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Physical and mechanical characteristics of oil palm leaf and fruits bunch stalks for bio-mulching

T Mandang[1], R Sinambela[2] and N R Pandianuraga[3]

[1]Dept. of Mechanical and Biosystem Engineering, Institut Pertanian Bogor
[2]Doctoral student of Graduate School, Institut Pertanian Bogor
[3]Undergraduate student of Dept. of Mechanical and Biosystem Engineering, Institut Pertanian Bogor

Email : tineke_mandang_2003@yahoo.com

Abstract. This paper discusses specifically on physical and mechanical characteristics of oil palm leaf and FFB stalks as parameter used to select appropriate method for size reduction of materials which will give optimum performance as bio-mulch. Physical and mechanical properties of oil palm leaf and fresh fruit bunch (FFB) stalks are basic data in determining the appropriate method of size reduction in order to find optimum size of material for bio-mulching. The output of this research were (1) the physical characteristics i.e.size (length, width, thickness),and moisture content; (2) mechanical propertiesi.e. shear strength, tensile strength, and hardness. Previous researches showed that the use of mulches, both organic and synthetic mulches were able to maintain soil moisture, reduce nutrient leaching, to maintain soil organic matter, soilaggregates, reduce runoff/erosion, and prevent weed growth. Oil palm frond collected after harvesting activities is generally placed on a "gawanganmati"under oil palm trees. The materials are expected to decompose naturally. However, currently, the materials are not fully managed and just remain in the field which takes space and disturb the field operation during production of oil palm. In fact the materials are potential as bio-mulch if it is in proper size that can be well distributed in the field. In this study, the materials used for mulchingareoil palm leaf and FFB stalks. Toshorten the decomposition time of the mulch, one of the aspects that should be suppressed is the size of the mulch.In terms of achieving optimumimpact of materials as bio-mulch, it is necessaryto determine the shape, dimensions, moisture content, strength and hardness of materials.

1. Introduction

Mulch as a material used to cover the landsurface with the purpose of maintaining soil moisture, suppress weed, and pest sothatthe plant (crop) will grow in optimum conditions. Mulch in the surface of land will also reduce the evaporation and protect the seed or seedling from insect and animal attacks. Mulching will also minimize competition of nutrients uptakes by root crops and weeds.

Currently materials for mulching are consisted of: 1) organic mulch (bio-mulch) such as crop residues, 2) un-organic small stones, gravel, bricks, etc, 3) synthetic mulch, such as mulch, suc as plastics sheets and other chemical materials.

One of the conservation tillage methods is soil tillage without any mechanical treatment and instead using mulch materials. Conservation is obtained by covering the land surface which minimize the evaporation and surface run-off and erosion. In the temperate area, mulching becomes an important process of crop production, especially for leavy vegetables during winter to protect soil from evaporation. While in a tropical area, mulching is still considered expensive and so only apply to crop with high economic value. For other cash crops, crop residue is common material for mulching.

Crop residue is mostly available on the farm, cheap and so become the only material used by the farmer. Cropresidue is one of bio-mulch material. The direct impact of mulch is to increase the nutrient in the soil by the decomposition process of bio-mulch materials. However for the main function of mulch which to protect the soil from evaporation and weeds, then good bio-mulch materials should be hard and difficult to decompose, meaning that the materials will remain in the soil surface for longtime, at least for one planting season. Rice straw, imperatacylindricalleaf are categorized as good materials for mulching.In industrial crop plantation which coversvery wide area, most popular mulching is by using cover crops, such as legume plants.By considering the potential of plant residue which is left in the area, then plant residue may also be used as mulch materials. However, there should be a method to modify the plant residue to be more effective in covering the surface.

2. Objectives

The objective of this study is to identify the on physical and mechanical characteristics of oil palm leaf and FFB stalks as a parameter used to select the appropriate method for size reduction of materials which will give an optimum performance as bio-mulch.

