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PHYSICAL CHARACTERISTICS OF ULTISOLS AND THE IMPACT ON SOIL LOSS DURING SOYBEAN (*Glycine max* Merr) CULTIVATION IN A WET TROPICAL AREA

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ABSTRACT

Physical characteristics are among soil properties affecting the susceptibility to erosion. Determination of physical characteristics of Ultisol was aimed to evaluate the dynamics of the soil properties as well as the impact on soil erosion and runoff (RO) during soybean cultivation in a wet tropical area. Soybean was planted within erosion plots (18 m^2) at 25% slope in Ultisols Limau Manis (having > 5000 mm annual rainfall).Soil samples for physical properties (soil texture, bulk density, total pore, permeability, aggregate stability,and organic carbon) as well as amount of RO and soil loss were analyzed at 5 different times (stages) during the cultivation. The results showed that there were fluctuations in physical properties of Ultisol during the cultivation. Likewise, the amount of runoff and soil loss also changed during the study. Among the physical properties analyzed, the aggregate stability index of the soil was highly correlated to the amount of RO (R^2=0.73) and soil loss (R^2=0.94). The amount of RO and soil loss was controlled by soybean development at the average rainfall intensity (≤ 36 mm/day), not at rainfall intensity (>36 mm/day). Thus, It is suggested not to open heavy clayey and low organic carbon (OC) soils for seasonal crop farming during rainy season in wet tropical areas.

Keywords: erosion, soil physical properties, soybean cultivation, runoff, ultisols

INTRODUCTION

Soil physical properties as a factor determining soil fertility not only affect land productivity but also environmental quality, especially for soils cultivated under the wet area such as West Sumatra. Ultisol is a marginal soil dominantly found in West Sumatra. However, it has been intensively cultivated for agricultural lands, lately. The soil was reported to have low aggregate stability due to high clay and low soil organic matter (SOM) (Yulnafatmawita*, et al.,* 2013). High annual rainfall (Yulnafatmawita *et al.*, 2010), combined with wavy to hilly topography in Limau Manis, caused the soil to be very susceptible to erosion, mainly if it is exposed or without any coverage.

Plant canopy gives different percentage of coverage during cultivation as well as for different crops. Seasonal crops are used to give high alteration in shading soil surface compared to perennial plants during the growth. Intensively tilled and opened soil surface before planting annual crops under high rainfall areas have caused the soil to be prone to degradation, especially at early stage of the crop growth. As plants develop, soil surface is more shaded. This means that the negative impact of kinetic energy of rainfall on soil surface reduces. Consequently, the physical properties of the soil will alter. Changes in soil physical properties will impact soil degradation. As reported by Peng and Wang (2012), vegetative cover and land use management decreased runoff and soil loss.

Soil loss or erosion both reduces soil fertility *in situ* and pollutes *ex situ* region through soil sediment and plant nutrients associated in it. The nutrient concentration carried is higher in cultivated lands. Therefore, the *in situ* soil becomes degraded, especially for low aggregate stability soils such as Ultisol Limau Manis. This Ultisol has originally low physical fertility (Yulnafatmawita *et al*, 2010, 2013) meaning highly susceptible to degradation if it is cultivated. Some scientists reported that cultivation degraded soil physical properties (Muukkonen *et al.*, 2009) and increased run off and soil loss (Girmay *et al*., 2009), while it caused cropped land to decrease (Gyssels and Poesen, 2003; Marques *et al*., 2007;Martínez-Zavala *et al*., 2008).

Cultivating soybean contributes to dynamics of soil surface coverage. At first, soil will be totally uncovered, then it becomes partly or even fully covered by the crop canopy. The coverage will depend on the stages of soybean cultivation. Therefore, the soil surface is not always exposed to rainfall. It means that the kinetic energy of the rainfall will affect differently on soil physical properties during the cultivation. How far the effect of surface land coverage during soybean cultivation on soil physical properties as well as the amount of RO and erosion is important to study under wet areas. This research was aimed to analyse some soil physical properties of Ultisol, as well as the relationship on the amount of RO and soil loss at different stages of soybean cultivation in Limau Manis Padang, a wet tropical area.

