

Comparison of Soil Physical Properties in Rice Fields under Conventional and Mulch-No-Tillage Systems

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Abstract

Comparing different land management systems is crucial for understanding their impact on soil physical properties and rice productivity. This research was conducted in Bangkal Village, Banjarbaru City, as part of the Udara Bersih Indonesia program, which promotes the Mulch No-Tillage system. The study aimed to compare the effects of no-tillage with organic mulch (MNT) and conventional tillage (CT) on soil physical properties and rice yield within a 0.5 ha area under similar environmental conditions. Twelve samples were collected from each land type and analyzed using a quantitative comparative approach with an independent t-test. Parameters observed included water-stable aggregates, bulk density, field water content, COLE index, and rice yield. The results showed that MNT had significantly higher water-stable aggregates (53.05%) than CT (42.85%), as well as a higher field water content (94.94%) compared to CT (68.71%). The COLE index under MNT was lower (0.06; medium category) compared to CT (0.20; very high category), indicating lower shrink-swell potential and better soil stability. Bulk density showed no significant difference between MNT (0.81 g cm⁻³) and CT (0.88 g cm⁻³), possibly due to the short implementation period of MNT. Rice yields under MNT reached 4.5 ton/ha and 6.5 ton/ha, while CT produced 3.0 ton ha⁻¹ and 3.6 ton ha⁻¹ during the two planting periods. This study strengthens the empirical evidence that the no-tillage system with organic mulch can improve soil physical quality and enhance agricultural productivity, providing a more sustainable and resilient approach to managing tropical paddy soils.

1. Introduction

Tillage systems are a significant factor in determining soil characteristics, including physical, chemical, and biological properties. Tillage has both direct and indirect effects on soil quality, underscoring its crucial role in sustainable land management. Therefore, tillage practices must be implemented in accordance with specific problems encountered in the field. Excessive conventional tillage can lead to soil degradation, such as reduced aggregate stability, significant decreases in water availability, and increased soil compaction, ultimately hindering root growth (Zahro et al., 2024).

The high risk of soil degradation caused by Conventional Tillage (CT) has led to the adoption and development of No-Tillage (NT) systems worldwide since the 1960s (Friedrich et al., 2012). Research conducted by Blanco-Canqui and Ruis (2018) reported that NT systems increase wet aggregate stability by 1–97% and available water content by 44%. No-tillage may either increase or decrease soil bulk density; however, Proctor Test results by Blanco indicated that NT reduced compaction potential by 4–13% at a depth of 0–15 cm. This suggests that surface soil structure becomes more stable and less prone to compaction even under external pressure. Although no-tillage

NT systems have been extensively studied, comparative investigations between the Mulch No-Tillage (MNT) system and CT, particularly under local conditions in Indonesia, remain scarce.

The MNT system is a soil management practice that utilizes organic mulch as a surface cover without the addition of fertilizers or other biomass, and without soil inversion. In contrast, CT involves incorporating fertilizers or biomass and mechanical plowing. The implementation of MNT in Indonesia began under the Clean Air Indonesia (*Udara Bersih Indonesia, UBI*) program, initiated by the Field Indonesia Foundation in collaboration with national ministries and provincial governments. The UBI program aims to improve air quality in Indonesia, which is crucial for public health and environmental sustainability. Its focus is on the agricultural sector—both a contributor to and a victim of air quality degradation due to practices such as land burning, pesticide use, and emissions from agricultural machinery (Field Indonesia, 2023).

Field Indonesia collaborates with two Ministries and eight Regional Governments, including the City Government of Banjarbaru. One of the pilot areas for the UBI program is Bangkal Village, Cempaka District, Banjarbaru City, which also serves as the study site for this research. According to the program's annual report, the MNT method has increased crop yields by 13% to 100% compared to the CT system. In several regions of Indonesia, such as West Sumatra, rice yields under MNT (4.5 ton ha⁻¹) were higher than those under CT (3.5 ton ha⁻¹). These findings indicate that MNT has significant potential to enhance crop productivity over time and serve as an alternative approach to sustainable agricultural management (Field Indonesia, 2023).