3. Literature review

3.1. Mulch

Mulch is material that is intended to cover crop cultivationarea to maintain soil moisture and suppress weed growth and disease to make the plants grow well. With the mulch material on the soil surface, weed seeds will be blocked. As a result, the plants will be free to grow without competition with weeds in the soil mineral and nutrient uptakes. The lack of competition with these weeds provides benefits regarding increasing crop production. In addition to the mulch material on the surface, rain water energy will be borne by the mulch material. Soil aggregates remained stable and avoided the destruction process. All types of mulch can be used for erosion control purposes.

Direct function of mulch on soil chemical properties occurs through weathering of materials mulch. This function is only happening on the type of mulch that is easily weathered such as rice straw, reeds, grasses, and other plant debris. This is one of the advantages of mulching plant remains than weathered plastic mulch. Mulching technology can prevent evaporation. In this case the water that evaporates from the soil surface will be retained by the mulch material and falls back to the ground. As a result, the evaporation of water into the air only occurs through the process of transpiration and make land planted have enough water. Through this plants transpiration process, plants can absorb water from the soil in which has been dissolved a variety of nutrients that plants need [1]. According to Fauzan[1], there are several kinds of mulch which are:

1. Organic mulch
   Covers all agricultural waste materials that are economically less useful such as rice straw, corn stalks, peanut stem, leaf and stem of the banana leaf, the leaf of sugarcane, reed, and sawdust.
2. Un-organic Mulch
   Covers all rock material in a variety of shapes and sizes such as gravel, pebbles, coarse sand, brick, and stone gravel. For annual crops, the mulching material is rarely used. Mulch material is more often used for potted plants.
3. Synthetic-Chemical Mulch
   Covering plastic materials and other chemicals, plastic materials shaped sheet with sunlight penetrating diverse. Plastic materials commonly used today are often used as a mulch material is transparent plastic, black plastic, plastic silverware, silver and black plastic.

3.2. Oil palm

In the botanical world, all plants are classified to facilitate the identification of scientific; method of scientific names (Latin) was developed by Carolus Linnaeus. Palm oil plantations are classified as follows:

Kingdom :*Plantae*
Division :*Embryophyta Siphonagama*
Class :*Angiospermae*
Order :*Monocotyledonae*
Family :*Arecaceae*(*Palmae*)
Genus :*Elaeis*
Species :*E. guineensis* Jacq., *E. oleifera* (H.B.K) Cortes, and *E. odora*

Oil palm grows well in lowland tropical moist climates that are along the equator between the northern latitudes 23.5^0-23.5^0 south latitude[2]. The requirements for the oil palm plants are as follows:

a) Rainfall: $\geq$ 2000 mm/year and evenly throughout the year with a period of dry months (<1000 mm/month) not more than 3 months.
b) Average temperatures: daytime 29^0-33^0C and nighttime 22^0-24^0C.
c) Elevation : <500 m. above sea level
d) The sun shines all year, at least 5 hours per day.
e) Sunlight intensity of 1410 to 1540 J / cm^2 / day.

Oil palm (*E. guineensis*) is commercially cultivated in Africa, South America, Southeast Asia, South Pacific, as well as several other areas with a smaller scale. Oil palm plantations are from Africa and South America, precisely Brasilia. In Brazil, this plant can be found growing wild or semi-wild along the banks of the river. Palm oil is included in the sub-family *Cocoideae* which is native in South America, including the species *E. oleifera* and *E. odora*.

3.3. Oil palm leaf

The number of leaves in an oil palm plant increase from 30 to 40 in a year at the age of 5 to 6 years. After that, the generation of leaf decreases to about 20 to 25 per year. PS (2007) explains that oil palm leaf has a shape that resembles a coconut leaf that forms a compound leaves arrangement, even finned and bony alignment. Oil palm leafforms a sheath that extends for more than 7.5-9 m. The number of leaflets in each leaf frond ranged between 250-400 strands. Young leavewas still pale yellow buds. At the fertile soil, the leaf quickly opens so more effectively in the process of photosynthesis and respiration. Production of leaf each year in North Sumatra may reach 20-24 leaves. Older leafbegins to form to take as long as 6-7 years. Fresh palm leafis dark green and healthy.

