Effects of degree of oil palm frond mulching using tractor mounted mulcher blades

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Abstract

This study investigates the influence of blade lifting angles, tractor forward speed, and tractor power take off (PTO) speed on the degree of mulching. Four blades with different lifting angles, two tractor PTO speeds, and three tractor forward speeds were assessed using the parametric test at the Universiti Putra Malaysia oil palm plantation. The result shows that the best-fit regression equation was a quadratic regression with a high coefficient of determination. It indicates that any change in this three-factor interaction has a significant effect using Tukey's Studentized mean comparison and can predict the degree of mulching. Seventy-four percent of the degree of mulching variance is explained by blade lifting angles, tractor forward speed, and tractor PTO speed. Since the blade lifting angle was a major predictor of the degree of mulching, this result implies that any change in the blade lifting angle can provide a significant prediction of the degree of mulching in an oil palm plantation. Additionally, the predicted model can further be used to predict the degree of mulching during field operations, replanting, and access for mulching of oil palm fronds. A detailed field evaluation of the performance of a tractor-mounted mulcher with different blade lifting angles in other parts of Malaysia is highly recommended to cater for the differences in soil moisture content and bulk density.

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See online Appendix for additional Figures.

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Introduction

Mulching is a sequence of operations intended to cut and mix the soil and the dry oil palm fronds during replanting. The oil palm fronds and oil palm trunks are preferably scattered or windrowed for the vertically operated steel mulcher blade to penetrate 20 cm below the skid/tyre cut and mulch the fronds and trunks. Before mulching it is generally recommended to wait 2-3 months for the felled or pruned oil palm fronds to dry (Pandey, 2004). The oil palm fronds and trunks are cut to the desired degree by a mulching tool, in particular by its blade system, then mixed well with the soil and adequately manipulated during replanting. These are relevant parameters for determining energy efficiency requirements in the implement (Godwin, 2007). For soil mulching the force required to drag the mulcher blades into the soil is the criterion used to measure blade suitability (Arvidsson *et al.,* 2004; Olatunji and Davies, 2009). The primary feature related to the nature and application of soil mulching blades is the relationship between the mulching implement and the soil (Shen and Kushwaha, 1998). The mulching blade's geometry and soil conditions influence the force required for each given implement. Therefore, the combination of soil-tool-mulching and blade geometry should be studied to evaluate blade performance. The energy applied by the mulching blades to the soil must be efficiently exploited by incorporating the oil palm fronds into the soil. The power requirement per soil unit mulched with the fronds of the oil palm must be low. The mulching blade system capacity should be high, as reported by Yovel *et al*. (2008). The soil parameters used to determine mulching blade performance are blade penetration depth and soil conditions.

In many parts of the world, mulching is commonly used in fields, orchards, forests, and landscapes (Kader *et al.,* 2017). In general, it reduces weed competition, maintains soil temperature and decreases soil evaporation (Zhao *et al.,* 2014). It protects the soil from erosion due to wind, water and traffic. Furthermore, mulching suppresses renegade dust from the soil (Chalker-Scott, 2007). It also improves soil properties by enhancing moisture retention efficiency, releasing various nutrients and boosting biological activities (Pinamonti, 1998).

Mulching is a technological process during which residues of crushed plants are left on the surface. It is used primarily for cutting and crushing residues of green plants, old grass on permanent grasslands, and treat fallow lands. Mulching on arable land can also be used to crush crop residues (Andrejs, 2006; Mayer and Vlášková, 2007; Syrový *et al.,* 2013).

The specialized activity of mechanical mulching oil palm fronds and trunks is taking on a new positive dimension in Malaysia, as researchers are now considering this process instead of other approaches by implementing soil-engaging implements and tractive tools. This has become relevant in the light of more reliable and sustainable global developments as well as new emerging technologies and ideas (Awalludin *et al.,* 2015). It has also been stated that the implementation of chemical and biological waste oil palm residue management in Malaysia is still not adequate to eliminate the residues (Intara *et al.,* 2013) and that the number of tractors and equipment does not balance the costs associated with these two approaches (Farooq *et al.,* 2011). However, these problems were due to the lack of appropriate data for the proper design of agricultural machinery and equipment (tractor mounted mulcher) and the inadequacy of certain imported forest mulchers. We hope that the best tractor-mounted mulcher blade will be obtained based on the degree of mulching oil palm fronds that is our research objective.

Materials and methods

Experimental design

Experiments were conducted to study the effects of the degree of mulching on the performance of four mulcher blades at the Universiti Putra Malaysia oil palm plantation. Soil profiles were classified as textures of sandy clay loam. For this analysis, three determining factors were chosen: the lifting angles of the blade at four degrees (0^o, 60^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^{-1}) and tractor PTO speed at two levels (540 and 1000 rpm, or 56.55 and 104.7 rad/s), which lead to 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 as shown in Appendix Figure 1. In the experiments, a tractor with a working width of 1.4 m coupled with a "HM50" mulcher (by Howard, Rawang, Selangor - Malaysia, www.howardmy.com) was used. The running length was 5 m and the plot size was 7 m^2. A 0.5 m-wide swath was left on each side of the plot for wheeling. ANOVA was used to analyze the significant and non-significant treatment effects and Tukey's means separation method (α<0.05) was adopted to identify significant differences among treatment means using statistical analysis systems, such as (SAS 9.2) 2010 software. A mulcher implement (1.4 m) and a New Holland tractor (G240) were used, as shown in Appendix Figure 2.

