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Effects of Tractor Mounted Mulcher Blades on the Mulching Depth of Oil Palm Fronds

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ABSTRACT

Pruning generate large amount of oil palm fronds (OPFs) waste. Mulchers are expensive and damage estate infrastructures during mulching. A tractor-mounted mulcher produced by Howard Company has not been evaluated. Three different blades were developed using Solid Works. They were compared with original blade in terms of mulching depth. Data acquisition were done at Universiti Putra Malaysia oil palm by four blades with lifting angles 60º, 90º, 120º, and 150º, two tractor PTO speeds (540 and 1000 rpm) and three tractor forward speeds (1, 3, and 5 km/h). ANOVA test in CRBD showed significance at ($P<0.05$). Tukey's Studentized Range (HSD) test showed significant difference between the means ($P<0.05$). Analysis of multiple linear regression on mulching depth showed significant results, where p = 0.0435, R^2 = 0.5792 indicating the model was significant. Based on interaction, blade with 120º lifting angle at tractor forward speed of 5 km/h and tractor PTO speed of 1000 rpm gave the best depth of mulching with mean value of 14.10 cm.

KEYWORDS

Blade lifting angles, Oil palm fronds, Tractor PTO speed, Tractor forward speed

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INTRODUCTION

The oil palm (Elaeis guineensis) is a tropical tree, known as the African oil palm found in western and central Africa and is one of two species of oil palms in the Arecaceae or palm family. As a major exporter and producer of palm oil in the world, Malaysia's current plantation area covers around 5 million hectares, which is approximately 73% of the agricultural land. In the oil palm mill, only 10% palm oil is produced and the other 90% is in the form of wastes which generates the largest amount of biomass, estimated at 80 million dry tonnes annually (Abdullah et al., 2013).

The oil palm fronds are stacked up during pruning and replanting activities. The availability of fronds during the pruning activity was computed using an estimate of 10.4 tonnes ha^{-1}, which currently gives an average of 6.97 million tonnes per annum. Meanwhile, it was assessed at an average of 54.43 million tonnes per annum of oil palm fronds will be available during the replanting process in the years of 2007 – 2020 (Haafiz et al., 2014).

Oil palm fronds and trunks are presently generating environmental burden, as their present discarding methods are hazardous. It serves as the habitat of insects, rodents, and diseases which destroys young seedlings and reduces yield and causes crop losses of 40% and 92%, respectively, as reported by Aljuboori, (2013). The objective of this paper is to compare the performance of four tractor-mounted mulcher blades with respect to the depth of mulching and recommend the best among them and the scope is on the oil palm fronds generated in the plantation farm. At present, there is limited research on mulcher implements in Malaysia.

Mulching is a technological technique during which crushed oil palm residues and shredded trunks are mulch and buried in the soil. It primarily used for crushing and pulverizing oil palm fronds residues and shredded trunks, and for destroying the inhabitant of insects and rodents, diseases, decreasing soil erosion and increasing nutrients. The technique can be applied to mulch plant biomass on farmland (Andrejs, 2006; Bayala et al., 2012; Syrový et al., 2013).

The existing possibility of mulching implements to preserve surface residue pulverization is predominately dependent on the main active part of the implement blades tilt angle and geometry (Raper, 2002). To determine the performance of two types of the agricultural implement on mulching oil palm fronds operating at two different depths of mulching during two farming seasons. It was found that disk-type implements mulch crop residue better than the Chisel-type. Operating a mulcher at a deeper depth during mulching using a disk-type reveals to have higher mulching efficiency but the level of energy consumption was higher. This disadvantage of disc type mulcher discouraged farmers from patronizing the implement.

The pulverizing operation requires ideal depth expended on the farms. Therefore, depth of mulching requirements is important in order to determine the blade-lifting angle and geometry that could be used for the tractor mounted mulcher in pulverizing oil palm fronds. The depth required for mulcher implement will also be affected by the soil conditions and the geometry of the mulcher blades (Taniguchi et al., 1999; Olatunji and Davies, 2009).

Mulcher pulverizing depths can be adjusted easily. The rotating blades cut the oil palm fronds and mix it homogeneously throughout device depth of mulching, performing beyond other tractor-mounted tools in terms of mulching (Mandal et al., 2013).