Previous studies have shown that MNT contributes to better soil physical conditions than CT. The system enhances soil aggregate stability and increases the proportion of water-stable aggregates. Additionally, the presence of organic mulch can reduce bulk density by 23–25% and improve field water retention, demonstrating its vital role in maintaining soil structure and moisture balance in tropical agroecosystems (Muzakki et al., 2020; Phefadu and Munjonji, 2024).

In addition to these parameters, the Coefficient of Linear Extensibility (COLE) index is also a crucial factor to consider, particularly in indicating the swelling–shrinkage potential of paddy soils (Reeve et al., 1980). Rezaee et al. (2020) identified the COLE index as a key parameter for evaluating soil quality indices in rice fields. A higher COLE index increases the risk of crack formation, which can physically damage plant roots. These findings highlight the significance of the COLE index, however, few studies have examined the relationship between tillage practices and the COLE index.

The importance of understanding how tillage systems influence soil physical properties led to the conduct of this study, which aimed to compare the physical characteristics of paddy soils under MNT and CT systems. The parameters analyzed include Water-Stable Aggregates (WSA), Bulk Density (BD), field moisture content, COLE index, and crop yield. The limited number of local studies comparing soil physical properties under MNT and CT systems, particularly those incorporating the COLE index as an indicator of soil volume stability, makes this research highly relevant. The results are expected to provide valuable insights and serve as a data-driven basis for optimizing local paddy field management.

2. Research Methods

2.1. Research Location

This research was conducted from June to July 2025. Soil sampling was carried out in Bangkal Subdistrict, Cempaka District, Banjarbaru City, South Kalimantan. Soil physical analyses were performed at the Soil Physics Laboratory, Department of Soil Science, Faculty of Agriculture, Lambung Mangkurat University.

2.2. Research Implementation

This study employed a quantitative comparative method to evaluate differences in soil physical properties and rice yield between MNT and CT system. Soil sampling was conducted on two plots, each covering 0.5 ha. Both systems were located within the same area (less than 5 meters apart) and under identical environmental conditions, ensuring a more accurate comparison. The MNT plot had only been managed for eight months (two planting periods) after previously being operated under the CT system. In contrast, the CT plot examined in this study had been continuously cultivated under CT management since the beginning of rice farming on that land. Sampling followed a grid-based purposive sampling design, with two sampling points per grid, resulting in 12 samples from each plot. Samples consisted of disturbed and undisturbed soils collected from a depth of 0–20 cm using a ring sampler and a hand hoe, yielding a total of 24 representative samples. Sampling was conducted during the rainy season, near the second rice harvest period. Rice yield data were obtained through a 2.5 m × 2.5 m quadrat harvest, then extrapolated to a 0.5 ha scale for each plot. Yield data from two cropping periods were provided by the Agricultural Extension Office (BPP) of Cempaka.

All soil physical parameters were analyzed following standard local laboratory protocols. Water-stable aggregates were measured using the elutriation method with an elutriator. Bulk density was determined gravimetrically using the procedure described by Dong and Ochsner (2018). This involved weighing moist soil

samples, oven-drying them at 105°C to a constant weight, and calculating bulk density from the mass and volume. Field water content was determined by comparing the weights of fresh and oven-dried soil samples, with the fresh samples weighed immediately after collection to preserve field conditions (Dong and Ochsner, 2018).

The COLE index was analyzed using the method described by Silva et al. (2017). The index was determined by measuring the change in length of a soil sample (1.5 cm diameter syringe) from its wet to dry state. The COLE value was calculated as the ratio of the difference between wet and dry lengths to the dry length, representing the soil's shrink-swell potential. Higher COLE values indicate greater shrink-swell potential and lower structural stability, while lower COLE values signify more physically stable soil conditions.