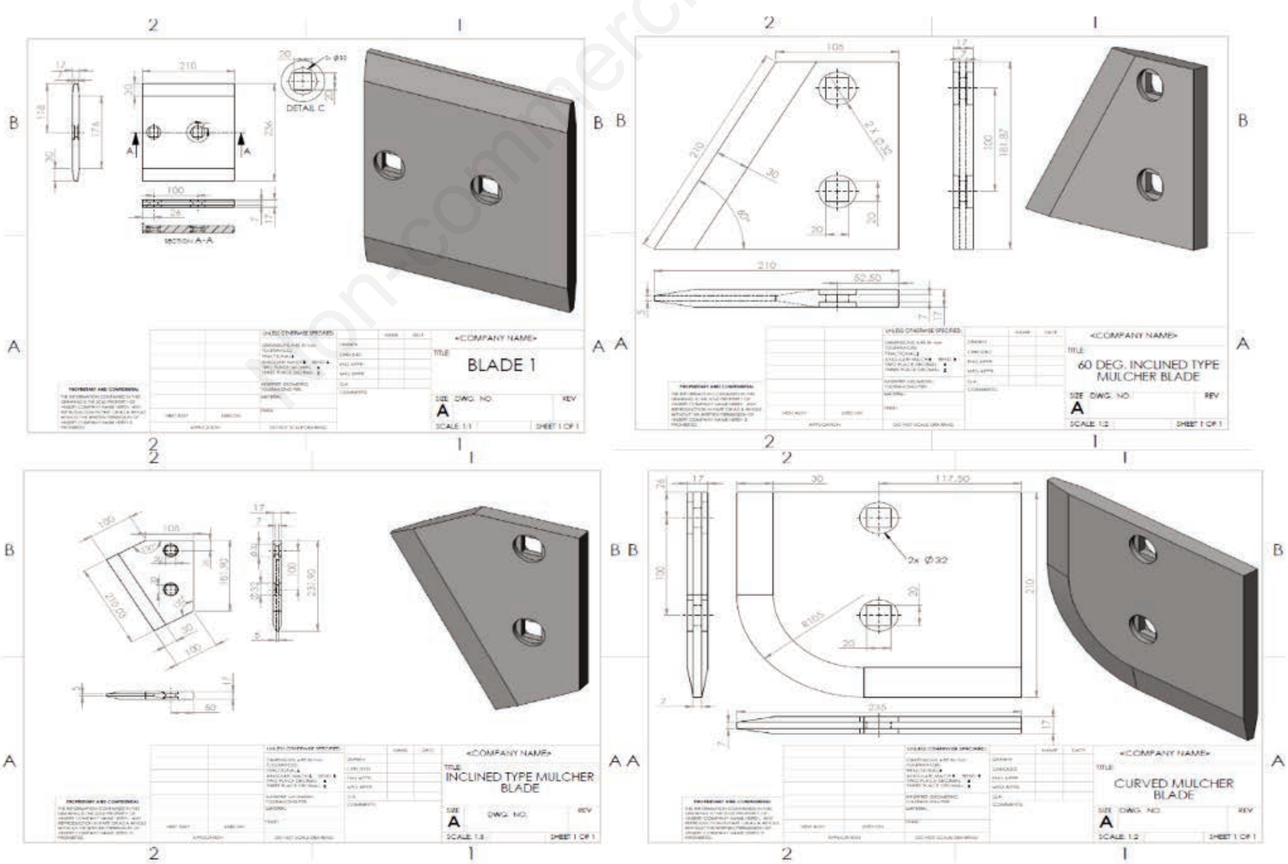

Figure 1. Orthographic and 3D model mulcher blades with 0°, 60°, 120° and 150° lifting angles.

Field experimental procedure

The forward tractor speeds used in the mulching operations were 1, 3, and 5 km. h^{-1}. Such forward speeds were achieved by changing the engine throttle at the minimum engine speed and by setting three different tractor forward speeds as reported by Raghavendra and Yadahalli (2018). The tractor PTO gear is generally changed in the first or second gear (540 or 1000 rpm) for mulching during the replanting period. The tractor operator would adjust the mulching pitch of a tractor-mounted mulcher by controlling precisely the tractor forward speed to meet the mulching and field performance assessment needs (Jahun, 2018). It is recommended that the PTO rotational speed is adjusted continuously in order to increase mulching efficiency, while making the mulching field performance assessment. Our aim was to explore the advantage of tractor's PTO shaft's variable rotational speed. These targeted speeds were obtained by tractor operation at PTO speeds of 540 and 1000 rpm and gearbox position adjustment. The mulcher blades were changed at every set of operations, as shown in Appendix Figure 3.

Physical and mechanical characteristics of palm fibres

Originally, oil palm plant (Elaeis guineensis) was from the tropics of Western Africa. The crop was brought from Singapore Botanical Gardens to Malaysia in 1870 as decorative plant. The tree was planted in palm estates on a large scale, then its commercial value was recognized. The oil palm belongs to the species Elaeis guineensis belonging to the family of Palmaceae (Owolarafe *et al*., 2007). Large plantations generate a huge amount of biomass waste, such as oil palm trunks, fronds, empty fruit bunches and leaves left in the plantation area, which are not often properly managed. Among all of this biomass, oil palm fronds are the major waste generated in the plantation area. The oil palm frond (OPF) are obtained during pruning to harvest fresh fruit bunch and become available daily throughout the year (Noor *et al.*, 2016). Morphologically, the properties of the oil palm fronds differ depending on the frond body and also its age. A fundamental study on the properties of oil palm fronds and trunk was carried out differentiating the parenchyma and vascular bundles. It was found that cell distribution and moisture content varied between the inner, middle and outer parts of the oil palm fronds and trunks, because of the different ratios of parenchyma and vascular bundles in each of these parts (Muhammad *et al.,* 2012). However, technology improvement for mulching oil palm fronds and trunks requires accurate information on both the physical and mechanical properties of Elaeis guineensis. The efficiency of these unit operations (mulching) rely on the mechanical behaviour of oil palm fronds and trunks under pulverization, since they require the use of energy (Raji and Favier, 2004).

In order for many operations, oil palm fronds have physical and mechanical properties. These properties are very important prior to mulching operations. Dungani *et al.* (2018) investigated the physical, mechanical and chemical properties of various oil palm waste to assess its suitability to various applications.

