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Minimum tillage on vertisols lowland increases rice production and soil properties

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Abstract

Current land management is a challenge for wetlands vertisol soil types, especially on the rice production, which often clashes with future soil quality. This study aimed to obtain optimal performance of rice growth and physical and chemical properties of vertisol soil on various tillage systems. The study was carried out in the vertisol rice fields of Batu Bolong sub-village, Ungga village, Southwest Praya District, Central Lombok Regency, West Nusa Tenggara during the second growing season (March–October) in 2021. The experimental design was arranged in a Completely Randomized Design consisting of three levels of: no-tillage as T1, minimum tillage as T2, and maximum tillage as T3, with each treatment being repeated five times. The use of production inputs and infrastructure was uniform in all experimental plots. The results showed that T2 treatment had some of the best parameters for rice growth and yield as well as the physical and chemical properties of the land. Plant height and number of tillers at T2 were significantly more maximal in observing the vegetative phase. The dry weight of 1000 grains and rice productivity from the highest were respectively T2 > T1 > T3. The physical and chemical parameters of the soil also showed the same order. Thus, it can be said that minimum tillage is the best tillage system to obtain the growth and yield of rice in the second growing season and the most optimal physical and chemical properties of vertisol soil.

INTRODUCTION

Vertisol is the potential soil type due to its reasonably high land productivity (Wubie, 2015), even higher than Inceptisol and Alfisol (Sakti et al., 2021). The high value of CEC and having a pH value that tends to be neutral are positive characteristics of Vertisol, as shown by (Hamoud et al., 2019) that the increase in clay content in the soil is in line with the increase in K uptake in rice. On the other hand, physical properties of Vertisol have immense expansion of powerful (Pal et al., 2012), adhesive and plastic properties (Somasundaram et al., 2018) so that it becomes a challenge for management (Debele and Deressa, 2016). It has been widely reported that the degradation of the physical and chemical properties of vertisol occurs due to improper management (Kundu et al., 2015; Sione et al., 2017), and it is susceptible to soil compaction (Nunes et al., 2015; Keller et al., 2019). This degradation will lead to a decrease in crop productivity (Kundu et al., 2015; Wang et al., 2021), especially rice which is one of the primary commodities in the world (Sayeed and Yunus, 2018) as well as in Indonesia (Maat, 2015).

The advanced science and technology nowadays has answered many challenges on the efforts to increase rice productivity, such as the use of new varieties (Hasbianto et al., 2021), the optimal cropping systems (Abduh et al., 2020), the use of organic fertilizers (Amanullah et al., 2016), inorganic (Sheudzen et al., 2020), the soil amendment (Haque et al., 2021), the

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weed management (Parameswari and Srinivas, 2017), pests and diseases (Ning et al., 2017), and the postharvest (Danbaba et al., 2019). This information can be easily accessed through applications on android (Nutini et al., 2021). However, the challenge now and in the future is to maintain and improve the soil quality as a growing medium. The reality is that the land preparation process from the preparation stage to harvesting often does not consider the soil type. After all, the challenges are the unsuitability of soil for land preparation equipment, poor drainage, and waterlogging, so it leads to runoff and soil erosion (Dinka and Lascano, 2012).

The pattern of rice cultivation in wetlands is always synonymous with silting of land (Sione et al., 2017), which often has an impact on soil degradation (Fang et al., 2019; Qi et al., 2022), without exception in paddy fields with vertisol soil type (Paul et al., 2021). Furthermore, it has been widely reported that the application of no-tillage and maximum tillage positively and negatively impacts the physical and chemical properties of soil. Some of it was soil carbon (Briedis et al., 2018; Vazquez et al., 2019), bulk density (Fang et al., 2019), aggregate stability (Hati et al., 2021; Kraemer et al., 2021; Malobane et al., 2021), availability of P (Zhang et al., 2021), and fluctuations in CO_2 in soil aggregates (Reeves et al., 2019). Other research also reported the impacts on the root systems (Fang et al., 2019), and the increase in plant productivity (De Moraes Sá et al., 2014; Li et al., 2019; Hati et al., 2021). However, each type of processing mentioned above has weaknesses.