MATERIALS AND METHODS

A field experiment was conducted in Limau Manis, Padang West Sumatra from July to October 2012. The area having 25% slope is located at 100º 27' 46.5'' E, 00º 54'28.2'' S, and the altitude is ± 270 m *asl*. Soil within each erosion plot (18 m^2) was limed (for 2 x exchangeable-Al), cultivated, and then incubated for 15 days before sowing soybean seeds. Parameters such as soil texture, bulk density, total pore (TP), hydraulic conductivity (HC) rate, aggregate stability index (ASI) were analyzed according to the procedure in Klute (1986). Soil organic carbon (SOC) was analyzed using dichromate wet oxidation method, while runoff and soil loss were directly measured from erosion plots in the field. The soil samples were collected and analyzed, and RO and soil loss were measured for 5 times during soybean cultivation (or since soil was cleaned at the beginning of cultivation until 2 weeks after soybean was harvested). Data resulted were statistically analyzed using F-test, and continued using HSD at 5% level of significance if the F-calculated>F-table. Correlation between soil loss as well as runoff and the soil physical properties were analyzed.

RESULTS AND DISCUSSION

Initial Soil Properties

Based on Table 1, the physical characteristics of Ultisols in Limau Manis having 25% slopes were quite poor. Not only did the soil have too high clay content (>80%) but it also had low organic carbon (OC < 2%) content. The aggregates of clayey soils with low SOC content were reported by Yulnafatmawita *et al.* (2013) to be unstable because the bonding agent of the aggregates was mostly dominated by clay particles which are easy to disperse when they get wet. As stated by Wuddivira *et al.* (2009) that aggregate breakdown and splash detachment were significantly higher under high clay and low organic matter soils. Islam and Weil (2000) also reported that tillage causing accelerated erosion could impact in disruption of macroaggregates and loss of labile organic matter. The single clay particles after being dispersed will be suspended in water above soil surface before they are eroded if it keeps raining. As explained by Muukkonen *et al.* (2009) that disruption of aggregate structure increased the turbidity and concentration of suspended solids in the percolates, or they will be precipitated on soil surface and cause the soil pores to be clogged.

Table 1.Initial properties of Ultisols Limau Manis

Parameter	Texture			Org-C	pH	Al-exch	BD	TP	Sat.Hydr. Cond.	Aggr Stab. Index
	%-Sand	%-Silt	%-Clay	(g kg^{-1})		me/100g	kg m^{-3}	%	cm h^{-1}	
Value	15.81	2.01	82.16	18.8	5.19	1.92	12.4	53.36	0.79	0.49

The soil in this reseach area was found to have low soil aggregate stability (<0.50) and saturated hydraulic conductivity (<1 cm h^{-1}). Low aggregate stability of soil having small amount of organic matter (OM) content was also found by Zehetner and Miller (2006) under volcanic landscape which does not have active amorphous materials. These properties accelerate the process of soil erosion by water, especially if the soil is open or cultivated. The amount of rainfall during this reseach is presented in Figure 1.

Figure 1 shows that the research area was quite wet. The amount of monthly rainfall was > 100 mm (August=387.1, Sept.=580.14, and Oct.=502 mm). The average rainfall was about 40 mm/day, but it was not evenly distributed. There was an extremely high amount of rainfall when the research was conducted, that was on September 12, 2012 (186 mm/day). This extreme data following a 4-day rain consecutively altered the impact of soil physical properties on the amount of RO and soil loss under soybean cultivation in Ultisols. The dynamics of soil physical properties as well as on the impact on RO and soil loss are presented in Table 2, 3, 4 and Figure 2.

Dynamics of Soil Physical Properties

The changes of soil physical properties during soybean cultivation are presented in Table 2. It shows that among all of the soil properties (BD, TP, HC, SAS, and OC) except the texture analyzed fluctuated during the cultivation period. Soil BD decreased by 16% and 27% at stage 2 and 3, respectively compared to the 1st stage of cultivation. Then, the value of the BD increased again by 7% and 23% at the 4th and 5th, respectively, compared to the 3rd stage of soybean cultivation. Since it inversely relates to BD, the total pore of the soil reached the highest percentage at stage 3 (increase by 27% compared to initial or the 1st stage), then it decreased again approaching the value of the 1st stage at the end of cultivation.