A mulching implement, especially the blade lifting angles, must mulch the soil and mix it properly with the oil palm fronds to the required degree and work the soil adequately. The energy applied to the soil by the mulching blades must be exploited efficiently in incorporating the oil palm fronds into the soil. The capacity of the mulching blade system must be high, as reported by Jones et al.,(1990). The soil parameters used to determine the performance of mulching blades are soil volume disturbed, depth of penetration of the blades and soil condition.

Variations of soil strength decrease or increase the penetration rate of the mulcher implement. When the soil is very hard or compacted, the penetration ability of the implement decreases significantly, and thereby, the whole frame of the implement is forced to be lifted. Reference (Nalavade et al., 2011) stated that disc implements, can cut through crop residues rolls over roots and other obstructions and can operate in the non-scouring soil, by using scrapers. They do not provide complete coverage of trash and are not be applicable to plantation farming. The objective of the study was to compare the performance of the four tractor-mounted mulcher blades for mulching oil palm fronds based on the depth of mulching.

MATERIALS AND METHODS

Experiments were conducted at University Putra Malaysia plantation farm to study the effects of depth of mulching on the performance of four mulcher blades. Soil profiles were categorized as sandy clay loam textures. Three factors of influence were chosen for this study; namely, the blade lifting angles at four levels (60^o, 90^o, 120^o and 150^o), as shown in Figure 1, tractor forward speed, V_0 at 3 levels (1, 3 and 5 km/h) and tractor PTO speed at two levels (540 and 1000 rpm, or 56.55 and 104.7 rad/sec), giving a total of 24 treatments. This was considered as a factorial concept fitted into a completely randomized block design (CRBD). Each test was conducted in three replications, which gave a total of 72 experimental plots. A tractor working width of 1.4 m for Howard Mulcher HM 50 was used in the study, a run length of 5 m and an applicable plot size of 7 m^2. A swath of 0.5 m width was left on the sides of each plot for wheel ways. After the mulching operations, each plot depth of mulching was measured using a specialized graduated steel ruler. ANOVA was used to analyze which treatment effects were significant and non-significant and the method of Tukey's means separation method ($\alpha < 0.05$) was deployed to determine significant differences between treatment means using statistical analysis systems (SAS 9.2) 2010 software. A mulcher implement (1.4 m) and a New Holland tractor (G240) were used, as shown in Figure 2.

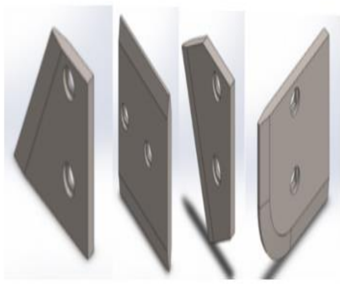

Figure 1: Blades with 60^o, 90^o, 120^o and 150^o Lifting Angles used for the Comparison

Figure 2: New Holland Tractor (G240) and Mulcher Implement used for Field Data Collection

RESULTS AND DISCUSSIONS

Analysis of Variance (ANOVA) on Effects of Blade Lifting Angles, Tractor Forward Speed, and Tractor PTO Speed on Depth of Mulching

Analysis of variance (ANOVA) was conducted to determine whether there were significant effects of blade lifting angles, tractor forward speed, and tractor PTO speed on depth of mulching of oil palm fronds on a plantation, as shown in Table I. The results of the ANOVA analysis show that there is a highly significant effect of the blade lifting angle (F=44.02, P = 0.0001 (P-value) < 0.05) on the depth of mulching. This result suggests that the difference in the geometry in blade lifting angles has a significant effect on the depth generated due to mulching, which implied that mean depths are not equal to blade lifting angle. Tractor forward speed levels during mulching operation also showed a significant effect on the depth of mulching (F=28.03, P = 0.0001 (P-value) < 0.05) showing that the higher the speed level, the deeper the mulch. This is can be concluded that at least one of the speed levels is significantly different, meaning there was a significant difference in the depth of mulching at different speed level. The tractor PTO speed that provided power for the mulching operation had a significant effect on the depth of mulching (F=7.33, P = 0.0095 (P-value) < 0.05). This implies that tractor PTO speed has a significant effect on the depth of mulching. The mean depth of mulching differs by tractor PTO speed which also showed a significant effect between blocks (F=0.02, P = 0.044 (P-value) < 0.05). This might be due to the undulating nature of the oil palm plantation.