The maximum use of heavy equipment in the maximum tillage system harms soil properties (Bennett et al., 2019), like the increase in the clay dispersion index (Basga et al., 2018). Pal et al. (2012) stated that such an increase is the leading cause of vertisol soil degradation. If this happens continuously, it will enlarge the cracks and make it more challenging to its agricultural process (Smagin, 2020), ultimately reducing land productivity. Therefore, proper land management, especially with vertisol soil type, is needed so that the quality of the soil is more stable and the productivity of cultivated plants is maintained and increased.

Referring to the information presented in the research results related to the positive and negative impacts of perfect tillage to no-tillage, there is no explicit explanation on the effect of minimum tillage on the physical and chemical properties of the soil, as well as the productivity of rice plants, especially in wetlands. This study was conducted to obtain optimal growth and yield of rice plants and the most optimal physical and chemical properties of vertisol on various tillage systems.

MATERIALS AND METHODS

The field experiment was conducted on the second growing session from April to July 2021, in vertisol lowland of Batu Bolong sub-village, Ungga, Praya Barat Daya District, Central Lombok Regency, West Nusa Tenggara (8^{o}42'32" S, 116^{o}12'38" E), at 127.3 m above sea level. The rice variety used was Inpari 32, planted using “jajar legowo 2:1” planting system which has been shown to give higher yields than other planting system (Abduh et al., 2020). Other planting systems were the jajarlegowo 3:1 (Maghfiroh et al., 2017), and 4:1 (Susilastuti et al., 2018), with two seeds per planting hole because the results indicated the highest yield compared to 1, 3, 4 and 5 (Paudel et al., 2021).

The experimental design was arranged in randomized complete block design (RCBD) with soil tillage as the treatment and five blocks as replications. The treatments were no-tillage as the T1, minimum tillage as the T2 and maximum tillage as the T3. In the T1 treatment, the experimental plot was not treated at all. The remaining pieces of rice stalks in the first growing season were only buried by stepping on them. The T2 treatment was carried out by turning the soil surface once using a hoe and leveling it. In comparison, the T3 treatment was carried out by turning the soil many times using a hoe until it became perfect mud. Each plot was 5 m x 5 m, water inlet, outlet, and plot with a width of 0.3 m. Each main plot was covered with plastic to a depth of 0.3 m from ground level to minimize run off and seapage.

Transplanting was done when the rice nursery was 14 days old. The types and doses of fertilizers and pesticides were applied uniformly to all experimental plots. The irrigation system applied was also uniform in all experimental plots using the alternate wetting and drying (AWD) method with a watering threshold in a depth of -15 cm below the soil surface (Lampayan et al., 2015). PVC pipes to aid observation with a length of 35 cm were installed in a depth of 20 cm to observe the underground level. The PVC pipe was equipped with a measuring instrument in the form of a ruler to observe the ground water level.

The provision of water with the AWD method began to be applied when the plants entered the age of 10

Table 1. Initial physical and chemical soil properties of vertisols

Parameter		Values	Unit
Physical	Texture	Clay	
	Sand	34	%
	Silt	20	%
	Clay	46	%
	Bulk Density (BD)	1.21	$g.cm^{-3}$
	Particle Density (PD)	2.28	$g.cm^{-3}$
	Total of porosity (η)	46.1	%
	Soil Moisture (KL)	6.12	%
	Field Capacity	37.59	%
	Permanent Wilting Point	15.28	%
	Available Water	22.31	%
	Permeability 10'	0.12	$cm.jam^{-1}$
	Permeability 20'	0.11	$cm.jam^{-1}$
	Permeability 30'	0.11	$cm.jam^{-1}$
	C-Organic	1.15	%
	Water content	34.81	%
Chemical	pH-H_2O	6.74	%
	N-Total	0.05	%
	EC	156.1	$\mu S.cm^{-1}$
	K-Exchangable	2.22	$cmol.kg^{-1}$
	Na-Exchangable	2.62 1	$cmol.kg^{-1}$
	Ca-Exchangable	29.22	$cmol.kg^{-1}$
	Mg-Exchangable	2.33	$cmol.kg^{-1}$
	CEC	19.22	$cmol.kg^{-1}$
	P Total	0.14	%
	K Total	0.04	%
	Available P	0.14	g/ g