Useful information on OPF properties is important for testing new fibers for blade design. Depending on their properties, OPF fibers tend to have a distributed strength. Based on the measurement of tensile strength from the peak force ratio and the cross-sectional area on a perpendicular plane or at the fracture point, a single OPF fiber strength test was run and Young's modulus from the tensile strain curve liner segment was calculated (Nasrin *et al.,* 2008). Based on the percentage of amorphous and crystalline substances and also organic compounds (Sreekala *et al.,* 2000), the mechanical behavior of natural OPF fibre was determined.

The characteristics/conditions of the oil palm fronds were extracted from the above-mentioned analysis. Table 1 describes the physical properties of palm fiber components compared with other sources. The tensile strength and the modulus are mechanical properties that characterize the fibre main structure. If the cellulose content increases, generally the tensile strength and Young's modulus of palm fibers increases too, as reported by Aji *et al*. (2009).

Srivaro *et al*. (2018) stated that the modulus of resistance (MOR) and modulus of elongation (MOE) of oil palm fronds in relation to the fraction of fibers range from 7 to 58 MPa for MOR, 0.5-7.0 GPa for MOE, respectively. All test specimens failed due to the bottom face fracture caused by the tensile stress in the bottom face, which exceeded the tensile strength in the fiber direction of both species (*Elaeis guneensis*). It was observed that an increasing fraction of fibers significantly increased both values of oil palm fronds, thus indicating that fibers play an important role in both values of oil palm fronds. Table 2 shows the mechanical properties of OPF and the physical properties of palm biomass fibres.

Table 1. Physical properties of oil palm biomass fibres.

Fibre	Fibre length (mm)	Fibre diameter (m)	Lumen widths (m)	Density (g/cm^3)	Fabril angle (o)	References
Oil palm frond	0.80-142	8-300	8	0.7-1.55	46	Husin *et al*., 1987; Sreekala *et al*., 2000; Bismarck *et al*., 2005
Oil palm frond	0.59-159	11-19.7	8.20-11.66	0.6-1.2	40	Husin *et al*., 1987; Bismarck *et al*., 2005; Kalam *et al*., 2005
Oil palm trunk	0.60-122	29.6-35.3	17.60	0.5-1.1	42	Husin *et al*., 1987; Kalam *et al*., 2005; Mickvoski *et al*., 2009; Ahmad *et al*., 2010 Source: Sreekala *et al*., 2000

Table 2. Mechanical properties of oil palm frond.

Fibres	Tensile strength (MPa)	Young's modulus (GPa)	Elongation at break (%)	References
Oil palm fresh fruits bunch	50-400	0.57-9	2.5-18	Sreekala *et al*., 2000; Bismarck *et al*., 2005; Bakar *et al*., 2006
Oil palm fronds	20-200	2-8	3-16	Lab sources
Oil palm trunk	300-600	8-45	5-25	Bakar *et al*., 2006

Source: Sreekala *et al.*, 2000.

Tensile strength, elongation and fiber elasticity module are mechanical properties obtained in accordance with ASTM C1557 standards. For each factor setting as defined by Sreekala *et al*. (2000), five fiber tensile test lengths were tested at 100 mm in a Tinius Olsen machine at a cross-head speed of 8×10-6 m/min.

Procedure for processing of samples prior to and after mulching

The soil moisture content, bulk density, soil vane shear strength and relative humidity properties were taken at a soil depth of 20 cm at the start of rainfall (November 2016). The average results were 40.53 percent, 1.5 g/cm^3, 30.94 kPa, and 70 percent respectively.

The amounts of oil palm fronds on a field were calculated and weighed by collecting the material from a known location. 11 $t.ha^{-1}$ of pruned oil palm fronds were required as ground cover for each hectare of pruned oil palm fronds. Factors such as weather conditions, disease and insects throughout the growing season could cause this amount to vary (Henson *et al.,* 2012).

The quantity of oil palm fronds needed to protect the soil against erosion, rodent and insects inhabitants, such as Rhinoceros Beetle, depends on how the oil palm fronds are mulched into the soil and time as well as the anchorage and durability of the oil palm fronds. During the experiment, 3 $t.ha^{-1}$ of oil palm fronds were used based on the study conducted by Wilhelm *et al.* (2007).

In the experimental design plots for analyzing the moisture content, samples of oil palm fronds were collected at random on the day of mulching before operations began. The samples were immediately put in plastic bags and taken to the weighing and oven drying laboratory, where they were kept at 105°C for 24 hours. The next day, reweighing was performed to obtain the average moisture content of the fronds of oil palms. An estimated volume of 33,750 cm^3 of soil (25 by 25 cm and 5 cm depth) was scooped randomly from the top of the soil in nine points in each experimental plot using a quadrant as shown in Appendix Figure 4. The experimental layout for sampling is shown in Appendix Figure 5.

Effects of mulcher blades geometry on mulching oil palm fronds

When a mulching operation is performed with a rotary mulcher implement in the field, the soil texture will be a function of soil conditions, blade geometry, blade kinematics, amount of oil palm residues available and soil flow dynamics. As the blades of a rotary mulcher rotate, each point on a given blade traces a trochoidal path in the soil. In the forward part of the trochoidal path, the blade will cut or fracture untilled soil together with oil palm fronds and in the return part of the trochoid, the blade will tend to mix the cut oil palm fronds and pulverize soil slices (Mandal *et al.,* 2013).

According to Celik *et al.* (2008), the working tools of the rotary machine executes a complex motion consisting of a relative rotary motion around the axis of the cutter drum with a velocity and forward motion with a velocity of V_t, as shown in Appendix Figure 6.

They calculated the height of the ridges at the bottom of the rotary blade which are formed by subsequent soil slices, as shown in Appendix Figure 7. They also reported that in order to obtain a smoother bottom of the tillage layer, however, the ridge height can be decreased by increasing the blade rotational speed, while maintaining a constant forward velocity.