Table 1: ANOVA on Effects of Blade Lifting Angles, Tractor Forward Speed, and Tractor PTO Speed on Depth of Mulching

Source	DF	Mean Square	F Value
Model	25	26.68	16.84**
Blade Lifting Angles	3	69.73	44.02**
Tractor Forward Speed	2	44.41	28.03**
Tractor PTO Speed	1	11.61	7.33*
Block	2	0.02	0.02*
Blade Lifting Angles*Tractor Forward Speed	6	14.47	9.13**
Blade Lifting Angles*Tractor PTO Speed	3	8.29	5.24*
Tractor Forward Speed*Tractor PTO Speed	2	45.12	28.48**
Blade Lifting Angles*Tractor Forward Speed*Tractor PTO Speed	6	25.91	16.35**
Error	46	1.58	
Corrected Total	71		

***highly significant *significant*

The interactions between blade lifting angles with tractor forward speed, blade lifting angles with tractor PTO speed as well as the combination of tractor forward speed with tractor PTO speed of the mulching operation all contributed a significant effect on depth of mulching. With level of significance (F=9.13, P = 0.0001 (P-value) < 0.05), (F=5.24, P = 0.0034 (P-value) < 0.05), and (F=28.48, P = 0.0001 (P-value) < 0.05). Revealing that all the treatment two-way combination of blade lifting angles with tractor forward speed, blade lifting angles with tractor PTO speed and tractor forward speed with tractor PTO speed have a highly significant effect on the mean depth of mulching of oil palm fronds. The interaction effect indicates that the relationship between blade lifting angles, tractor PTO Speed, and tractor forward speed with the depth of mulching depends on the blade lifting angles, tractor PTO speed and tractor forward speed. The treatment three-way interaction of blade lifting angles, tractor forward speed, and tractor PTO speed also showed the highly significant effect on the depth of mulching (F=28.48, P = 0.0001 (P-value) < 0.05). These entail that at least one of the mean depths of mulching for the combination of blade lifting angles, tractor forward speed, and tractor PTO speed is significantly different. We can conclude that there is an interaction of blade lifting angles, tractor forward speed, and tractor PTO speed in the mean depth of mulching. Analysis of variance indicating significance in the main and interaction treatment will not be enough for concluding the level of significance. Therefore, there is a need to determine where the difference lies. The level and variation in the significance level can only be resolved using the comparison of mean.

Effects of Blade Lifting Angles on Depth of Mulching

The treatment means comparison conducted on the average depth of mulching for main effects and interaction effects of blade lifting angles, tractor forward speed and tractor PTO speed on the depth of mulching is illustrated in Table 2 presents the means comparison using Tukey's means comparison for the effects of blade lifting angles on the depth of mulching. The post hoc test means separation is demonstrating that means with same letters are not significantly different. The depth of mulching mean for blades with 60° and 120° lifting angles are not significantly different, with the depth of mulching means of 15.8 and 15.5 cm deep. Similarly, depth of mulching means of 21.2 and 20.9 cm for a blade with 90° and 150° lifting angles, respectively, are not significantly different. The variation in the mean depth of mulching will also help in concluding that there has been a significant difference between blades with 60° and 90° lifting angles. Similarly, 120° and 150° blade lifting angles are significantly different. Generally, the depth of mulching with 150° blade lifting angle gave the highest depth of mulching, while the blade with 120° lifting angle gave the lowest depth of mulching. We may conclude that the blade with120° lifting angle depth could be recommended for mulching operations. The findings are in agreement with the study of Naderloo et al., (2009).

Table 2: Effects of Blade Lifting Angles on Depth of Mulching

Blade Lifting Angles, Degrees	Mean
60	17.89[a]
90	21.27[b]
120	17.51[a]
150	20.91[b]

Means having the same letters are not significantly different from the column at P<0.05 level using Tukey's test

Effects of Tractor Forward Speed on Depth of Mulching.

