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Management effects of ultisol on soil physical and chemical properties as well as maize growth in oil palm replanting area

Teguh Budi Prasetyo*, **PK Dewi Hayati**

Department of Soil Science, Faculty of Agriculture, Universitas Andalas, Kampus Unand Limau Manih, Padang – 25163, Indonesia

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Abstract

This experiment was conducted at ultisol under oil palm replanting area. The objectives of this research were to study the effect of tillage and soil amelioration techniques on soil physical and chemical properties, to find the appropriate tillage system to intensify maize production, and to find out best maize variety. The experiment was conducted in Split Plots under RCB design with 3 replications. The main plot was a combination of tillage and soil amelioration techniques, *i.e.* intensive tillage (A), intensive tillage with application of lime (B), intensive tillage with application of organic matter (C), minimum tillage (D), minimum tillage with application of lime (E), minimum tillage with application of organic matter (F), and zero tillage (G). Lime and organic matter were applied at the rate of 1x exchangeable Aluminium and 10 t/ha, respectively. The sub plot was maize genotypes, *i.e.* hybrid and open pollinated varieties. Each plot consisted of four 3-meter long rows. Results revealed that combination of intensive and minimum tillage system with soil amendments improved soil permeability (41.10 – 50.14 cm h^{-1} and 13.52 – 18.52 cm h^{-1} for combination of tillage with lime application and organic matter application respectively), exchangeable aluminium, P availability and cation exchange capacity. Both responded similarly on maize plant height, cob and pod dry weight, but became better maize performance compared to zero tillage. Sukmaraga variety performed higher plant height (18.3 cm) and pod dry weight (12.9 g) than the commercial hybrid, indicating high tolerance of Sukmaraga to acid soil.

Keywords: Amelioration, Soil management, Ultisol, Tillage

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**Corresponding author email:*
teguhbudiprasetyo@agr.unand.ac.id

Introduction

Maize is one of strategic commodities that has received special attention in Indonesia due to its important position in the economy and national food security. Maize is utilized in a wide variety of products for human food, animal feed and raw materials for industry. Maize demand grew higher than its production which only grew 6% per year (Indonesia investments, 2015), thus the productivity of maize growth failed to meet the domestic demand. Efforts to increase the production of maize become a necessity in achieving national food security and also food sovereignty.

An extensification of planting area is one of the efforts in increasing maize production. However, the arable land for the extensification have problem with low productivity. Most of the soil in Indonesia is ultisol occupied around 25% of arable land in Indonesia (Subagyo et al., 2004). Most are found in Kalimantan and Sumatera islands, and are usually cultivated for rubber and oil palm plantations having good yield with proper management practices.

Ultisol is highly weathered soil with relatively low native fertility. The soil has been formed under forest vegetation (Shamshuddin and Fauziah, 2010). This acid soil has low soil pH (less than 5.5), high aluminium saturation (> 48%), low cation exchange capacity (< 24 $cmol_c$ kg^{-1}), low basic saturation (< 35%), low P concentration (< 8 ppm), low organic matter, high bulk density, slow soil permeability, and high erodibility (Prasetyo et al., 2001). These factors together with low bases cause the soil having low productivity. Due to expansion of plantations, it is estimated that ultisol usage for sustainable agriculture is increasing. Shamshuddin and Fauziah (2010) reported that the soil can be productive as well as other good soil with proper management practices. An improvement of physical and chemical properties of the ultisol can be done through the application of lime (Kisinyo et al., 2014; Shamshuddin et al., 2009), gypsum (Shamshuddin et al., 2009), organic matter and fertilizer (Shamshuddin and Fauziah, 2010).

Rubber and oil palm plantations produce good yield in ultisol. In the early years of crop age, farmers plant maize as a cash crop or inter-crop. Maize becomes a main crop cultivated by farmers in oil palm or rubber plantations that are widespread throughout Sumatera. However, maize produces unsatisfactorily yield in this soil. Low productivity and aluminium toxicity are being constraints for maize production in ultisol.

Oil palm plantations usually have undulating to hilly contour, thus management of the soil for both maize cultivation and soil conservation purposes becomes critical. Management of acid soil should be adapted to the typology of the soil. The objectives of the research were were to study the effect of tillage and soil amelioration techniques on soil physical and chemical properties, to find the appropriate tillage system to intensify maize production in oil palm replanting area, and to find out maize variety producing high yield in acid soil.