The matrix equations for describing the motion of the blade of the rotary tiller were described by Mandal *et al*. (2013). These equations were used for the graphical representation of an arbitrary blade cross-section to show the relative motion of the blade with respect to the trichoidal path of the cutting edge. This method was used to study the effects of changes in rotor and translational velocities and in blade orientation angles.

It was also reported that the shape of the rotary blade is an important factor that influences its power requirement, torque characteristic and specific energy requirement.

He assumed such re-tillage to be the main source of high energy consumption associated with deep rotary tillage. From these observations, Shibusawa hypothesized that significant reductions in energy and power requirements for deep tilling rotary tiller can be achieved, if re-tillage could be avoided.

Procedure for sieving mulched oil palm fronds

The test procedure followed was the BS 1377 Standard described by Osborne *et al*. (2014). In the laboratory, the soil/oil palm fronds were collected from the mulched field and laid out on a polythene plastic sheet and left to air-dry. A polythene plastic sheet was also used to cover the samples to avoid contamination. Dry times varied, as they depended on how wet the samples were at the time of harvesting and the humidity in the environment. Aggregations or lumps were then broken down thoroughly with fingers, or with mortar and pestle, in order to ensure that the sample of mulched soil consisted mainly of individual particles. During the first few days of drying, the procedure was repeated, but without trying to break the soil apart. Air-dried mulched samples were dried within 4 days. The process below was followed: i) a subset of three to five mulched soil samples from the various treatments was air-dried and weighed; ii) these samples of mulched soil were left to air-dry by incubating them overnight (at least 8 hours); and iii) the mulched soil samples were weighed again and compared with previous weights.

At this level, dry mulched soil was weighed for a total mulched soil weight (WT) which was the sum of the weights used for the WT value in each aggregate size class. Each air-dried mulched soil sample was slightly emptied and sieved with a panel sieve size close to the size class of the largest scale aggregates. The mulched soil sample was added to the sieve until the entire sample was used. Mechanical sieve shaker with measuring range *: 25 μm-125 mm, sieve motion: angular motion -3D motion, amplitude: digital, 0->2 mm, suitable sieve diameter: 400 mm/450 mm were the specifications used. A product of RETSCH UK Ltd laboratory mills, a leading solution provider for neutral-to-analysis sample preparation and characterization of solids produces the equipment. This tool is an electric motorized portable sieve shaker that uses a rapid vertical motion to screen the mulched sample of soil. This rapid vertical movement also helps clear the openings. The mechanical sieve shaking was completed in twenty (20) minutes to sieve the mulched soil samples, as shown in Appendix Figure 8. The degree of mulching was obtained using mechanical rotary sieve shaker to separate mixture of (soil/oil palm fronds and trunks) which passed from the sieve mesh of 10 mm to the total weight of all mulched oil palm fronds produced.

The 10 mm sieve choice was based on measurement of combined size spread and aggregate solidity using enclosed sieve technique and was used to examine aggregate spreading as reported by Ping, Sung, Joo, and Moradi (2012). The results obtained show that no significant difference was detected at depths of 15-30 cm due to the regular decomposition and density of the organic matter in the top cover of the soil.

Sieved mulched soil aggregates were collected in a plastic bag from the top of the sieve screen for storage. The process was repeated with more material passing through the screen until the aggregate size classes of interest were collected.

To determine the degree of mulching (Eqs. 1 and 2) were used as shown below:

$$\eta_p = \frac{\text{Quantity of material passing through a specified sieve}}{\text{Quantity of mulched material}} \times 100 \quad (1)$$

$$\eta_p = \frac{Q_{Ni}}{Q_T} \times 100, [\%] \quad (2)$$

Where

Q_{Ni} = quantity of materials passing through the *i*th sieve, i= 1, 2, 3 … n

Q_T = total quantity of material mulched per plot, g

After the sieve analysis, each sieved sample sizes for four different blades are as shown in Figure 2.

All average recordings were made within the same plot, and were averaged on the basis of the mulching conditions of the treatment. At the time of the mulching tests on 5×1.4 m adjacent field, single passes were made on oil palm frond leftovers (Figure 3). In completely randomized block design (CRBD) the treatments were repeated three times.

Results and discussion

Effects of machine parameters on the degree of oil palm frond mulching

The data collected during the field blade performance assessment with different lifting angles were analyzed using the analysis of variance (ANOVA) to determine if there were significant effects of blade lifting angles, tractor forward speeds, and tractor PTO speeds on the degree of oil palm frond mulching, as shown in Table 3. The results of the ANOVA indicated that there was a highly significant difference in the blade lifting angles (F=241.01, P=0.0001 (P-value)<0.05) on the degree of mulching. This clearly explains that the change of the blade geometry at blade lifting angles had a highly significant effect on the degree of mulching. This means that the average degree of mulching among blade lifting angles is not the same. The level of tractor forward speeds during mulching operation also indicates that the degree of mulching is significantly different (F=3.31, P=0.0455 (P-value)<0.05). This analysis revealed that the better the degree of mulching, the greater the speed of the mulching operation. It can be concluded that one of the tractor forward speed mean values was considerably different. The speed of the tractor PTO had a very significant effect on the degree of mulching (F=30.82, P=0.0001 (P-value)<0.05). This showed that tractor PTO speeds had a significant effect on the degree of mulching. The experimental plot was uneven, if one compares the upper part and the lower part of the field, therefore this affected the distribution of soil moisture along the slope, with relatively dry, moist and wet soil respectively in the upper section, middle section and lower section of the field. Consequently, the experimental plots were replicated using a randomized complete block design, thus minimizing the variations along the slope and eliminating the error due to these variations. This block design also indicated a significant effect (F=2.86, P=0.0274 (P-value)<0.05). This might be due to differences in terrain during mulching of oil palm fronds which made the soil friable.