Decreasing BD and increasing TP were probably affected by the land coverage due to the soybean canopy as well as by soil surface roughness. Gyssels *et al*. (2005) reported that vegetative cover was the most important parameter for splash and interril vegetation.

Canopy coverage on land surface was the highest during stage 3 and 4 (increase by >10 times compared to the 1st stage) and then it significantly decreased at the 5th stage (approximately the same as the 1st stage) of the soybean cultivation as the crops were harvested. High coverage of soil surface by plant canopy increased the interception of kinetic energy of rainfall; therefore, the impact on soil aggregate degradation decreased. Then, root development as crops grew helped to bind soil aggregates, creating channel for water. Consequently, the soil became more porous; more spaces within a volume unit cause decrease in BD or increase in TP of the soil. In addition to the role of fine roots in binding soil aggregates, increasing SOC (by 1.6 times) resulting from plant growth also helped to cement the soil aggregates to be more stable (by 1.5 times).

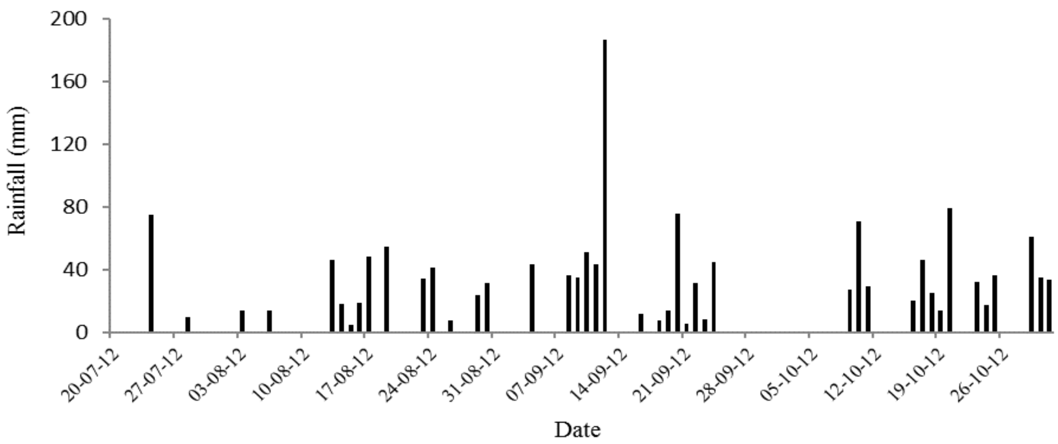

Figure 1. Rainfall distribution in Limau Manis Padang from July to October 2012

Coarser soil surface, higher TP, and more stable soil aggregates due to crop growth triggered high hydraulic conductivity rate; therefore, more rainfall was stored in the soil profile. In Table 2, the hydraulic conductivity did not linearly represent the SMC percentage in this research. The SMC seemed to be affected by both rainfall and soybean growth in which more developed crops absorbed more water. As a result, the SMC became lower, except that of the 3rd stage of soybean cultivation. Soil moisture content decreased by 7.0-18.0%, while rainfall increased by 9.5-175.0% during cultivation compared to that of the 1st stage of soybean growth. Increasing SMC at the third stage of soybean growth was mainly caused by extremely high rainfall at this stage and also due to continous rain for 3 days before taking soil samples. The effect of crop growth on some soil physical properties is presented in Figure 2.

Figure 2 shows dynamics of soil physical properties and surface coverage of soil during soybean cultivation. In general, the high coverage increased soil physical properties, except soil bulk density. High coverage by soybean canopy was followed by root development due to crop growth. Root functions to loose soil, bind aggregates, and excrete some OC known as root exudates. As a consequence, soil BD decreased, but total pore and OC content increased. These effects increased aggregate stability index, soil moisture, and soil hydraulic conductivity since OC helped to bind and stabilize soil aggregates. Stable aggregates keep pores in their shape and are able to keep the water flow constantly.

Unlike the other soil physical properties analyzed, soil moisture and aggregate stability index presented in Figure 2 showed different pattern. Soil moisture tended to decrease by crop growth, except at the 3rd stage. This might be due to the impact of crop growth. The amount of water needed is comparable to the development of the crops. On the other hand, aggregate stability index seemed to increase by time, except at the 3rd stage. This could be influenced by OC, and root function as previously explained. Unusual data for soil moisture and aggregate stability index at the third stage were very much affected by extremely high rainfall at that stage.