days after planting where previously flooding had been carried out in all experimental plots to facilitate the planting process to minimize the critical phase after the transplanting process. When the underground level was at -15 cm from the surface, the water was added to a height of 3–5 cm, and the water entrance and exit were closed.

Parameters of physical and chemical properties of the soil (Table 1) were analyzed at the Soil Laboratory of the Research Institute for Agricultural Technology, NTB. The samples were from before and after the study. The actual pH and humidity data were measured three times using the “Tamura DM-15 Soil Tester pH and Soil Moisture Meter”. The actual electrical conductivity data was measured twice using “EUTECH CON 150”. Plant height, number of tillers, production components (grain weight, harvest grain, grain water content, dry yield) and physiological components of the plants were observed as vegetative and generative parameters. Plant height and number of tillers were observed at 35 days after transplanting (DAT), 50 DAT, 65 DAT, and finally at harvest. Components of production and plant physiology, including the weight of 1000 grains, number of clumps, weight of grain at harvest, weight of dry milled grain, and seed moisture content, were observed at harvest using a seed moisture content measuring device called Smart Digital JV006 Tester. The data were analyzed by ANOVA and Least Significant Different test at 0.05 probability level.

RESULTS AND DISCUSSION

The response of rice plant growth on tillage treatment in this study indicated that minimum tillage and no-tillage were better than maximum tillage. Plant height in the vegetative rice growth phase (35 DAT, 50 DAT, and 65 DAT) was higher at no-tillage than that at minimum tillage. Furthermore, plant height at minimum tillage treatment was higher than at the maximum tillage (Figure 1). Number of tillers was higher in maximum tillage treatment than no-tillage and minimum tillage in generative phase of 90 DAT. This pattern looked the same for the number of tillers, where higher numbers were always obtained from plots with no-tillage and minimum tillage compared to plots with maximum tillage.

The highest tiller number at 35 DAT was obtained at the minimum tillage treatment for 25.12 and followed by the no-tillage treatment for 24.38, which was significantly different with maximum tillage treatment for 20.88 (Figure 2). This pattern of tiller number was also similar at age of 50 DAT, where no tillage and minimum tillage treatments were significantly higher than the maximum tillage treatment for about 26.18, 26.15, and 22.6 respectively. Furthermore, there was no significant difference of tiller numbers between all treatments at 65 DAT. However, the highest tiller number at 90 DAT was obtained at no-tillage for 15.78, although this was not significantly different from the minimum tillage treatment for 15.28, but was actually significantly different from the maximum tillage treatment, of 13.78. In addition, the minimum tillage treatment was not significantly different from the maximum tillage treatment.

Yield of rice at various tillage management of vertisol soil is presented in Figure 3. The highest number of clumps was obtained from the minimum tillage treatment, 517 clumps > maximum tillage, 509 > no-tillage 452. The highest weight of 1000 grains was obtained at the minimum tillage treatment for 32.9 gram, although this was not significantly different from no tillage treatment for 32 gram, but it was significantly different from maximum tillage treatment. This sequence was also seen in measuring rice productivity in each tillage treatment.