2.3. Data Analysis

Data analysis was based on the parameters measured in this study. Laboratory results were subjected to statistical analyses. Descriptive statistics were first applied to provide an initial overview of the data, followed by comparative statistical tests to determine the significance of differences between the two systems (Independent t-test). Prior to the comparative analysis, an F-test was performed to assess the homogeneity of variance. If the data were homogeneous, an independent t-test assuming equal variances (t-test: Two-Sample Assuming Equal Variances) was applied; if not, an independent t-test assuming unequal variances (t-test: Two-Sample Assuming Unequal Variances) was used. The results were presented in tables and figures to support data interpretation. Data processing was conducted using Microsoft Excel with an add-in program.

3. Result and Discussion

3.1. Land Characteristics

The rice fields in Bangkal Subdistrict, Cempaka District, rely on rainfall as their sole source of irrigation (rainfed). In MNT system, rice straw from the previous harvest is used as organic mulch to cover the soil surface, without the addition of fertilizers or other biomass inputs, following the method implemented in Udara Bersih Indonesia (UBI) program (Field Indonesia, 2023). In contrast, CT system applies a combination of basal and chemical fertilizers. Land management practices also differ between the two systems: in MNT, no plowing is conducted, either by machine, animal, or manually with a hoe, while in CT, plowing is performed prior to planting using a mechanical plow. Both fields are located in the same area, thus assumed to share similar environmental conditions.

In line with the UBI program, the MNT field had been managed for approximately eight months, equivalent to two rice growing seasons, before this study. Before adopting the MNT approach, the same field was previously managed under the CT system. The CT field investigated in this study has been continuously cultivated by local farmers as a traditional paddy field. Although the duration of implementation between the two systems differs considerably, the observed results already indicate notable improvements under the MNT system within a relatively short period.

3.2. Water-Stable Aggregates

The value of water-stable aggregates in the no-tillage system was significantly higher, at 53.05%, compared with 42.85% in the conventional tillage system (Figure 1). This suggests that variations in land management practices can lead to substantial differences in aggregate stability.

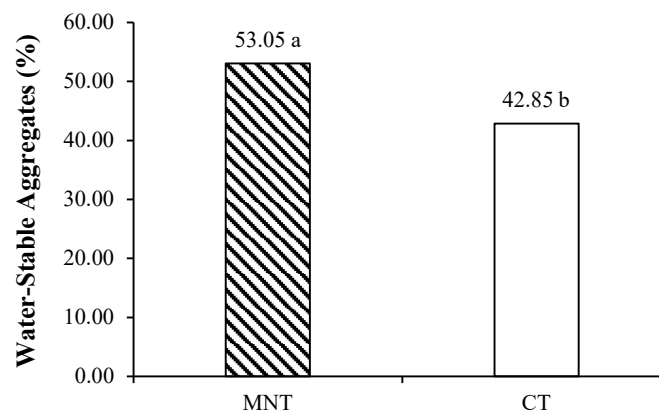


Figure 1. Water-stable soil aggregates under Mulch–No-Tillage (MNT) and Conventional Tillage (CT) system. Bar charts marked with different letters indicate significant differences based on the Independent t-test (homogeneous data) at the 95% confidence level.

According to Sui et al. (2012), higher water-stable aggregate values improve soil structural quality by resisting erosion, enhancing infiltration, and increasing pore space. The higher aggregate stability observed under MNT system indicates better soil structural quality compared to the CT system. This difference is likely attributed to the intensive mechanical disturbance during plowing in CT fields, which disrupts the natural soil structure and causes the breakdown of aggregates.

The superior water-stable aggregates found under MNT suggest a more preferable soil physical condition than CT. A recent study in China by Wu et al. (2024) reported that aggregate fractions resistant to disintegration upon wetting (water-stable aggregates) act as a critical physical framework for soil organic carbon (SOC) sequestration and structural reinforcement. Their findings demonstrated that an increase in macroaggregate fractions (>0.25 mm) was significantly associated with higher SOC stocks and greater water infiltration capacity in silt loam soils.

