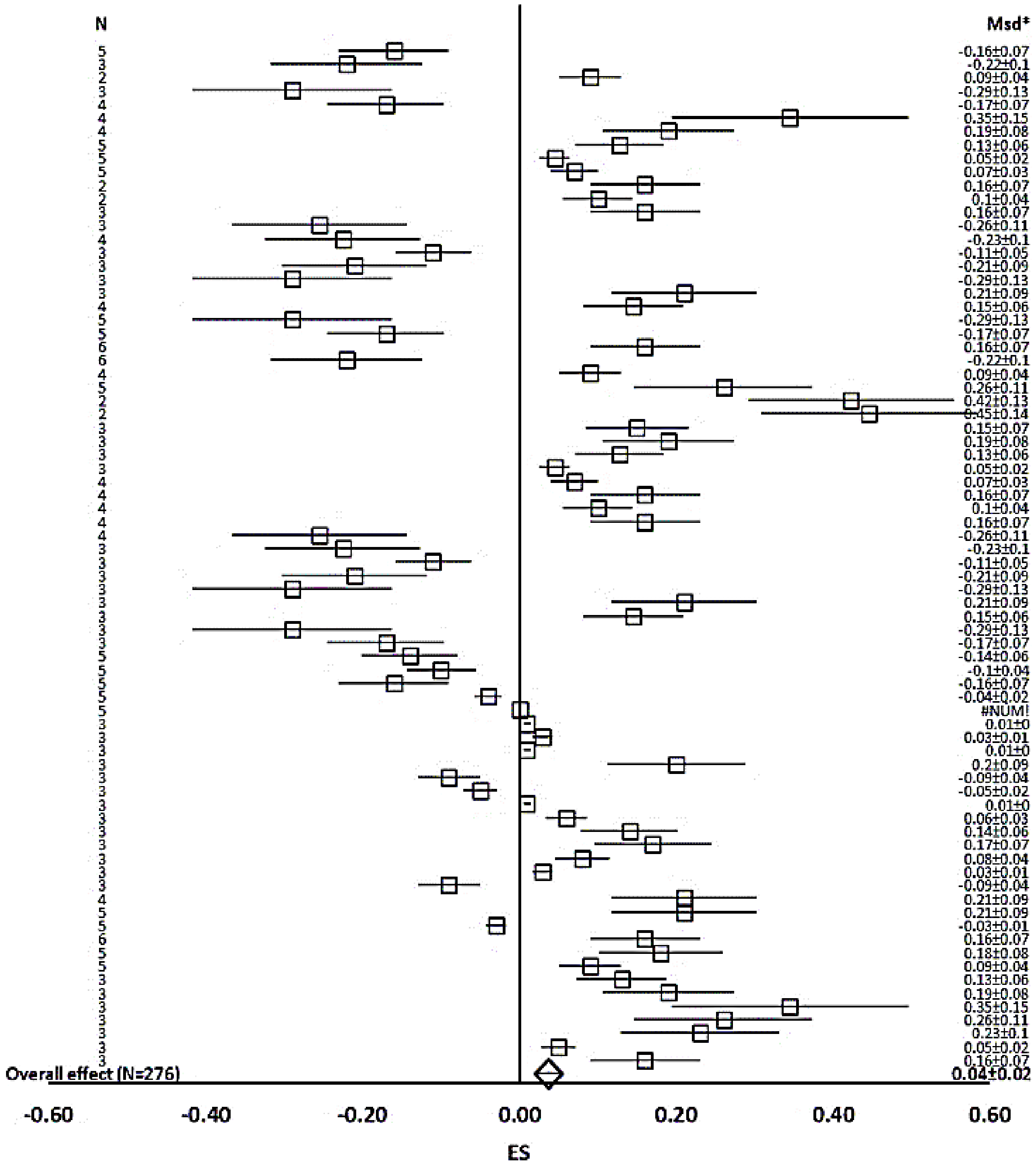


**Figure 2.** Forest plot of the comparison of bulk density in the pasture management (P) and (NT) for a depth of 0-30cm with the control (BD = 1.39 Mg $m^{-3}$). *Msd = Means ± standard deviations (95% confidence interval); ES = Effect size (difference between mean bulk density in pasture management (P) and (MT) and control for soils).