The combination of blade lifting angles and tractor forward speeds, blade lifting angles with tractor PTO speeds as well as interactions between tractor forward speeds and tractor PTO velocities for mulching oil palm fronds had a highly significant effect on the degree of mulch. Their levels of significant difference are (F=9.14, P=0.0001 (P-value)<0.05), (F=12.58, P=0.0001 (P-value)<0.05) and (F=15.13, P=0.0001 (P-value)<0.05). The combination effect shows that this relation depends on the geometry/lifting angles of the blade, tractor forward speeds and PTO speeds of the tractor. The interaction between blade lifting angles, tractor forward speeds and tractor PTO speeds also indicated very significant effects on the degree of mulching (F=14.62, P=0.0001 (P-value)<0.05). This means that at least one of the mean degree of mulching for the interaction is significantly different. We cannot depend on the ANOVA to check the importance of the key effects and their interaction. However, the level and change in mean level can best be determined by mean separation to check where the parity lies.

Effects of blade lifting angles on degree of mulching

The results of blade lifting angles are plotted in Appendix Figure 9 using a separation method based on Tukey's test for the main effects. Furthermore, the mean comparison test performed by Tukey and the mean of the degree of mulching shows that having the same letters does not vary significantly. Blades with lifting angles of 0°, 60°, 120° and 150° were significantly different with mean values of 60.70, 35.78, 67.75, and 53.71 percent respectively, considering a level of significance of 5 percent. This means that the change in the mean mulching degree would help to infer that there was a significant difference between the lifting angles of the blade. On the basis of the mean, we can observe that the blade with

Table 3. Effects of machine parameters on the degree of mulching.

Source	DF	Mean square	F value
Model	25	549.79	39.07**
Blade lifting angles	3	3391.31	241.01**
Tractor forward speeds	2	46.55	3.31*
Tractor PTO speeds	1	433.70	30.82**
Block	2	40.26	2.86*
Blade lifting angles•Tractor forward speeds	6	128.66	9.14**
Blade lifting angles•Tractor PTO speeds	3	177.05	12.58**
Tractor forward speeds•Tractor PTO speeds	2	212.88	15.13**
Blade lifting angles•Tractor forward speeds•Tractor PTO speeds	6	205.77	14.62**
Error	46	14.07	
Corrected total	71		

DF, degree of freedom; PTO, power take off. **Highly significant; *significant.

Figure 2. Different degree of mulching of mulched oil palm fronds using four different blades retained and passed through a 10 mm sieve (A) blade with 0° lifting angle (B) blade with 60° lifting angle (C) blade with 120° lifting angle and (D) blade with 150° lifting angle.

a lifting angle of 60° achieved a poor performance in terms of mulching degree of mulching, whereas the blade with a lifting angle of 120° gave the best results in the degree of mulching and, therefore, is recommended for mulching oil palm fronds.

Effects of tractor forward speeds on degree of mulching

The result of variance analysis (ANOVA) showed that tractor forward speeds had a significant effect on the degree of mulching during the mulching of oil palm fronds. This means that the mean was not the same among tractor forward speed levels. Appendix Figure 10 describes the mean separation method used by Tukey to account for the effects of the tractor forward speed on the degree of mulching at a level of 5 per cent. Tukey's mean comparison test was also performed and the mean degree of mulching showed that it is not significantly different to have the same letters. It shows that the degree of mulching with tractor forward speeds of 1 and 3 km.h^{-1} did not vary significantly from the mean mulching degree with average values of 53.47 and 53.92 percent respectively. At a tractor forward speed of 5 km.h^{-1}, the degree of mulching with a mean value of 56.07 per cent was significantly higher. This clearly indicates that the effect of at least one of the tractor forward speed rates on the degree of mulching is significantly different. The results also indicate that a better degree of mulching was reported at the highest level in terms of tractor forward speed which is in contrast to the theoretical value.

Effects of tractor power take off speeds on degree of mulching

The tractor PTO speeds provided the power needed for mulching oil palm fronds which led to a highly significant difference in the degree of mulching, as indicated in the ANOVA. Tukey's mean separation was performed and demonstrated that mean having similar letters are not significantly different. Appendix Figure 11 shows the mean mulching degree. Results show that there was a significant difference in the degree of mulching of oil palm fronds at a 5 per cent significance level between tractor PTO speeds of 540 and 1000 rpm. The observed average values were 56.94 and 52.03 per cent respectively. Based on these results, the tractor PTO speed of 540 rpm gave a better degree of mulching, thus meaning that the power required to mulch oil palm fronds sufficiently is obtained by the lower speed of the PTO tractor.

Effects of blade lifting angles and tractor forward speeds on degree of mulching

The interactions of the two-way treatment between blade lifting angles and tractor forward speeds on the degree of mulching had shown that the degree of mulching means were significantly different. The mean comparison carried out based on Tukey's Studentized test indicates that means having the same letters do not differ significantly. Figure 4 shows the mean mulching degree indicating that a blade with a lifting angle of 150° is associated with a significant difference at 5 km.h^{-1} tractor forward speed with an average value of 50.18 per cent on the degree of mulching at 5 per cent. The results show that blade lifting angles and geometry play a significant role in producing a good degree of mulching. This reveals that the blade with a lifting angle of 120° achieved the best degree of mulching based on the interactions that can be recommended for mulching oil palm fronds, while the blade with a lifting angle of 60° had the worst performance.