The highest rice yield was obtained from the

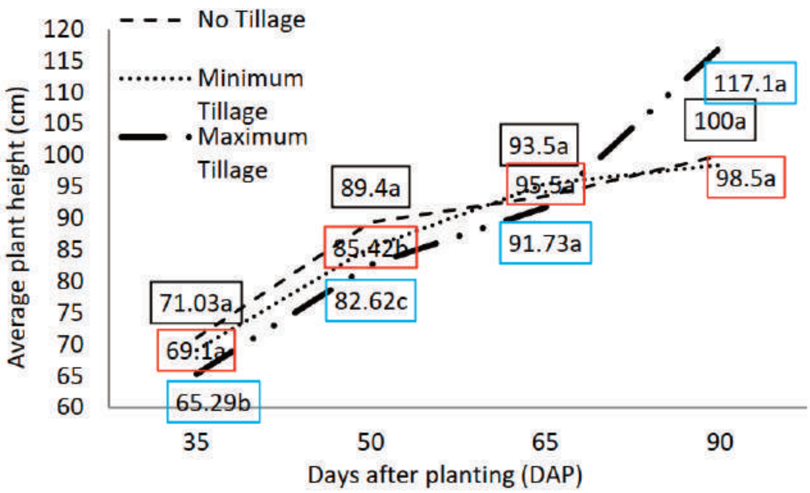

Figure 1. Average of plant height at 35 DAP, 50 DAP, 65 DAP, and 90 DAP
Remarks: Means followed by the same letter are not significantly different at α = 0.05.

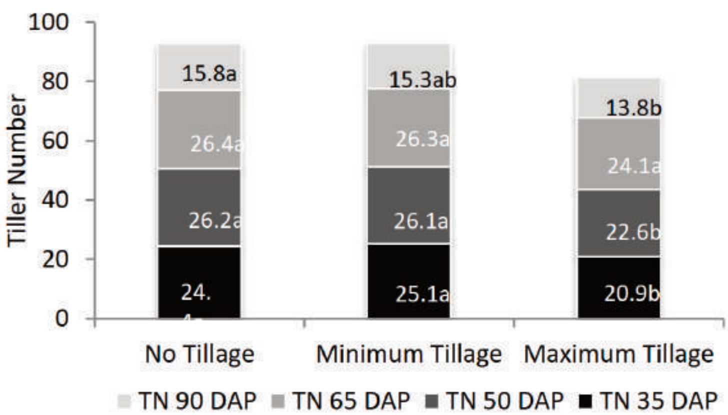

Figure 2. Average number of plant at 35 DAP, 50 DAP, 65 DAP and 90 DAP
Remarks: Means followed by the same letters are not significantly different at α = 0.05; TN = Tiller Number.

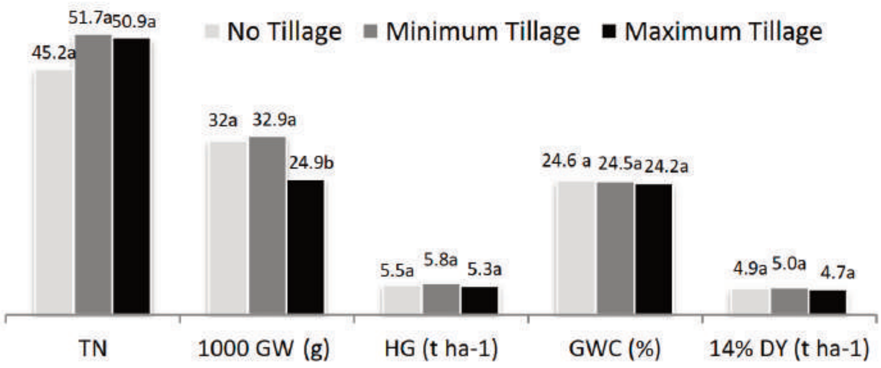

Figure 3. The effects of soil tillage on rice yield parameters
Remarks: Means followed by the same letters are not significantly different at α = 0.05; TN = Tiller Number; GW = Grain Weight; HG = Harvested Grain; GWC = Grain Water Content; 14% Dry Yield = 14% DY) HDG and MDG parameters.