ANOVA results, as shown in Table 1, illustrate that tractor forward speeds of the tractor during mulching had a significant effect on the depth of mulching. This suggests that the means among the levels of speeds are not all equal, and at least one of the means is different. Table 3 shows the Tukey's means comparison method for the effects of tractor forward speeds (1, 3, and 5 km/h) on the depth of mulching. The depth of mulching means with same letters are not significantly different. It shows that depth of mulching with tractor forward speeds of 1 and 3 km/h are not significantly different with means of 18.7 and 18.4 cm, while depth of mulching at tractor forward speed of 5 km/h is significantly different from the means of depth of mulching at tractor forward speeds of 1 and 3 km/h. We can conclude that the higher the tractor forward speed during mulching the deeper the mulching of the oil palm fronds with soil. The same trend of the effect of depth of mulching on soil disturbance was reported by Makange and Tiwari, (2015).

Table 3: Effects of Tractor Forward Speed on Depth of Mulching

Tractor Forward Speed, km/h	Mean
1	18.75[a]
3	18.48[a]
5	20.96[b]

Means having the same letters are not significantly different from the column at P<0.05 level using Tukey's test

Effects of Tractor PTO Speed on Depth of Mulching

Power required for mulching was supply by the tractor PTO speed and had a significant effect on the depth of mulching. ANOVA results have indicated that there is a significant difference in depth of mulching at different tractor PTO speeds. Tukey's means comparison conducted showed that means with same letters are significantly different; Table 4 shows that there was a significant difference between tractor PTO speed of 540 and 1000 rpm in the depth of mulching indicating that the depth of mulching varies with tractor PTO speeds. The tractor PTO speed of 1000 rpm with 19.8 cm depth was higher than the 540-rpm depth at 18.9 cm. We can conclude that the higher the tractor PTO speed the deeper the depth of mulching.

Table 0: Effects of Tractor PTO Speed on Depth of Mulching

Tractor PTO Speed, rpm	Mean
540	18.99[a]
1000	19.78[b]

Means having the same letters are not significantly different from the column at P<0.05 level using Tukey's test.

Effects of Blade Lifting Angles and Tractor Forward Speed on Depth of Mulching

The effect of blade lifting angles and tractor forward speed on the depth of mulching has indicated that at least one of the means of the depth of mulching is significantly different. Table 5 presents that blade with 60° lifting angle did not show any significant difference. We can establish that at tractor forward speed of either 1, 3 or 5 km/h has no any effect on the depth of mulching with mean depths of 18.0, 17.4 and 18.1 cm. Similarly, blade with 90° lifting angle did not indicate any significant difference in the level of tractor forward speed because the mean of the depth of mulching is significantly the same having mean depths of 21.5, 20.6, and 21.5 cm, respectively.

The average depths of mulching in the blade with 120° lifting angle among speed levels has indicated no significant difference in the tractor forward speed levels of 1 and 3 km/h with mean values of 16.9 and 16.6 cm, but there was a significant difference between depth of mulching with tractor forward speed of 5 km/h with an average mean of 19.1 cm. The blade with 150° lifting angle has indicated a significant difference within the tractor forward speeds level; there was a significant difference between tractor forward speed of 5 km/h with 1 and 3 km/h with an average depth of 24.9 cm with 18.6 and 19.1 cm. This confirmed the study by Perdok and Kouwenhoven (1994) that the faster the tractor forward speed, the more intensive the blade action.

Table 5: Effects of Blade Lifting Angles and Tractor Forward Speed on Depth of Mulching

	Blade Lifting Angles, Degrees			
Tractor Forward Speed, km/h	60	90	120	150
1	18.09[ab]	21.55[d]	16.70[ab]	18.65[abc]
3	17.42[ab]	20.68[cd]	16.65[a]	19.17[bcd]
5	18.16[ab]	21.57[d]	19.19[bcd]	24.92[e]

Means having the same letters are not significantly different from the column at P<0.05 level using Tukey's test.

Effects of Blade Lifting Angles and Tractor PTO Speed on Depth of Mulching

Blade lifting angles with tractor PTO speed combination demonstrated a significant difference in the depth of mulching as shown in Table 6. Blade with 60° lifting angle with both tractor PTO speeds 540 and 1000 rpm had no significant difference in depth of mulching with depths of 18.4 and 17.3 cm. Blade with 90° lifting angle did not show any significant difference in average depth of mulching with a tractor PTO speeds of 540 and 1000 rpm. Similarly, blade with 120° lifting angle at tractor PTO speeds 540 and 1000 rpm illustrated the non-significant difference with average depths of 20.7 and 21.7 cm respectively. The blade with 120° lifting angle indicated that there was no significant difference among different tractor PTO speed levels with a recorded average means of 16.8 and 18.1 cm respectively. The blade with 150°

lifting angle established a clear significant difference in mean depth of mulching at tractor PTO speeds of 540 and 1000 rpm with averages of 19.9 and 21.9 cm, respectively. The average tractor PTO speed on mulching oil palm fronds has increased with the increase of the depth level as reported by Naderloo et al., (2009).