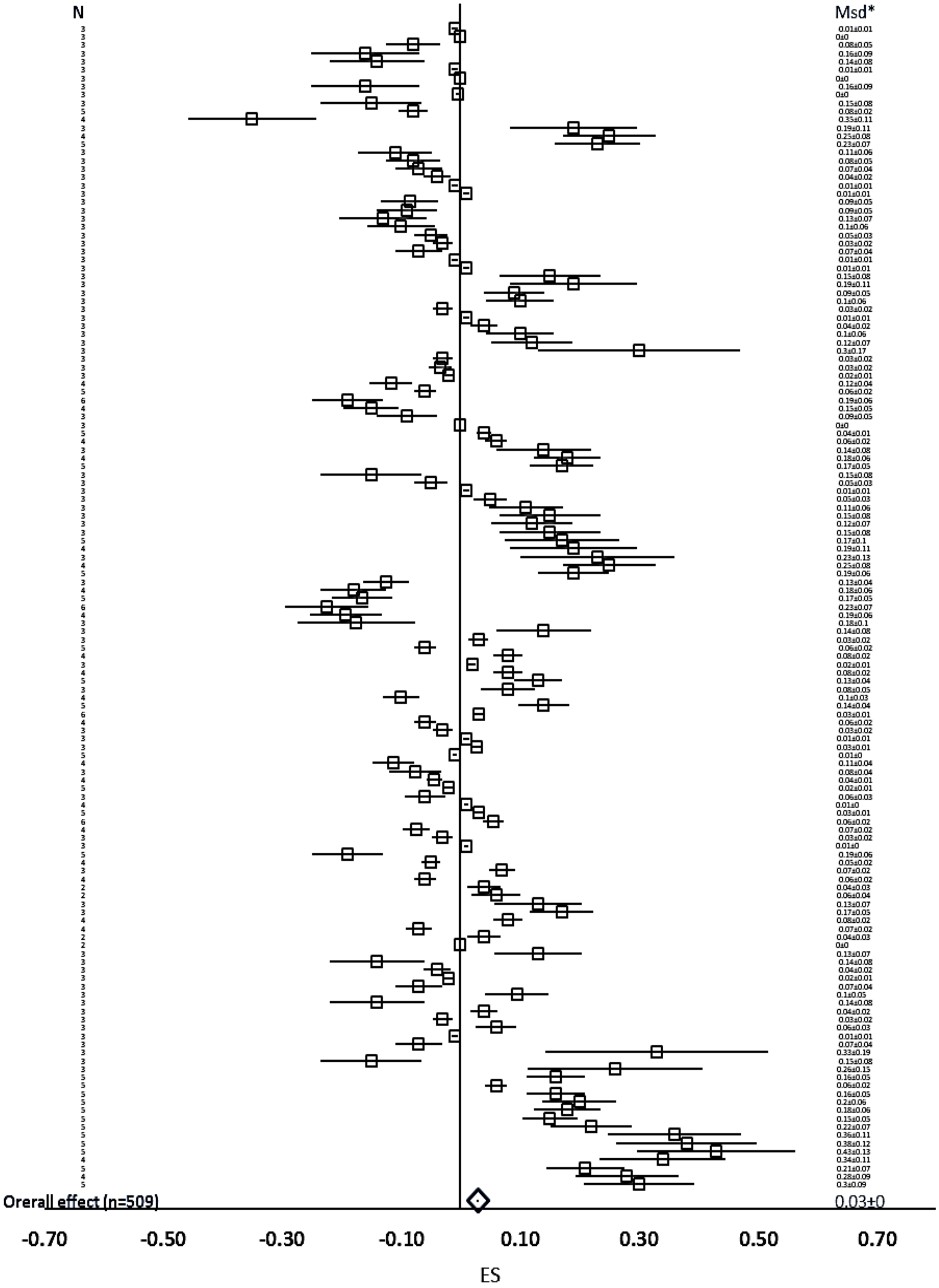


**Figure 3.** Forest plot of the comparison of bulk density in no-tillage (NT) management for a depth of 0-30cm with the control (BD = 1.39 Mg $m^{-3}$). *Msd = Means ± standard deviations (95% confidence interval); ES = Effect size (difference between mean bulk density in no-tillage (NT) management and control for soils).