Effects of blade lifting angles and tractor power take off speeds on degree of mulching

Figure 5 presents graphically the effect of blade lifting angles and tractor PTO speeds on the degree of mulching. The analysis of variance performed gave a highly significant result in terms of mulching degree. The mean comparison test conducted by Tukey's Studentized test, and the mean mulching degree indicate that having the same letters is not significantly different Based on the tests, for tractor PTO speeds of 540 rpm and 1000 rpm accordingly, the blade with 0° lifting angle showed no significant difference with averages of 60.49 and 60.92 percent at 5 percent level of significance. The blade with a lifting angle of 60° and at tractor PTO speeds of 540 and 1000 rpm reveals a significant difference in the degree of mulching with averages of 38.80 and 32.75 percent respectively**.** The blade with a lifting angle of 120° at tractor PTO

Figure 3. Mulched oil palm fronds in experimental plots.

speeds of 540 rpm and 1000 rpm indicates a significant difference of 74.40 and 61.09 percent in the degree of mulching. Finally, a blade with a lifting angle of 150° shows no significance in the degree of mulching, while the oil palm fronds are mulched**.** The best performing mulching blade was the blade with a lifting angle of 120° and a tractor PTO speed of 540 rpm. This means that the lower the tractor PTO speed (540 rpm) during mulching of oil palm fronds, the higher level of degree of mulching.

Effects of tractor forward speeds and tractor power take off speeds on degree of mulching

The mean degree values of mulching oil palm fronds for two-way treatment combinations of tractor forward speeds and tractor PTO speeds are shown graphically in Figure 6. The analysis of variance shows a highly significant effect at the level of 5 per cent. Tukey's mean comparison test was also performed and the mean degree of mulching shows that it is not significantly different to have the same letters. Tractor forward speeds of 1 and 3 km.h^{-1} with tractor PTO speed of 540 rpm were not significantly different in the degree of mulching with averages of 56.04 and 53.34 per cent, whereas the tractor forward speed of 5 km. h^{-1} was significantly different on the degree of mulching with mean of 61.44 percent. Similarly, tractor forward speeds of 1, 3, and 5 km.h^{-1} at tractor PTO speeds of 1000 rpm did not show a significant difference in the degree of mulching with values of 50.89, 54.40 and 50.70 percent respectively. An increased degree of mulching was observed with an increase in tractor forward speed. The best degree of mulching was achieve with a tractor forward speed of 5 km.h^{-1} and a tractor PTO speed 540 rpm.

Effects of blade lifting angles, tractor forward speeds and tractor power take off speeds on degree of mulching

The field data were analyzed statistically using ANOVA to illustrate that the effect of blade lifting angles, tractor forward speeds and tractor PTO speeds on the degree of mulching showed significant differences at a level of 5 per cent. The mean comparison test of Tukey was carried out and the mean mulching degree indicated that having the same letters is not significantly different. Figure 7 shows graphically the mean degree of mulching. Tractor

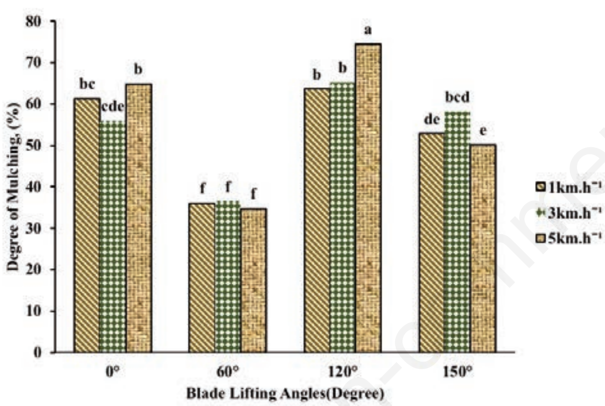

Figure 4. Effects of blade lifting angles and tractor forward speeds on degree of mulching.

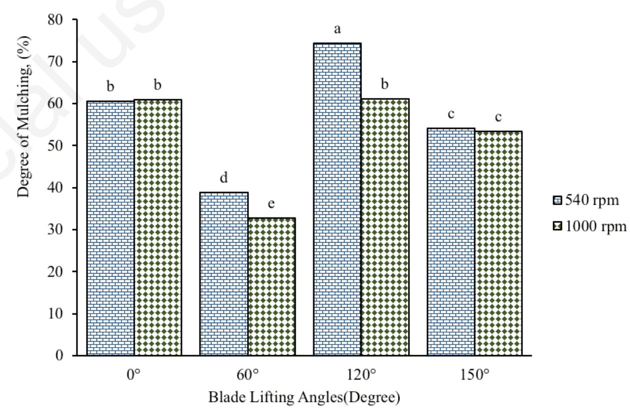

Figure 5. Effects of blade lifting angles and tractor power take off speeds on degree of mulching.

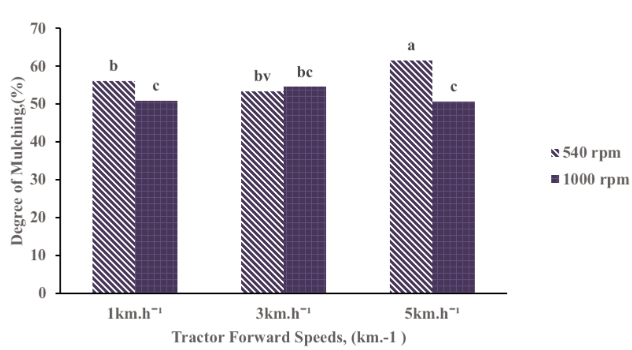

Figure 6. Effects of tractor forward speeds and tractor power take off speeds on degree of mulching.

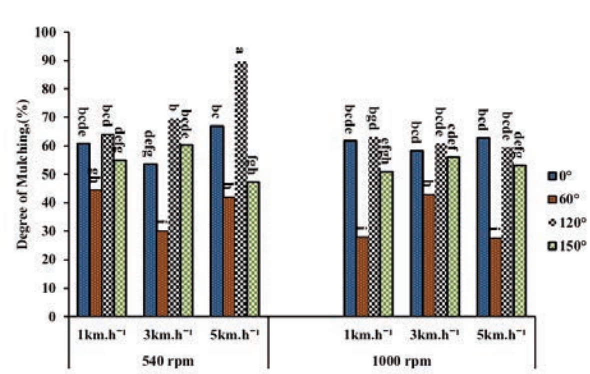

Figure 7. Effects of blade lifting angles, tractor forward speeds and tractor power take off (PTO) speeds on degree of mulching.