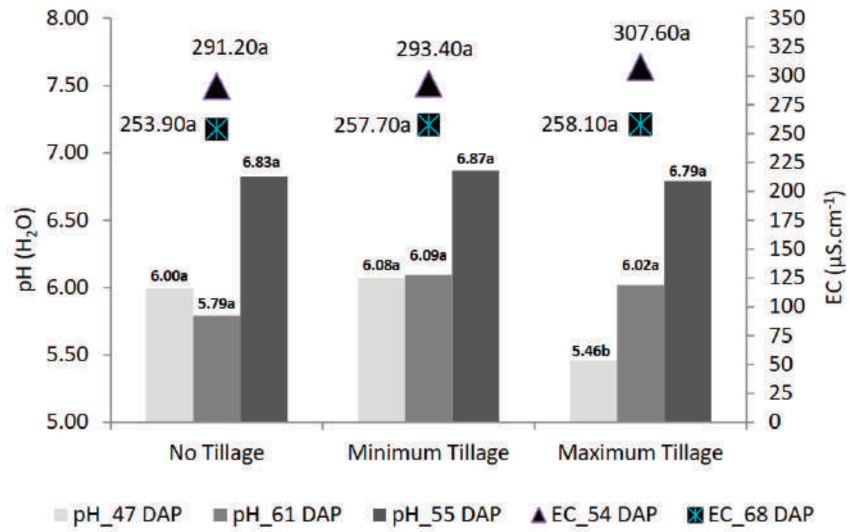

Figure 4. Level of soil acidity and electrical conductivity at several observation periods
Remarks: Means followed by the same letter are not significantly different at α = 0.05.

minimum tillage treatment followed by no-tillage and the lowest was obtained from the maximum tillage treatment, although these were not significantly different. Similar trend of yield was also found at dry yield (14% moisture content). The soil acidity level was observed three times at 47 DAT, 55 DAT, and 61 DAT. There was no significant difference between each treatment except at 47 DAT. The lowest acidity level was obtained at the maximum tillage treatment of 5.46 (Figure 4). There was significant difference between no tillage and minimum tillage with values of 5.995 and 6.075 respectively. At 55 DAT, the highest pH value was obtained from the minimum tillage treatment 6.87, followed by no-tillage 6.83 and maximum tillage 6.79, although these were not significantly different. At 61 DAT, the highest pH value was also obtained at the minimum tillage treatment of 6.092 followed by the maximum tillage treatment of 6.017 and no tillage one of 5.792.

Electrical conductivity measurement was carried out twice at 54 DAT and 68 DAT (Figure 4). There was no significant difference between all treatments in each observation period. The highest value in the first observation was obtained from the maximum tillage treatment with 307.6 $S.cm^{-1}$ followed by the minimum tillage with 293.4 $S.cm^{-1}$ and the no-tillage with 291.2 $S.cm^{-1}$. The electrical conductivity value in the second observation also shared similar trend to the first measurement, but the values were much lower with 258.1; 257.7; and 253.9 $S.cm^{-1}$ for maximum tillage; minimum tillage; and no tillage treatment, respectively.

The soil moisture measurement showed a significant variation in the first observation, especially when the water level was in a depth of -15 cm from the soil surface (Figure 5). On the no tillage treatment, the average moisture value was 3.14 % which was significantly different from the maximum tillage treatment with a value of 1.8, although it was not significantly different from the minimum tillage treatment. In the second observation, when the water table was parallel to the soil surface, each value obtained for the no tillage; minimum tillage; and the maximum tillage treatment was 2.8; 2.13; and 3.45 % respectively. Finally, the third observation was carried out on the water level at the height of 3 cm above soil surface. Similar to the observation at 0 cm water conditions, the results of observations in this third observation were also not significantly different between each treatment. Sequentially, the average soil moisture values for the no-tillage, minimum tillage, and maximum tillage treatment in the third observation were 8.96, 8.75, and 8.73 % respectively.