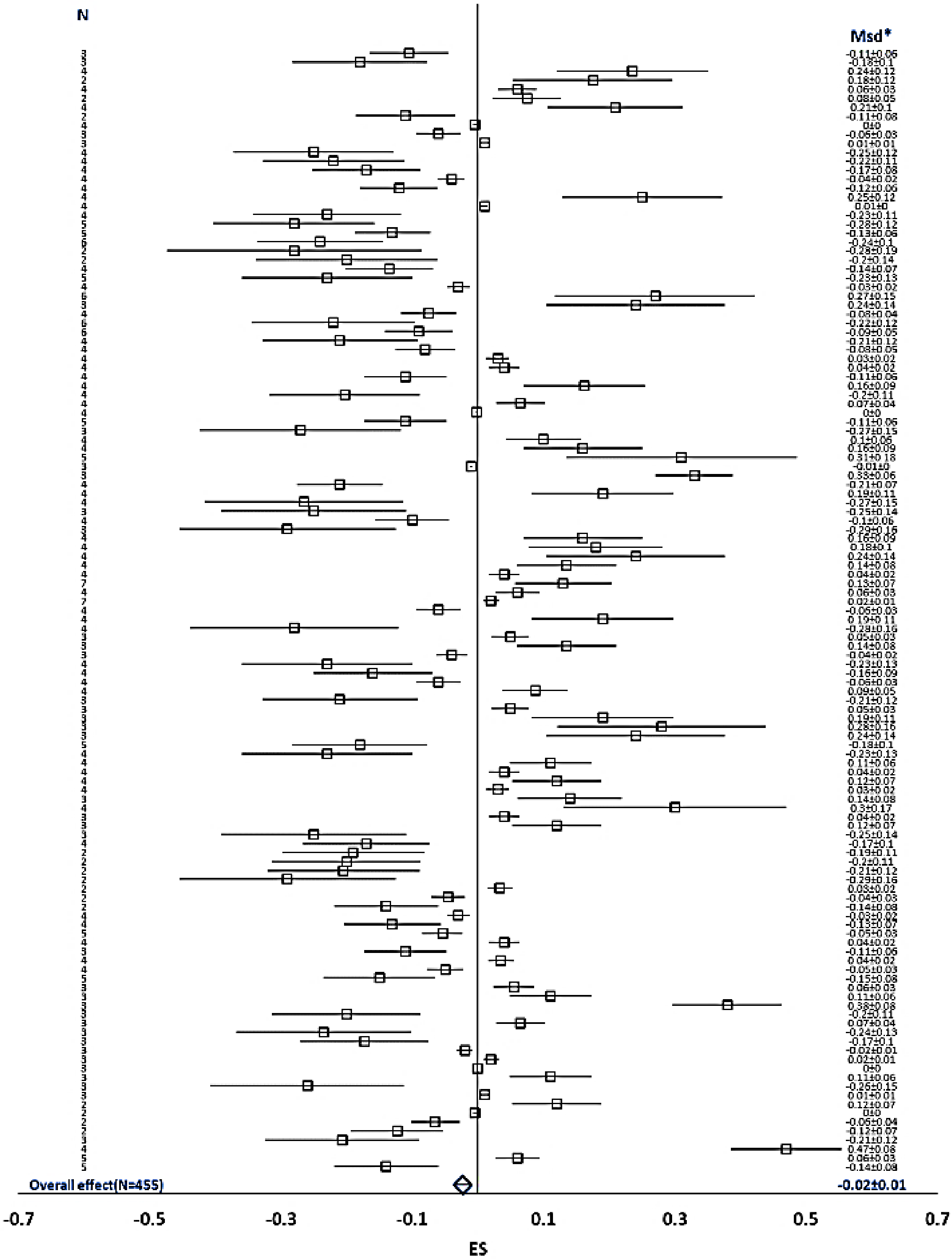


**Figure 4.** Forest plot of the comparison of bulk density in conventional tillage (CT) and (MT) management for a depth of 0-30cm with the control (BD = 1.39 Mg $m^{-3}$). *Msd = Means ± standard deviations (95% confidence interval); ES = Effect size (difference between mean bulk density in conventional tillage (CT) and (MT) management and control for soils).