Table 4. Linear and quadratic regressions on the effects of machine parameters on the degree of mulching.

	Model	Equation	Sig. F	R^2	Adj. R^2
Degree of mulching	Linear	DMulching = 39.45 + 0.203Btype + 0.651Fs – 0.011PTOS	<0.0001	0.2673	0.2350
	Quadratic	DMulching = –0.11Btype2 + 2.48Btype + 0.651Fs – 0.011PTO – 67.70	<0.0001	0.742	0.727

Btype, blade lifting angles; Fs, forward speeds, PTOS, tractor power take off speeds.

forward speed interactions at 1 km.h^{-1}, a tractor PTO speed of 540 rpm, a blade with lifting angle of 60° indicate a significant difference with a mean value of 44.36 percent, while blades with lifting angles of 0°, 120° and 150° show no significant differences in the degree of mulching with averages of 60.89, 64.10 and 54.8 percent on the degree of mulching of oil palm fronds. Likewise, at tractor forward speed of 3 km.h^{-1} and tractor PTO speed of 540 rpm, blades with 60° and 120° lifting angles were significantly different in terms of the degree of mulching with averages as 30.07 and 69.93 percent, while blades with 0° and 150° lifting angles were not significantly different with mean values of 53.64 and 60.19 percent accordingly. Similarly, blades with lifting angles of 60° and 150° at tractor forward speeds of 5 km.h^{-1} and tractor PTO speeds of 540 rpm did not show substantial differences in the degree of mulching with averages of 41.97 and 47.21 percent. However, blades with lifting angles of 0° and 120° showed a significant difference in the degree of mulching with mean values of 66.93 and 89.67 percent respectively.

The interaction of tractor forward speed of 1 km.h^{-1} and tractor PTO speed of 1000 rpm resulted in blades with lifting angles of 60° and 150° to show significant differences in the degree of mulching with averages of 27.79 and 50.82 percent respectively, whereas blades with lifting angles of 0° and 120° had no significant differences in the degree of mulching with mean values of 61.84 and 63.15 percent. Similarly, at tractor forward speed 3 km.h^{-1} and tractor PTO speed 1000 rpm, a blade with 60° lifting angle indicated a significant difference with an average of 42.89 percent. However, blades with 0°, 120° and 150° lifting angles were not significantly different at 58.20, 60.81 and 56.09 percent mean mulching levels respectively. Finally, at tractor PTO speeds of 1000 rpm and tractor forward speeds of 5 km.h^{-1}, blades with a lifting angle of 60° showed a significant difference with a mean value of 27.60%, while blades with lifting angles of 0°, 120° and 150° were not significantly different with averages of 62.73, 59.32 and 53.15% respectively.

Linear and quadratic regressions on the effects of machine parameters on the degree of mulching

Multiple regressions were used to analyze the mean values of the degree of mulching oil palm fronds to determine, if blade lifting angles, tractor forward speeds and tractor PTO speeds were predicting the degree of mulching significantly. Using a multiple linear regression model as shown in Table 4, the results show that the model is significant P=0.005 and the value of the coefficient of determination, R^2 is 0.2673. The determination coefficient of the multiple linear regression model is low and unreliable for predicting the degree of mulching. A further test was conducted to generate more data for predictive purposes for more comprehensive multiple regressions analyses. A multiple quadratic regression analysis was carried out and the results show a highly significant P=0.0001 and a determination coefficient, R^2=0.742. The best-fit regression equation was a quadratic regression, with a high determination coefficient. This shows that a change in the interaction of these three factors has a significant effect and predicts the degree of mulching. The quadratic regression analysis gave a strong correlation between the parameters of the machine and the degree of mulching. This may be due to the interactions of the three factors, and the degree of mulching using a high level of soil pulverization in the mulching treatment is more appropriate. The regression equation was a second-order polynomial equation with a high determinative coefficient. These relationships are in line with Manuwa's reported work, 2010. Because of the very high values of R^2 (determination coefficient), the models prove to be very reliable and could be used to have accurate predictions.

Conclusions

The aim of the study was to find the best model of mulching blades in an oil palm plantation in Malaysia for a tractor-mounted mulcher to mulch oil palm fronds. This will enable plantation farmers to make informed decisions about the degree of mulching waste from oil palm fronds, which is a major constraint. Three different mulcher blades mounted on tractors were redesigned to assess their performance compared to the control blade in terms of the degree of mulching. The best degree of mulching (89.67 percent) was found to be with the blade with a 120° lifting angle at a tractor forward speed of 5 km.h^{-1} and a tractor PTO speed of 540 rpm. Mulching of oil palm fronds is recommended before planting seedlings in oil palm plantation. The multiple quadratic regression analysis was found to be the best-fitted model for predicting the degree of mulching, as the sample validity was higher (74.2%).

References

Aji I., Sapuan S., Zainudin E., Abdan K. 2009. Kenaf fibres as reinforcement for polymeric composites: a review. Intl. J. Mech. Mat. Engr. 4:239-48.

Andrejs V. 2006. Possibilities to reduce energy intensity of mulching in dependence on quality of work. Diploma thesis, Czech University of Life Sciences Prague, Prague, 57 pp.

Arvidsson J., Keller T., Gustafsson K. 2004. Specific draught for mouldboard plough, chisel plough and disc harrow at different water contents. Soil Til. Res. 79:221-31.

Awalludin M.F., Sulaiman O., Hashim R., Nadhari W.N.A.W. 2015. An overview of the oil palm industry in Malaysia and its waste utilization through thermochemical conversion, specifically via liquefaction. Ren. And Sust. Engr. Res. 50:1469-84.

Bakar A.A., Hassan A., Mohd Yusof A.F. 2006. The effect of oil extraction of the oil palm empty fruit bunch on the processability, impact, and flexural properties of PVC-U composites. Intl. J. Palm. Mat. 55:627-41.