In the process of harvesting the FFB, it started with removing thefrond under the FFB to make FFB stalk visible for the operator to harvest or cut the FFB at the certain point. It means that frond which was removed from the tree were relatively at the same stage regarding physical condition.

Palm leaf as can be seen in Figure 1, consists of the following sections[3]:

1) Set of leaflets that have a blade (*lamina*) and bone child leaf (frond).
2) *Rachis* which is where the child leaf attached.
3) Leaf stalk (*petiole*) which is part of the leaf and stems.
4) Leaf sheet which serves as a protection from the buds and stems.

Weight and nutrient content of oil palm leafas shown in Table 1.

Table 1. Weight and nutrient content ofoil palm leaf.

Frond part	N (%)	P (%)	K (%)	Mg (%)	Ca (%)	Fresh (kg/palm)	Dry (kg/palm)
Rachis	0.45	0.049	1.52	0.11	0.43	12.3	2.94
Leaflets	2.18	0.116	0.98	0.21	0.52	4.0	1.45

Source: Khalid *et al* 1999[4]

As shown in table 1, nutrient content of oil palm leaf is mostly in the leaflets and nitrogen (N) is the highest content among the elements. It means that the lealets has potential as bio-mulch material and so the sorce of nutrient for soil improvement. In terms of weight, *rachis* is twice greater than leaflets but it has low nutrient content. As mentioned previously that oil palm midrid (with its natural size) is just left in the field until decomposed naturally. However, without any catalyst treatment, the natural decomposition will take a long time, and so become an obstacle in field operation of oil palm production process.

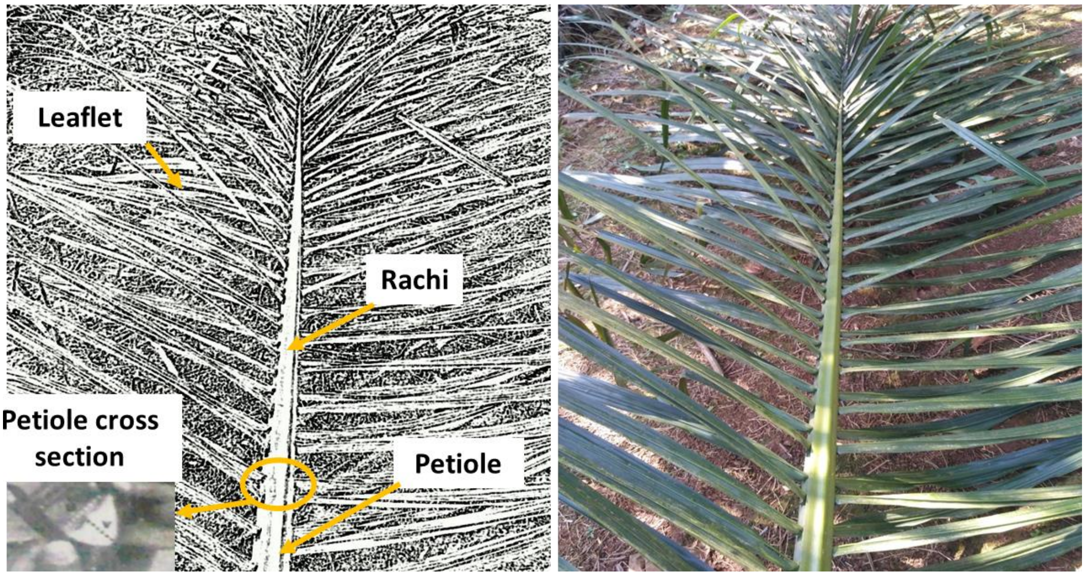

Figure 1. Oil palm leafand leaflets.