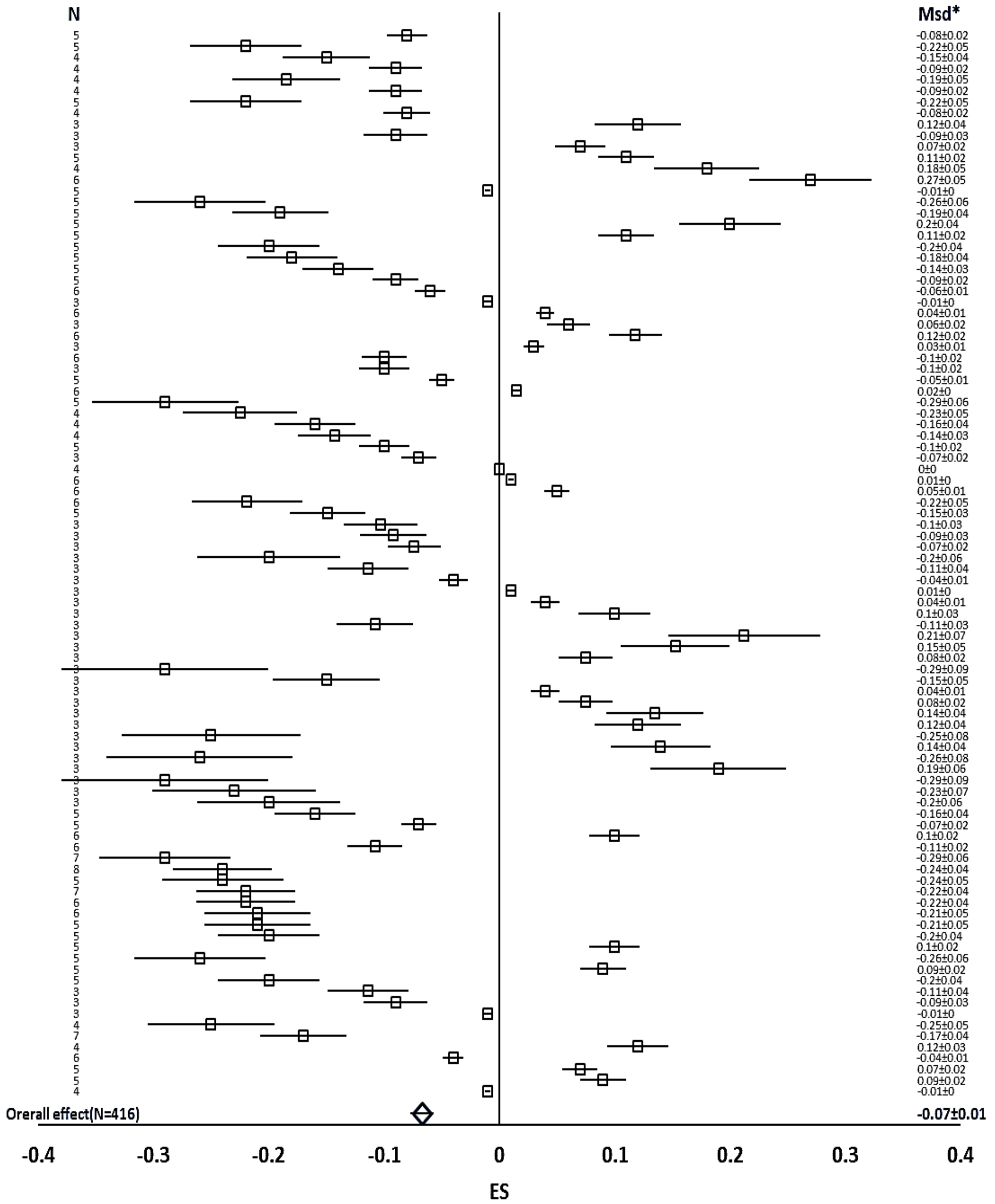


**Figure 5.** Forest plot of the comparison of bulk density in minimum tillage (MT) management for a depth of 0-30 cm with the control (BD = 1.39 Mg $m^{-3}$). *Msd = Means ± standard deviations (95% confidence interval); ES = Effect size (difference between mean bulk density in minimum tillage (MT) management and control for soils)

For P management, the literature (Vizzotto et al., 2000; Paulo & Almeida, 2016; Pulido et al., 2018; Bonetti et al., 2019), shows that the density value of soil can reach values above 1.40 Mg $m^{-3}$ in compacted pastures due to animal trampling, stocking rate and forage species.

It's important to consider, for management that inverts the soil, that many producers do not use crop rotation, to reduce soil density, and they prefer to sow deeper (in the CT management is probably the result of intense soil preparation for sowing the crops) or use minimum tillage (MT) (Nunes et al. (2015), Peixoto et al. (2020). Reichert et al. (2009) showed that the excessive traffic of machines and the use of agricultural implements to turn the soil causes its physical deterioration and lower bulk density (Silveira et al., 2012; Silva et al., 1997; Inagaki et al., 2021), but according to Fernandes et al. (2008), the energy cost of the operation (MJ $ha^{-1}$) with plowed or scarified soil is about 50% higher than the no-tillage system with crop rotation.

From the data collected in the literature, it was possible to separate two groups of bulk density and management in clayey soils indicative of compaction: the managements that perform little or no manipulation of the soil, such as pasture and no-tillage, densities between 1.41-1, 45 $Mg.m^{-3}$ (average 1.43 Mg $m^{-3}$), and for the others, such as conventional plowing and minimum tillage, soil densities between 1.31-1.38 $Mg.m^{-3}$ (average 1.35 Mg $m^{-3}$). Finally, we conclude that compaction must be analyzed considering the texture and type of soil management.

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