Table 6: Effect of Blade Lifting Angles and Tractor PTO Speed on Depth of Mulching

	Blade Lifting Angles, Degrees			
Tractor PTO Speed, rpm	60	90	120	150
40	18.46^{ab}	20.76^{cd}	16.84^{a}	19.91^{bc}
1000	17.32^{a}	21.78^{cd}	18.18^{ab}	21.91^{d}

Means having the same letters are not significantly different from the column at P<0.05 level using Tukey's test.

Effects of Tractor Forward Speed and Tractor PTO Speed on Depth of Mulching

Table 7 presents the Tukey's mean comparison for the effects of tractor forward speed and tractor PTO speed on the depth of mulching. Tractor PTO speed of 540 and 1000 rpm has not shown any significant difference at 1 and 3 km/h. This shows that the tractor forward speed and tractor PTO speed did not show any difference in depth of mulching. The 540 and 1000-rpm tractor PTO speed interaction with tractor forward speed of 1 km/h having depth mean values of 18.9 and 18.5 cm. Similarly, the tractor PTO speed of 540 and 1000 rpm with a tractor forward speed of 3km/h shows no significant difference with average depths of mulching of 19.0 and 17.9 cm. The 5 km/h interaction with tractor PTO speed of 500 and 1000 rpm, which has indicated a significant difference with an average depth of mulching 18.9 and 22.9 cm. Since there was no any significant difference between 1 and 3 km/h at tractor PTO speed of 1000 rpm. We can conclude that tractor forward speed and tractor PTO speed combination has no significant effect in determining the depth of mulching of mulching oil palm fronds in field operation.

Table 7: Effect of Tractor Forward Speed and Tractor PTO Speed on Depth of Mulching

	Tractor PTO Speed, rpm	
Tractor Forward Speed, km/h	540	1000
1	18.95^{a}	18.54^{a}
3	19.04^{a}	17.92^{a}
5	18.99^{a}	22.93^{b}

Means having the same letters are not significantly different from the column at P<0.05 level using Tukey's test.

Effects of Blade lifting Angles, Tractor Forward Speed and Tractor PTO Speed on Depth of Mulching

Analysis of variance depicted that the effect of blade lifting angles, tractor forward speeds and tractor PTO speed on the depth of mulching has a significant (P<0.05) effect. The mean separation using Turkey's method has shown that mean depth of mulching with same letters is not significantly different, illustrated in Table 8. The combination of tractor PTO speed 540 rpm and tractor forward speed 1km/h, blades with 60^{o}, 90^{o} and 150^{o} lifting angles did not show a significant difference, with averages of 21.3, 20.2, and 19.0 cm respectively. There was a significant difference between blade with 120^{o} lifting angle with a mean depth of mulching of 15.1cm and the other blades with (60^{o}, 90^{o}, and 150^{o}) lifting angles. At tractor PTO speed of 540 rpm, and 3 m/h blade with 60^{o}, 90^{o} and 120^{o} lifting angles are not significantly different, with the mean depth of mulching of 18.9, 20.8, and 19.1 cm respectively. Although, blades with 150^{o} and 120^{o} lifting angles are not significantly different with the depth of mulching for a blade with 150^{o} to be 17.3 cm. Similarly, 5km/h tractor forward speed at 540 rpm tractor PTO speed, blades with 60^{o} and 120^{o} are not significantly different at depths of mulching of 15.0 and 16.2cm while blades with 90^{o} and 150^{o} lifting angles are not significantly different with a recorded depth of mulching averages of 21.1 and 23.4