Consistent with the previous soil physicochemical data, several other parameters in Table 2 also showed the optimum average value obtained from the minimum tillage treatment. For example, T2's highest total N value of 0.06 percent was significantly different from T1 and T3's which was 0.04 percent value. Likewise, the value of C-organic, CEC, C/N ratio, available water, Particle Density, and Bulk Density indicated the best average value from the T2 treatment. However, it was not significantly different from the T1 and T3 treatments.

Minimum soil tillage significantly affected most rice growth and yield parameters as well as soil physical and chemical parameters, compared to no-tillage and maximum tillage. Sakti et al. (2021) demonstrated that the ratoon rice cropping system (regrowing rice plants from the results of previous crop pruning, which significantly reduces soil tillage) improved rice growth and yield parameters as well as physical and chemical properties of the soil (it requires soil preparation first). The results of previous studies have described the impact of conventional tillage systems through puddle pores.

Mud resulted from conventional tillage maximally and continuously caused damage to macro aggregates and macro pores of the soil (Hati et al., 2021). It reduced

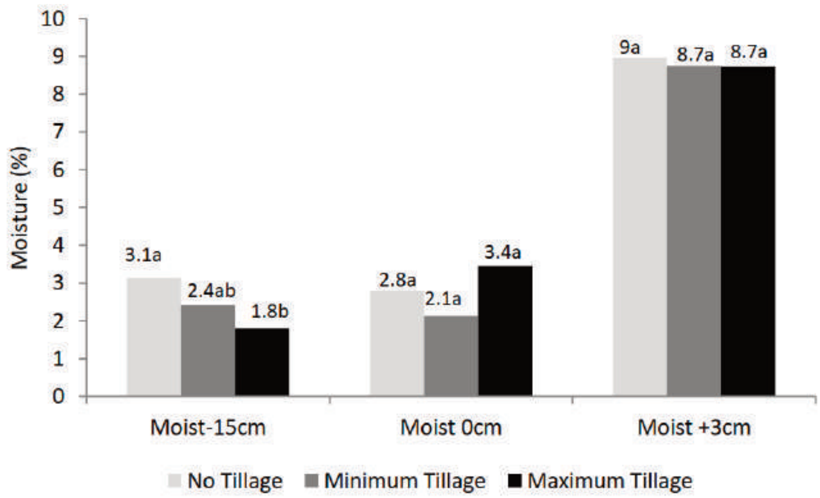

Figure 5. Soil moisture at different water table
Remarks: Means followed by the same letter are not significantly different at α = 0.05.

Table 2. Effect of soil tillage on physical and chemical properties of the soil

Treatment	N Total (%)	C-organic (%)	CEC ($cmol.kg^{-1}$)	C/N Ratio	Available water (%)	Particle Density ($g.cm^{-3}$)	Bulk Density ($g.cm^{-3}$)
T1	0.04 a	1.10 a	22.54 a	25.44 a	19.76 a	2.19 a	1.22 a
T2	0.06 b	1.29 a	26.74 a	23.20 a	21.34 a	2.20 a	1.22 a
T3	0.04 a	1.10 a	22.95 a	27.42 a	21.41 a	2.19 a	1.22 a
l.s.d.	0.012	0.905	5.431	8.644	3.594	0.148	0.015

Remarks: Means followed by the same letter are not significantly different at α = 0.05; T1 = no-tillage; T2 = minimum tillage; T3 = maximum tillage.

the length and surface area of lateral roots (Fang et al., 2019), thus causing a suboptimal number of tillers as has been observed in this research. Figure 3 shows that the weight of 1000 grains was significantly higher in the minimum tillage treatment than the maximum tillage. Also, on harvest dry grain (HDG) and dry yield (DY) parameters, the highest value was always obtained from the minimum tillage treatment followed by no-tillage. However, it was not significantly different from the maximum tillage treatment.