Runoff and Soil Loss

Amount of RO and soil loss (Table 3) decreased by 6% and 17%, respectively,while the amount of rainfall increased by 41% at the 2ndcompared to the 1st stage. This means that the kinetic energy of raindrops decreased due to increase in surface coverage (by 8.7 times) of soybean canopy as presented in Table 2. Moreover, lower RO was caused by improvement in soil physical properties as affected by root development and coarser surface soil by developed crops. Roots, besides improving macropores and aggregate stability, could guide water flow from soil surface into and within soil profile which improved hydraulic conductivity of the soil. Therefore, the amount of rainfall infiltrated to soilprofile increased. As reported by Gyssels and Poesen (2003), increase in shoot and root density decreased concentrated surface flow exponentially. Then, Ghestem *et al*. (2011) found that root architecture and the diverse traits affected the creation of root channels and consequently affect preferential flow.

Table 2. Dynamics of soil physical properties during soybean cultivation

Soil Physical Properties	Stages of soybean cultivation					P-Value
	1st = initial	2nd	3rd	4th	5th	
Soil Texture	clay	clay	clay	clay	clay	
Soil Moisture Content (%)	0.70 A	0.65 B	0.72 A	0.62 B	0.62 B	P<0.05
Soil Bulk Density (gcm^{-3})	1.24 A	1.04 AB	0.90 B	0.96 B	1.11 A	P<0.01
Total Soil Pore (%)	53.36 C	60.60 B	66.30 A	64.00 AB	58.00 BC	P<0.01
Sat. Hydraulic conduct.(cm h^{-1})	0.79 B	8.47 AB	13.00 A	3.61 B	1.91 B	P<0.01
Soil Aggregate Stability Index	0.49 B	0.56 B	0.84 A	0.63 B	0.65 B	P<0.01
Soil Org-Carbon (g kg^{-1})	18.80 B	28.70 A	29.40 A	26.80 A	21.80 B	P<0.05
Surface Coverage (%)	3.67 C	32.00 B	37.67 AB	43.33 A	2.00 C	P<0.01

Remarks: Data in row followed by different capital letters are significantly different based on HSD at 5% of significance