Material and Methods

Experimental design

This research was conducted in oil palm replanting area with the soil order was ultisol, in Batang Tongar, West Pasaman Regency in 2015. The area located at 0°08’59.3”N 99 ° 53’29.9’E. The altitude of the experimental area was 145 m above sea level. The experiment was carried out using split plot design with three replications. The main plot was a combination of tillage and soil amelioration techniques which consists of seven combinations of tillage and soil amelioration techniques, *i.e.* A = conventional tillage or intensive tillage system (completely ploughing), B = intensive tillage system with application of lime, C =intensive tillage system with application of organic matter (OM), D = minimum tillage (ploughing within row), E = minimum tillage with application of lime, F = minimum tillage with application of organic matter, and G = no tillage. Maize varieties that consist of a commercial hybrid and a composite Sukmaraga varieties were assigned to the subplot.

Ground magnesium limestone (GML) was applied at the rate of 1x exchangeable aluminium while organic matter (compost) was applied at the rate of 10 t/ha. The compost used was Petroganik, a granular compost which has 15-25 C/N ratio and minimum 15% C organic and the pH 4-9. Organic matter and GML treatments were applied manually before ploughing the soil to the depth of 15 to 30 cm. Soil samples were taken separately to determine the soil chemical properties from each plot three weeks after lime and organic matter application, while the samples for the physical soil properties were taken after two months.

Planting density was 0.75 m between rows and 0.25 m within rows. Each plot consisted of four 3-meter long rows, where only the two middle rows of 2.5-meter long were used as harvest area. Two seeds were sown manually, then the plants were thinned to one at 10 days after planting, therefore the final population density was 53333 plants/ha. Fertilizers were applied at the rate of 150 kg N/ha, 120 kg P_2O_5/ha and 100 kg K_2O /ha which applied as Urea, SP36 and KCl fertilizers. Plots were maintained with standard cultural practices.

Physical and chemical analysis

The physical soil properties observed were soil bulk density, total pore and soil permeability, whereas the chemical soil properties observed were the soil pH, exchangeable aluminium, availability of P, and cation exchange capacity (CEC). Chemical and physical soil properties data were compared to the soil criteria based on Hardjowigeno (2004). Regarding to plant growth, data collected were plant height, cob dry weight, and pod dry weight. Plant height were collected from a random sample of ten plants in the harvest area from each plot, while cob dry weight and pod dry weight were recorded from the whole plot harvest-area basis.

Statistical analysis

The data were subjected to the analysis of variance (ANOVA) using the General Linear Models (Proc GLM) of the Statistical Analysis System (SAS) version 9.1 (SAS/STAT®, 2003). Tukey test at 5% level was used to compare the means.

Results and Discussion

Effect of soil tillage and amelioration techniques to physical and chemical soil properties

Physical soil properties *i.e.* bulk density, total pores and soil permeability, and chemical soil properties *i.e.* pH, exchangeable Al, P availability and Cation Exchange Capacity (CEC) are presented in Table 1.

The physical properties of the ultisol showed that the soil bulk density and the total pore had similar criteria, i.e. moderate for all tillage and amelioration techniques, however soil permeability had different criteria for each tillage and amelioration techniques (Table 1). Applying organic materials intended to improve the soil structure, aeration and water holding capacity. Despite of all, soil tillage and soil amelioration application showed similar criteria for the soil structure, aeration and water holding capacity. Application of organic matter improve bulk density and total pores of ultisol. Lower bulk density and higher total pores of ultisol were achieved by organic materials compared to application of lime. Similar result was also reported by Okonkwo et al. (2011). Application of manure as organic material improved soil bulk density, total pores and water infiltration of ultisol in Nigeria.

The combination of tillage and lime or organic matter application increased soil permeability from the fast criteria into very fast. The soil permeability increased from 41.10 – 50.14 cm h^{-1} and 13.52 – 18.52 cm h^{-1} for combination of tillage techniques with lime application and combination of tillage techniques with organic matter application, respectively. It is noted that the increase of soil permeability associated with an increase of soil macro pores due to application of lime and organic matter.