Bismarck A., Mishra S., Lampke T. 2005. Plant fibers as reinforcement for green composites. ECCM15 - 15th European Conference on Composite Materials, Venice, Italy, 24-28 June 2012, 1-9.

Celik A., Altikat S. 2008. Geometrical analysis of the effects of rotary tiller blade path on the distribution of soil slice size. App. Engr. in Agric. 24:409-13.
Chalker-Scott L. 2007. Impact of mulches on landscape plants and the environment - A review. J. Environ. Hortic. 25:239.
Dungani R., Pingkan A., Sri A., Karnita Y., Tati K., Ichsan S., Ihak S. 2018. Biomaterial from oil palm waste: properties, characterization and applications. Intech Open. 76412.
Farooq M., Flower K., Jabran K., Wahid A., Siddique K.H. 2011. Crop yield and weed management in rainfed conservation agriculture. Soil Til. Res. 117:172-83.
Godwin R. 2007. A review of the effect of implement geometry on soil failure and implement forces. Soil Til. Res. 97:331-40.
Henson I.E., Betitis T., Tomda Y., Chase L.D. 2012. The estimation of frond base biomass (FBB) of oil palm. J. Oil. Palm. Res. 24:1473-9.
Intara Y.I., Mayulu H., Radite P. 2013. Physical and mechanical properties of palm oil frond and stem bunch for developing pruner and harvester machinery design. Intl. J. Sci. Engr. 4:69-74.
Jahun B.G. 2018. Development and field evaluation of blades with different lifting angles for mulching oil palm fronds prior to seedling planting. Unpublished Phd Dissertation Submitted to the Department of Agricultural and Biological Engineering Universiti Putra Malaysia.
Kader M.A., Senge M., Mojid M.A., Ito K. 2017. Recent advances in mulching materials and methods for modifying soil environment. Soil Til. Res. 2017;168:155-66.
Kumhála F., Kroulík M., Prošek V. 2007. Development and evaluation of forage yield measure sensors in a mowing-conditioning machine. Comp. Electr. Agric. 58:154-63.
Liau S., Ahmad A. 1991. The control of Oryctes rhinoceros by clean clearing and its effect on early yield in palm to palm replants. Paper presented at the Proc. 1991 PIPOC Intl. Palm Oil Conf. MPOB, Bangi, Malaysia.
Mandal S.K., Bhattacharya B., Mukherjee S. 2013. Optimization of design parameters for rotary tiller's blade. pp 533-539 in Proc. 1st International and 16th National Conference on Machines and Mechanisms (iNaCoMM2013), Dec 18-20 2013, IIT Roorkee, India.
Manuwa S.I. 2010. Soil bin investigation of the effect of width of tine and rake angle on draught and soil disturbance of sandy clay loam soil. J. Agric. Engr. Tech. JAET. 18:61-9.
Mayer V., Vlášková M. 2007. Mulching on soils put to rest. Agritech Sci. 1:1-5.
Nasrin A., Ma A., Choo Y., Mohamad S., Rohaya M., Azali A., Zainal Z. 2008. Oil palm biomass as potential substitution raw materials for commercial biomass briquettes production. Am. J. App. Sci. 5:179-83.
Olatunji O., Davies R. 2009. Effect of weight and draught on the performance of disc plough on sandy-loam soil. Res. J. App. Sci. Engr. Tech. 1:22-6.
Osborne S.L., Johnson J.M., Jin V.L., Hammerbeck A.L., Varvel G.E., Schumacher T.E. 2014. The impact of corn residue removal on soil aggregates and particulate organic matter. BioEnergy Res. 7:559-67.
Oworlarafe O.K., Olabige M.T. Faborade M.O. 2007. Physical and mechanical properties of two varieties of fresh oil palm fruit. J. Food Engr. 78:1228-32.
Pandey M. 2004. Present status and future requirements of farm equipment for crop production. Central Institute of Agricultural Engineering, Bhopal, 24:69-113.
Pinamonti F. 1998. Compost mulch effects on soil fertility, nutritional status and performance of grapevine. Nutr. Cycl. Agro. 51:239-48.
Ping L.Y., Sung C.T.B., Joo G.K., Moradi A. 2012. Effects of four soil conservation methods on soil aggregate stability. Mal. J. Soil Sci. 16:43-56.
Shen J., Kushwaha R.L. 1998. Soil-machine interactions: a finite element perspective. Marcel Dekker Inc., New York, USA 1998 pp.ix + 333 pp. ref.7 pp.
Sreekala M., Kumaran M., Joseph S., Jacob M., Thomas S. 2000. Oil palm fibre reinforced phenol formaldehyde composites: influence of fibre surface modifications on the mechanical performance. App. Comp. Mat. 7:295-329.
Srivaro S., Rattarana J., Noothong P. 2018. Comparison of the anatomical characteristics and physical and mechanical properties of oil palm and bamboo trunks. J. Wood Sci. 2018;64:186-92.
Syrový O., SvFtlík M., Pražan R., Pastorek Z., Kubín K., Gerndtová, I. 2013. Mobile energy devices and the approximate values of unit fuel and energy consumption (Mobilní energetické prostedky a orientaní hodnoty jednotkových spoteb paliv a energií). Research Institute of Agricultural Engineering, p.r.i., Prague, 56 pp. [in Czech].
Wilhelm W.W., Johnson J.M., Karlen D.L., Lightle D.T. 2007. Corn stover to sustain soil organic carbon further constrains biomass supply. Agro. J. 99:1665-7.
Yovel Y., Franz M.O., Stilz P., Schnitzler H.U. 2008. Plant classification from bat-like echolocation signals. Plos Comp. Bio. 4:e1000032.
Zhao H., Wang R.Y., Ma B.L., Xiong Y.C., Qiang S.C., Wang C.L. 2014. Ridge-furrow with full plastic film mulching improves water use efficiency and tuber yields of potato in a semiarid rain fed ecosystem. F Crop Res. 2014;161:137-48.