cm. The interaction between tractors forward speed of 1km/h with tractor PTO speed of 1000 rpm indicated that blade with 90° lifting angle is significantly different from blades with 60°, 120° and 150° lifting angles, with an average of 22.8 cm. The blades with 60°, 120° and 150° lifting angles with means of 14.8, 18.2, and 18.2 cm are significantly the same. Tractor PTO speed of 1000 rpm and at tractor forward speed of 3km/h, blade with 120° lifting angle is significantly different from the blade with 150° lifting angle with means of 14.2 and 21.0 cm, while blades with 60° and 90° lifting angles are not significant. Lastly, at tractor PTO speed of 1000 rpm and tractor forward speed of 5 km/h blades with 60°, 90° and 120° lifting angles are not significantly different with averages of 21.2, 21.9, and 22 cm respectively. The blade with 150° lifting angle is significantly different having a mean depth of mulching 26.4 cm.

Table 8: Effect of Blade Lifting Angles, Tractor Forward Speed and Tractor PTO Speed on Depth of Mulching

		540 rpm			1000 rpm		
Depth of Mulching, cm		1	3	5	1	3	5
Blade Lifting Angles, Degrees	60	21.35^{fgh}	18.93^{defgh}	15.09^{abc}	14.83^{ab}	15.91^{abcd}	21.22^{efgh}
	90	20.25^{efgh}	20.85^{efgh}	21.18^{efgh}	22.86^{ghi}	20.52^{befgh}	21.95^{fgh}
	120	15.17^{abcd}	19.10^{defg}	16.25^{abcd}	18.22^{bcdef}	14.20^{a}	22.13^{fgh}
	150	19.02^{cdefg}	17.30^{abcde}	23.42^{hi}	18.27^{bcdef}	21.04^{efgh}	26.41^{i}

Means having the same letters are not significantly different from the column at P<0.05 level using Tukey's test.

Linear Regression on the Effects of Blade Lifting Angles, Tractor Forward Speed and Tractor PTO Speed on Depth of Mulching

Multiple linear regressions were conducted to assess whether blade-lifting angles, tractor forward speed, and tractor PTO speed significantly predicted the depth of mulching. The results of the multiple linear regression models were significant, $p = 0.0435$, $R^2 = 0.5792$ as shown in Table 9, and the linear prediction equation with its coefficient in Equation (1) indicating that approximately 57% of the variance in depth of mulching is explainable by blade lifting angles, tractor forward speed and tractor PTO speed. Blade lifting angles was not a significant predictor of depth of mulching $t = 0.193$, $p = 0.847$ from Table 10. Based on this sample, change in blade lifting-angle did not have a significant effect on depth of mulching. Tractor forward speed significantly predicted the depth of mulching $t = 2.4713$, $p = 0.0167$. This indicates that on average changing the tractor forward speed during mulching of oil palm fronds will predict the depth of mulching. Tractor PTO speed was a significant predictor of depth of mulching, $t = 2.099$, $p = 0.044$. This is suggesting that the change in tractor PTO speed level will predict the depth of mulching operation in an oil palm plantation.

Table 9: Linear Regression Model Summary

Model	Sig. F	R^2	Adj. R^2
Linear	0.0235	0.5794	0.5103

$$\text{DMulching} = 14.53 + 0.018\text{Bt} - 0.55\text{Fs} - 0.022\text{PTOS} \tag{1}$$

Where;

DMulching = depth of mulching
Bt = blade lifting angles
Fs = tractor forward speed
PTOS = tractor PTO speed

Table 10: Linear Regression Coefficients

Variables	Coefficients	t Stat	P-value
Intercept	14.583	3.298	0.002
Blade	0.018	0.193	0.847
FS	0.553	2.471	0.016
PTO	0.022	2.099	0.044

Bt.- Blade Lifting Angles, FS.- Forward Speed, PTOS. – PTO Speed

CONCLUSION

Tractor mounted mulcher blade was found to be suitable for mulching oil palm fronds at different depths of mulching. Based on the results presented above, the blade lifting angles, tractor forward speed and tractor PTO speed combinations show significant effects on the depth of mulching with a blade with 120^o lifting angle giving a minimum depth of mulching at tractor forward speed of 5km/h. In conclusion, the blade lifting angles and tractor forward speed can be select for proper depth of mulching while mulching oil palm fronds. The predicted model was used to predict the depth of mulching for similar design and mode of mulching of oil palm fronds during replanting operation and subsequent field upkeep and access operations.

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