Several other research results also had different results. Romero et al. (2021) showed that the tillage system had a positive impacts on soil quality, in which plant residues by tillage returned to the soil compared to no-tillage where plant residues were only placed on the soil surface. Li et al. (2019) also reported that the application no tillage soil had increased the ability of the soil to maintain moisture and rice productivity. However, if it is carried out continuously, it will increase large aggregates and increase biopores, ultimately causing obstacles in maintaining irrigation water, especially in vertisol soils. According to the data shown in Figure 5, under arid conditions (lowest threshold before adding irrigation water to the experimental plot), the highest moisture content was found at the no-tillage treatment, followed by minimum tillage and the lowest at maximum tillage.

In addition to soil management factors, the water supply system also plays a role in influencing plant growth and yield as well as the physical and chemical properties of vertisol. As stated by Qi et al. (2022), the effects of wetting and drying resulted an increase and shrinkage of vertisols, which would improve the land management. Therefore, according to Hamoud et al. (2019), it is critical to practice proper water management for rice cultivation on vertisol land in order to maintain soil water content and increase plant growth due to adequate air and nutrient requirements via the roots to the stems. As illustrated in Figures 4 and 5, the effecte of various land management practices on the pH value at the time of irrigation water application varied. Sufficient space can support the formation of air circulation so that a pH value that is close to neutral and optimal for plant growth and yield is formed (Figures 1, 2 & 3).

The policy of producing large amount of rice from year to year without proper land management, especially with vertisol soil types, has reduced the soil quality. Reported by Sione et al. (2017), there is a significant decrease in soil quality, especially on land with a type of montmorillonite clay, if the land contributes 80% of rice plants for one year. Land management has a significant effect on pores and soil aggregates, which affects the organic carbon of soil. The content of organic carbon in the soil significantly affects soil fertility in terms of physical, chemical, and biological soil. One of these properties functions is to maintain the stability of soil aggregates, to increase CEC (Table 2), and to be the source of energy for microbes in the soil.

The highest organic carbon content was obtained from the minimum tillage treatment. As stated by Romero et al. (2021) and Briedis et al. (2018) that the increase in carbon content in the soil increases along with the right tillage system. It is because maximum tillage makes the remaining carbon above the soil surface easier to carry to the lower soil layer. In contrast, the treatment without tillage makes the remaining organic matter take longer to decompose. De Moraes Sá et al. (2014) also emphasized that the maximum continuous tillage significantly reduced the carbon content in the soil to a depth of 0–20 cm.

The particle density value also appears to be the highest in the minimum tillage treatment (Table 2) and the bulk density value, although the value was quiet small in the range of 0.01–0.02. These results align with the research results by Malobane et al. (2021), indicating that the bulk density value without tillage was higher than conventional tillage. Previous research has emphasized both the positive and negative impacts of no-tillage and maximum tillage management. The findings of this study detailed the effects of the two types of land management with the addition of minimum tillage on differences in physical and chemical characteristics. More detailed research on a broad scale is needed in the future in order to obtain more comprehensive data.

CONCLUSIONS

Improper tillage has a detrimental impact on both plants and soil. This study indicated that most of the growth parameters, plant yields, and soil chemical physical properties improved at minimum tillage treatment, followed by no-tillage treatment and finally the maximum tillage. Optimal growth was obtained from the minimum tillage treatment followed by no-tillage. The rice yield parameter also showed the highest value in the minimum tillage treatment and was significantly different from the maximum tillage treatment. The minimum tillage also provided optimal values for the physical and chemical properties of the soil, except for the soil moisture parameter. Observations at the -15cm water table phase obtained the highest value from no-tillage, but the minimum tillage was significantly higher than the maximum tillage. Further research with a broader scale should be conducted in order to obtain more complex data. The results of this study are expected to be a reference for farmers and policymakers in managing vertisol rice fields for rice cultivation and as material for further research.

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