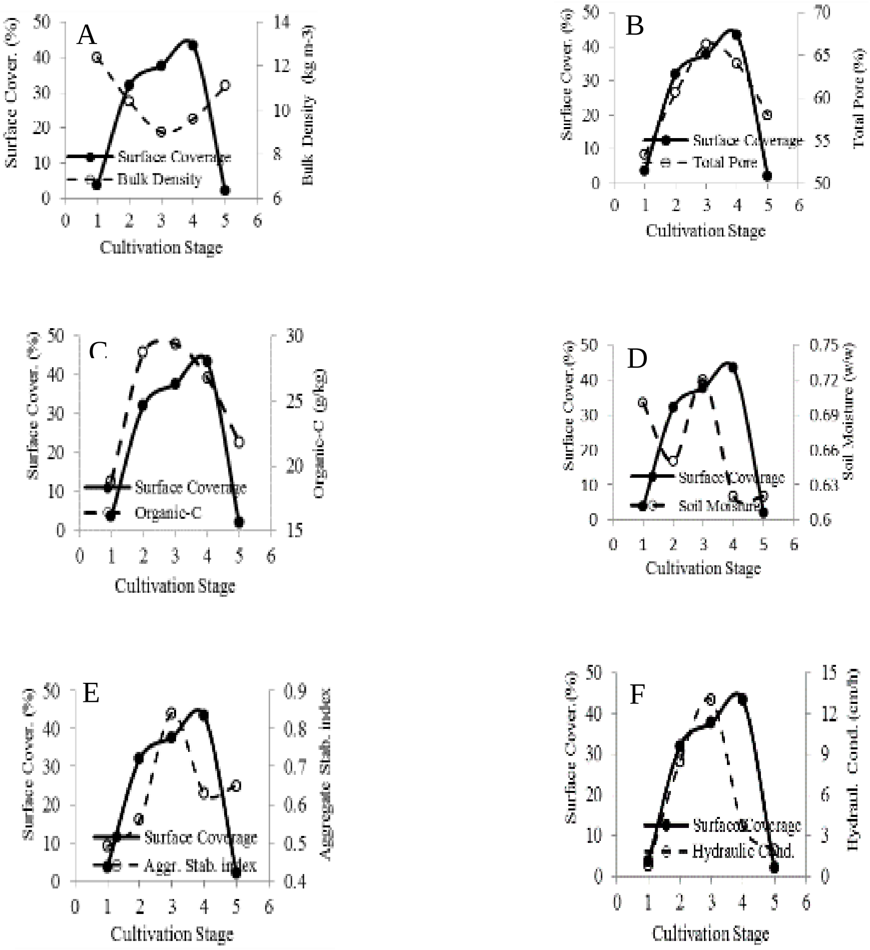

Figure 2. The effect of surface coverage on soil Bulk Density (A), Total Pore (B), Organic-C (C), Soil Moisture (D), Aggregate Stability Index (E), and Hydraulic Conductivity (F)) of Ultisol Limau Manis during soybean cultivation

Table 3. Total amount of rainfall, RO, and soil erosion during soybean cultivation

Parameter	Stages of soybean cultivation					P Value
	1st	2nd	3rd	4th	5th	
Rainfall (mm)	201.22	284.69	552.62	219.98	309.73	
RO (mm)	3.60 C	3.37 C	11.77 A	3.60 C	6.31 B	P<0.001
Soil Loss (t/ha)	0.42 C	0.35 C	5.09 A	1.17 B	1.22 B	P<0.001
RO Coeff. (%)	1.79 A	1.18 A	2.13 A	1.29 A	2.04 A	P>0.050

Remarks: Data on row followed by different capital letters are significantly different based on HSD at 5% of significance

Table 4. Relationship between rainfall and soil loss in Ultisol during soybean cultivation

Soybean Cultivation Stage	Rainfal (mm)	Rainfall Intensity (mm/day)	Soil loss		Runoff	
			Equation	R^2	Equation	R^2
1st	201.2	25.2±23.6	E = 0.8174 x + 58.141	0.11	RO=0.237 x + 4.385	0.08
2nd	284.7	35.6±14.9	E = 1.1405 x + 58.072	0.04	RO=0.170 x + 2.898	0.43
3rd	552.6	42.5±48.0	E = 3.9922 x + 311.81	0.99	RO=0.076 x + 9.456	0.80
4th	220.0	39.0±18.9	E = 2.0325 x + 113.13	0.54	RO=0.069 x + 11.408	0.03
5th	309.7	38.7±21.7	E = 2.3716 x - 17.231	0.96	RO=0.231 x + 6.626	0.35

Remarks: E = erosion (soil loss), RO = runoff, x = rainfall

Furthermore, the values of RO and erosion increased again by 227%, 178%,75% (for RO) and by 1105%,178%, and 188% (for soil loss) at the 3rd, 4th, and 5th stage, respectively, compared to the 1st one.The fact that the increase of RO and soil loss under higher percentage of surface coverage (> 10 times for the 3rd and the 4th stage) was due to increase in rainfall (by ≤9-175%). These data were against the normal condition. Generally, higher coverage of land by plant canopy decreases the amount of RO and erosion. As reported by some scientists that amount of RO and soil erosion was lower under the cropped than bare plots (Khisa *et al*.,2002; Gyssels and Poesen, 2003; Bochet *et al*., 2006; De Baets *et al*., 2007). However, different results were found in this research. The highest RO and soil loss appeared at the 3rd stage in which the surface coverage was high (>10 times). This was probably due to very high amount of rainfall within the stages regardless high surface coverage and improved soil physical properties. Very high rainfall during the last three stages causing erosion was highly affected by rainfall intensity.

During the third stage, the intensity of the rainfall was extremely high, it reached 186 mm/day (more than a half of the rainfall in the periode) with the average 42.5±48.0 mm/day (Table 4) or about 69% higher than that of the 1st stage.