The application of lime or organic matter together with intensive and minimum tillage techniques increased the soil pH and reduced aluminium in the soil solution. Application of lime may even completely limit exchangeable aluminium in the soil solution. An increase in soil pH resulting from the application of lime is higher than that resulting from the application of organic matter, *i.e.* 0.78 and 0.84 compared to 0.46 – 0.48.

Relatively similar results were reported by some scientists (Kisinyo et al., 2014; Nduwumuremyi et al., 2013; Rusyanto et al., 2017). Application of lime at the rate of 4 t ha^{-1} increased the soil pH from 4.6 to 5.5. Lime application donated a numbers of OH^- anions which increased OH^- anions in the soil solution that finally increased soil pH. According to Shamshuddin et al. (2009) and Nduwumuremyi (2013), an increase in soil pH resulting from application of lime is due to production of OH^- ions when limestone is dissolved and subsequently hydrolyzed.

Table-1: Physical and chemical properties of ultisol in West Pasaman due to soil tillage and amelioration techniques

Soil tillage and amelioration techniques	Bulk density (g cm^{-1})	Total pore (%)	Permeability (cm hr^{-1})	pH	Exc.Al ($cmol_c$ kg^{-1})	Available -P (ppm)	CEC ($cmol_c$ kg^{-1})
Intensive tillage (IT)	0.98^m	64.74^m	16.83^f	4.90	3.72	11.82	17.67
IT + lime 1 x exch.Al	0.93^m	66.50^m	54.22^{vf}	5.57	nd	15.11	19.59
IT + 10 t.ha^{-1} OM	0.90^m	66.77^m	26.64^{vf}	5.25	1.91	47.50	26.63
Minimum tillage (MT)	0.96^m	64.35^m	17.21^f	4.65	3.89	11.05	16.09
MT + lime 1 x exch.Al	0.94^m	65.67^m	63.26^{vf}	5.63	nd	17.16	20.58
MT+ 10 t.ha^{-1} OM	0.92^m	66.51^m	31.65^{vf}	5.27	2.25	41.02	23.76
No tillage (NT)	0.98^m	64.25^m	13.12^f	4.79	3.85	13.36	16.11

Note: m = moderate, f = fast, vf = very fast, nd: not detectable

The OH^- ions then react with aluminium in the soil solution to precipitate as aluminium hydroxide that may crystallized into gibbsite.

The decrease in Al resulted from combination of applying organic matter with intensive or minimum tillage systems was 1.94 and 1.71 $cmol_c$ kg^{-1}, respectively. An increase in soil pH resulted from application of organic matter was caused by declining exchangeable Al concentration in the soil solution due to binding of aluminium by organic acids in the form of complex or organo-chelation of Al. The decrease of aluminium affects in lowering donation of OH^- ions. The OH^- ions will hydrolyze Al and finally, it increases the soil pH. This is in accordance with Tang et al. (2007) and Ermadani et al. (2011) who stated that the decomposition of organic matter produces organic acids that can bind Al. It will form complex organo-Al that reduces solubility of Al, so that the soil pH increases. According to Tan (1998) organic acids, mainly fulvic and humic acids generated during the decomposition process, have a high affinity towards the Al in forming chelation.

Applying a combination between lime or organic matter and tillage techniques (intensive and minimum tillage) could improve soil availability of phosphorous. An increase of P was resulted from an organic matter application was greater than that from lime application, *i.e.* 27.66 and 34.14 ppm compared to 3.8 and 1.75 ppm for minimum tillage and intensive tillage, respectively. The higher availability of P was due to extra P contained in organic matter and P released by complex of organo-Al chelates. According to Barchia (2009) and Nunes et al., (2014), the organic matter disables P ions through organic acids which have a high ability in chelating Al. As a result, P becomes available for plant growth. An increase of P resulted from lime application was due to the release of P that was previously bound to Al by OH^- ions from hydrolised lime. Al subsequently deposited as $Al(OH)_3$.

Application of a combination of lime or organic matter and intensive as well as minimum tillage techniques improved CEC of the soil. An increase in soil CEC resulted from application of organic matter was greater than that resulted from application of lime, *i.e.* 7.65 and 10.52 compared to 4.47 and 3.48, respectively. Organic matter contains organic acids which have functional groups mainly carboxylic and phenolic which are the source of the negative charge when they dissociated (Tan, 2003; Adiaha, 2017). When soil pH increases as a result of liming or organic matter application, the CEC of the soils increases in tandem with the pH increase (Shamshuddin and Fauziah, 2010).