Organic mulch applied in MNT serves as a natural binding agent, enhancing soil aggregation. As mulch decomposes, organic compounds such as lignin and microbial polysaccharides infiltrate soil pores, functioning as natural adhesives between particles. This process contributes to the accumulation of SOC in the surface layer, which further supports aggregate stabilization. Consequently, the application of MNT improves soil structure, carbon retention, and overall soil functionality, making it a more sustainable management approach than CT (Wu et al., 2024).

3.3. Bulk Density

The bulk density value under the no-tillage system (0.81 g cm^{-3}) was not significantly different from that of the conventional tillage system (0.88 g cm^{-3}) (Figure 2). This suggests that differences in land management practices did not lead to significant variations in bulk density.

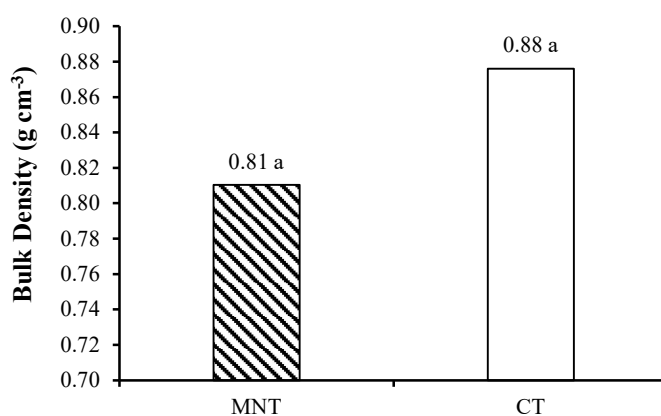


Figure 2. Bulk density under Mulch–No-Tillage (MNT) and Conventional Tillage (CT). Bar charts marked with the same letters indicate that bulk density (BD) is not significantly different based on the Independent t-test (homogeneous data) at the 95% confidence level.

Both fields showed bulk density values of $<1.2 \text{ g cm}^{-3}$. According to Mujiyo et al. (2024), soils with bulk density values ranging from 1.19 to 1.29 g cm^{-3} are already suitable as a growth medium for rice. The lower the bulk density, the more beneficial the soil is for cultivation. For clay soils, bulk density values of $<1.2 \text{ g cm}^{-3}$ are considered indicative of healthy agricultural land, thus, the bulk density values of both fields were still classified as suitable for crop production. The absence of significant differences in bulk density may be attributed to the relatively uniform field conditions. The MNT system has not yet been applied over a long period, which could explain the lack of significant differences.

The MNT system at the study site had only been recently implemented (as described in the site characteristics), and the field was previously managed under a CT system. Before the adoption of MNT, the soil had undergone intensive plowing using mechanical tillage equipment. When tillage is performed on wet soils, it can lead to decreased porosity and increased bulk density, which restricts root development and water infiltration. Under such conditions, soil recovery from previous tillage disturbance tends to be slow, making it challenging to observe improvements in soil physical quality within a short period (Liang et al., 2022; Yuan et al., 2020).

3.4. Field Moisture Content

The field moisture content under the MNT system (94.94%) was significantly higher than that of the CT system (68.71%) (Figure 3). This suggests that differences in land management practices led to significant variations in field moisture content.