Table 4 shows high correlation (R^2=0.99) between rainfall and soil loss and (0.80) between rainfall and RO at the 3rd stage of soybean cultivation. The rainfall and soil loss correlation was averagely high from the 3rd to the end of soybean cultivation. This was mainly caused by the rainy season which started in that month (September) in the area. It means that the eroded soil was highly correlated with rainfall intensity especially at the intensity ≥36 mm/day. It can be concluded that, under natural condition, plant canopy was not effective in reducing RO and erosion in Ultisols having 25% slope if the rainfall intensity >36 mm/day.

Unlike erosion, the amount of RO was not significantly affected by the rainfall intensity, except at the 3rd stage of soybean growth. At this stage, high correlation between RO and rainfall was probably due to the characteristics of the rainfall which was not evenly distributed (Figure 1). As for soil loss, the amount of RO at the 3rd stage was very much due to high average rainfall intensity (42.5±48.0mm/day). High amount of rainfall (Figure1), especially on September 12, 2012 (186 mm), caused the soil to became saturated fast or the rate of infiltration was much lower than that of rainfall. Therefore, it could be inferred that under a wet area such as in Limau Manis, the amount of RO was not significantly affected by rainfall (at ≤ 36 mm rainfall/day) except at extremely high intensity (42.5±48.0 mm/day). Cruse *et al.*(2006) reported that estimation of daily and annual spatial precipitation, runoff, and erosion illustrated a high level of spatial variability related to topography, precipitation characteristics, soils and management practices.

Table 5. Relationship between soil physical properties and Runoff as well as Soil Eroded

Soil Physical Properties vs Erosion			Soil Physical Properties vs Runoff		
OC-E	Ye= 0.260 X -0.397	R2=0.24	OC-RO	Yro=2.23 X +5.64	R2=0.05
BD-E	Ye=-1.221 X + 1.55	R2=0.52	BD-RO	Yro=-18.198 X + 30.46	R2=0.32
TP-E	Ye=0.033X - 1.735	R2=0.54	TP-RO	Yro=0.486 X -18.054	R2=0.32
HC-E	Ye= 0.031X + 0.073	R2=0.43	HC-RO	Yro= 0.226 X + 9.922	R2=0.06
ASI-E	Ye= 1.805 X - 0.889	R2=0.94	ASI-RO	Yro=30.007 X -7.811	R2=0.73

Remarks: E = erosion (soil loss), RO = runoff,Ye=calculated erosion, Yro=calculated runoff, x = soil physical properties

Based on Table 5, it can be inferred that among the analyzed physical properties, soil aggregate stability was the property of the Ultisols mostly affected either the amount of soil loss (R^2=0.94) or volume of RO (R^2 = 0.73). This was probably due to the fact that soil aggregate stability is one of soil physical properties mostly affecting runoff and soil which were eroded.

Soil having low aggregates stability will be easily degraded by rain having high kinetic energy or intensity. Therefore, the soil aggregates will become detached and even dispersed which can block soil pores, finally reduces infiltration, increases runoff and the amount of soil loss. As reported by Wuddivira *et al*. (2009) that soil having high clay with low organic matter content had higher aggregate breakdown and erosion under intense rainfall. This is found to be true that disruption of aggregated structure increased factors causing erosion (Muukkonen *et al*., 2009).

CONCLUSIONS

Based on data resulting from soybean cultivation, it can be concluded that most physical properties except texture of Ultisol under the wet area dynamically changed as crops developed. The best soil physical properties were generally found during maximum vegetative until early generative stages (on stage 3 and 4). The amount of RO and soil loss decreased (by 6% and 17%) as soil physical properties improved due to crop development on early vegetative growth (stage 2) even though the amount of precipitation increased by 41% with the rainfall intensity <36±15 mm/day). However, the effect of extreme precipitation intensity (the average ≥ 42.5±48.0mm/day) on RO and soil loss was stronger (R^2=0.80 and R^2=0.99, respectively) than that on improved soybean canopy and soil physical properties. Since maximum vegetative to the end (stage 3, 4, and 5) of soybean cultivation, the amount of RO sharply increased (by 3.27, 2.78, and 1.75 times, respectively) as well as soil loss (by11.05, 1.78, 1.88 times, respectively) compared to that of the 1st stage. Among soil physical properties analyzed, soil aggregate stability was highly correlated to the amount of RO (R^2=0.73) and soil loss (R^2=0.94). It is suggested not to cultivate heavy clay low OC soil for seasonal crop farming in a sloping area during rainy season.

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