Effect of soil tillage and amelioration techniques to plant growth

Based on the analysis of variance, there was no interaction between combination of various soil tillage and soil amelioration techniques and varieties in all variables observed. Soil tillage techniques affected on all variables observed (Table 2). Similar result was also performed by variety. Variety used in this experiment affected on plant height, cob and pot dry weight (Table 3).

Table-2: Effect of soil tillage and soil amelioration on plant height, cob, and pod dry weight on ultisol in West Pasaman

Soil tillage and amelioration techniques	Plant height (cm)	Cob dry weight (g)	Pod dry weight (g)
Intensive tillage (IT)	88.1^{abc}	49.7^{ab}	128.0^{ab}
IT + lime 1 x exc.Al	90.8^{a}	50.3^{a}	129.4^{ab}
OT + 10 $t.ha^{-1}$OM	90.3^{ab}	58.2^{a}	137.3^{a}
Minimum tillage (MT)	68.5^{bc}	29.5^{bc}	88.6^{ab}
MT + lime 1 x exc.Al	90.6^{a}	49.5^{ab}	128.1^{ab}
MT+ 10 $t.ha^{-1}$OM	85.9^{abc}	54.3^{a}	118.9^{ab}
No tillage (NT)	68.2^{c}	24.3^{c}	75.0^{b}

Means followed by the same letter within a column are not different based on Tukey test at $\alpha_{0.05}$

Table-3: Effect of soil tillage and soil amelioration on plant height, cob, and pod dry weight on ultisol in West Pasaman

Variety	Plant height (cm)	Cob dry weight (g)	Pod dry weight (g)
Sukmaraga	92.3^{a}	45.9^{a}	121.5^{a}
Commercial hybrid	74.0^{b}	44.3^{a}	108.6^{b}

Means followed by the same letter within a column are not different based on Tukey test at $\alpha_{0.05}$

The intensive and minimum tillage as well as application of lime or organic matter provided relatively similar response on plant height, cob, and pod dry weight (Table 2). Combination of soil tillage with soil amelioration significantly improved plant height, ranging from 17.7 to 22.6 cm. The combination also performed better cob and pod dry weight compared to no tillage,

Varieties of maize planted affected plant height and pod dry weight (Table 3). A composite variety of

Sukmaraga performed a higher plant height (18.3 cm) and pod dry weight (12.9 g) compared to a commercial hybrid variety. This indicates that the variety Sukmaraga consistently showed a high tolerance to Al in acid soil while commercial hybrids usually produced high yield in optimal or fertile soils.
This result was in line with that reported by Dewi-Hayati et al. (2014) and Dewi-Hayati et al. (2015). Physiological mechanisms of maize tolerance to Al was reported as an avoidance mechanism through exudation of organic acids into the rhizosphere. These compounds are released by roots as anions (Ryan et al., 2001). Due to the negative charge associated with their carboxyl groups, they can form strong complexes with Al. Sukmaraga variety might excrete more citrate than a commercial hybrid did, as reported by Piňeros et al. (2002) and Mariano and Keltjens (2003) that Al-tolerant maize genotypes excreted more citrate than Al-sensitive genotypes.

Conclusion

Combination of intensive and minimum tillage systems with soil amendments can improve soil permeability, pH, exchangeable aluminium, available P, and cation exchange capacity of ultisol. Both intensive and minimum tillage types with application of lime and organic matter responded similarly on maize plant height, cob and pod dry weight. However, combination of soil tillage and soil amelioration revealed better maize performance compared to zero tillage. A composite variety of Sukmaraga performed higher plant height and pod dry weight than a commercial hybrid, indicating high tolerance of Sukmaraga variety to acid soil. Intensive and minimum tillage with application of lime at the rate of 1x exchangeable Al or organic matter at the rate 10 $t.ha^{-1}$ were recommended to produce a better maize growth and yield on acid soil in oil palm replanting area.

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Contribution of Authors

Prasetyo TB: Conceived idea, conducted experiment and write up of article
Hayati PKD: Helped in experiment, statistical analysis and article write up

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