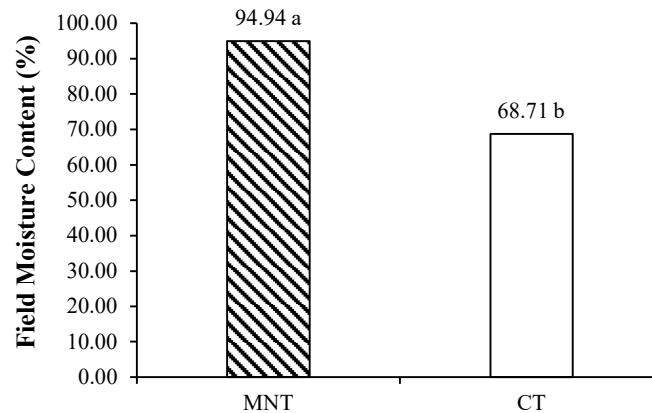


Figure 3. Field moisture content under Mulch–No-Tillage (MNT) and Conventional Tillage (CT). Bar charts marked with different letters indicate that the field moisture content differs significantly, as determined by the Independent t-test (heterogeneous data), at the 95% confidence level.

In contrast to bulk density values, which tend to be stable and difficult to change significantly in a short period of time, soil moisture is a physical property that is responsive (easily changes according to soil management). Field moisture content in this study was measured based on the actual moisture in the field. Both land systems (MNT and CT) showed significantly different field moisture values, with MNT having higher results. A study by Fatumah et al. (2020), which compared soil moisture content in no-tillage, conventional tillage, and reduced tillage systems, found that no-tillage land had the highest soil moisture (significantly different from conventional tillage), while conventional tillage land had the lowest soil moisture. This is due to the preservation of micropores, which remain undisturbed by heavy equipment, allowing water to be better retained and stored for a longer period. Soil cover in MNT with organic mulch also becomes one of the factors increasing soil moisture.

A study by Wang et al. (2022) showed that among various soil management systems tested, the no-tillage system maintained significantly higher soil water content compared to conventionally tilled soils. This is because the micropores in no-tillage soils remain intact and undisturbed by mechanical operations, allowing for improved water retention efficiency. The presence of these micropores is crucial for effective water management, particularly in maintaining soil moisture in paddy fields.

The use of organic mulch as a soil cover also plays a crucial role in preserving soil moisture. Zhang et al. (2022) found that the application of organic mulch increased soil moisture compared to bare soil. Organic mulch reduces evaporation by forming a protective surface layer, allowing water to remain in the soil for a longer time. The application of organic mulch in rainfed paddy fields can therefore serve as an effective strategy for maintaining field water content, considering that rainfall patterns strongly influence water availability.

3.5. Coefficient of Linear Extensibility (COLE) Index

The MNT system showed a significantly lower COLE index value (0.06) compared to the CT system (0.20) (Figure 4). This suggests that differences in land management systems lead to significant variation in the COLE index. The data indicate that the risk of soil shrink-swell in MNT is lower compared to CT. Based on the COLE index classification by Schfer and Singer in Umbugadu et al. (2021), the COLE index value of MNT (0.06) falls into the medium category, while CT (0.20) is categorized as very high (Table 1). A high COLE index reflects a greater potential for soil shrink-swell or severe shrinkage during dry seasons. This finding is also supported by local farmer Mr. Hadriansyah, who stated that during drought periods, soils under CT tend to dry and develop large visible cracks, unlike soils under MNT, which show minimal visible cracking.

Greater soil shrinkage, especially during dry seasons, can lead to the formation of cracks, which pose serious agronomic challenges. According to Safitri et al. (2024), larger cracks increase the risk of disrupted water supply to plants because roots struggle to access moisture from deeper soil layers. The application of organic mulch is an effective strategy to maintain soil moisture for extended periods and reduce the potential for soil shrinkage. The COLE index value also provides insight into soil organic matter content. A study by Beck-Broichsitter et al. (2016) found that the COLE index is inversely correlated with SOC content. Lower COLE index values are associated

with higher SOC levels. This suggests that a lower COLE index reflects better soil quality in terms of organic matter. Higher organic matter improves soil structure and enhances its ability to retain moisture. Therefore, the implementation of the MNT system is considered more beneficial for improving soil quality and stability under rainfed paddy field conditions.

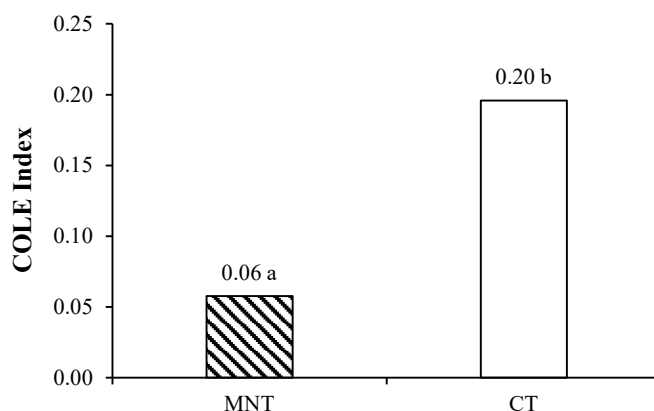


Figure 4. COLE index under Mulch–No-Tillage (MNT) and Conventional Tillage (CT). Bar charts marked with different letter notations indicate that the COLE index is significantly different based on homogeneous data, as determined by the Independent t-test at a 95% confidence level.

Table 1. COLE Index class based on Schafer and Singer (Umbugadu et al., 2021)

COLE index	Class
0.00 – 0.03	Low
0.03 – 0.06	Medium
0.06 – 0.09	High
>0.09	Very high

3.6. Crop Yield

The yield data indicate that different land management systems have an impact on rice production. The production data were obtained directly from the rice harvest records of the Cempaka Agricultural Extension Center.

Table 2. Rice production data across two planting periods with two varieties

Planting Period	System	Rice Variety	Yield (ton/ha)	Difference (%)
1	MNT	Unggul	4.5	50.0
	CT		3.0	
2	MNT	Siam Badin	6.5	80.6
	CT		3.6	

The yield data (Table 2) present rice production data across two planting periods using two cultivation systems. The results show that MNT produced 4.5 tons ha⁻¹, whereas CT produced 3.0 tons ha⁻¹, resulting in a 50.0% higher yield under MNT. In the second period, yields increased further, with MNT producing 6.5 tons ha⁻¹ compared to 3.6 tons ha⁻¹ under CT, corresponding to an 80.6% difference. The increase in yield across the two planting periods may be partially influenced by the different rice varieties cultivated (Unggul in Period 1 and Siam Badin in Period 2). Visually, rice grown under the MNT system exhibited more tillers and fuller grains compared to rice under the CT system, which supports the yield differences observed. This provides practical evidence to compare which system is more advantageous in terms of both economic return and effectiveness and efficiency. According to local farmers, rice planting under the CT system is often delayed (up to two months) due to the need for land preparation with a plowing machine beforehand.

Another important factor highlighted by Wihardjaka et al. (2020) is climate variability. Rainfed rice fields are highly dependent on rainfall, and with the increasing effects of climate change, drought poses a significant threat that can reduce yields. Therefore, determining the appropriate planting time is essential to ensure favorable climatic conditions for rice growth. Delays in planting under the CT system can negatively affect yields, as soil tillage with

heavy machinery requires additional preparation time. This delay can lead to suboptimal growth conditions and reduced yields due to restricted vegetative development.

A related study by Kasno et al. (2020) also emphasized that water management is a critical factor affecting rice productivity, particularly in rainfed systems. Adequate water availability during the growing season is vital for optimal crop growth and yield. The use of organic mulch has been identified as a potential solution for improving soil moisture retention in rainfed fields. Consistent with the findings of this study, the application of organic mulch increased field water content, which may explain the higher productivity of both rice varieties under the MNT system compared to the CT system.

4. Conclusion

The MNT system proved superior to the CT system in terms of soil physical properties, particularly aggregate stability, field water content, and the COLE index. Although bulk density did not differ significantly, the value is still considered favorable for rice cultivation. Soil physical properties play a crucial role in influencing rice yield. The improved soil physical conditions under the MNT system led to higher rice production. Therefore, the MNT system in this study is more recommended for land management, especially in the areas surrounding the research site.

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