3.4. Oil palm fruit bunch

Large plantation producesa largeamount of biomass such as the oil palm trunks, fronds, fruit bunches (FB) stalk and leaf. Those materials areleft in the plantation area and currently not being properly managed. Most of it is just disposed ofback into the fields. When harvesting, cutting the FFB is not set at the certain point. In fact for the processing of FFB, the stalk is not necessary because it will increase the energy for cooking and press the FFB to take out the oil from fruit bunch, and so the absence of stalk should be as short as possible. The FFB may be removed from FFB just after harvesting and remain it in the field. FFB stalks can be used for many another purpose as biomass for energy as well as for bio-mulch material.

(a) (b)

Figure 2. (a) Fresh fruit bunch (FFB), (b) empty fruit bunch (EFB).

The moisture content of FFB stalk is about 48% on a wet basis. The moisture content level of both FFB stalk when the material is used as bio-mulch.

4. Materials and methods

Materials, i.e., oil palm midrib and FFB stalk were obtained from oil palm plantation in Cikarawang, Bogor, West Java. The leaflets were removed from oil palm frond to measure its physical and mechanical characteristics. The FFB stalk was removed from FFB and measured the physical and mechanical characteristics.

The researchwas conducted in 1) Laboratorium of Mechanical and Biosystem Engineering, 2) Field Station in Leuwikopo. Institut Pertanian Bogor.Main instrument and tools used in this study were: 1) Universal Testing Machine (UTM), 3) Oven, 3)Yamanaka type penetrometer, 4) Digital scale, 5) Combine harvesting blade unit and 6) supporting tools: scissor, cutter, ruler, caliper, etc.

This research consists of 3 steps 1) study the characteristic of materials of oil palm leaf and FFB stalk and 2) Field test on the effectiveness of oil palm leaf material as bio-mulch and 3) Field test on the effectiveness of FFB stalk as bio-mulch. This report only covers step 1 and 2, as the step 3 is still under-go on a field test.

4.1. The procedure of Measuring Physical and Mechanical Characteristics of Oil Palm Leaf

Physical characteristics of oil palm leafwere measured using 15 samples of leaves(<5 years plant) and 15 samples (>20 years plant) with various moisture content. The measurement include length, width, thickness, the diameter of leaf bone, leaflets angle to rachis, leaflets weight, and moisture content. In the physical characteristicmeasurement, especially length, width, thickness, the bone diameter of a leaf, and the angle between leaflets and rachis, oil palm leaf was divided into three parts, namely the base, middle, and tip of the leaf, as described in figure 3a. Measurement points of palm leafwasdone on five measurement points, as described in figure 3b.

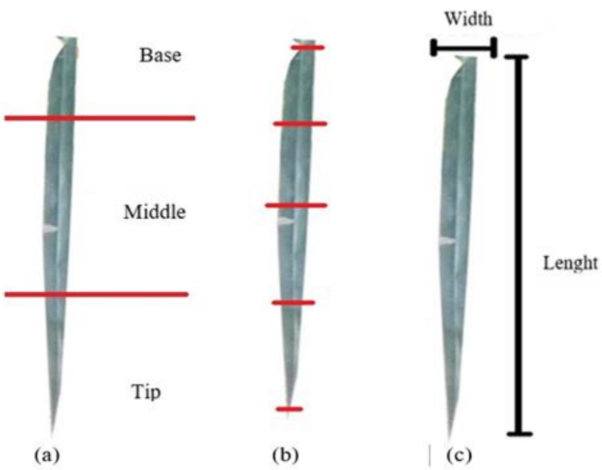

Figure 3. Parts and measurement points of oil palm leaf (a) part leaf (b) point of measurement (c) length and width.

Length and width measurement of oil palm leaf done by using a ruler and a measurement tape, as shown in figure 4b. Leaf thickness measurement and bone diameter of a leaflet done by using caliper as described in figure 4c.

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Figure 4. Oil palm leaflet bone (a, b) and the angle between *Rachis* and leaflet (c).

The oven method is used to determine the water content of oil palm leaf. Tools and materials that used in the water content measurement of oil palm leaf are ovens, digital Electronic Scale with the 600 gram maximum capacity and 0.1 gram minimum accuracy, aluminum foils, and scissors. Aluminum foils were shaped into a cube container without a lid and filled with palm leaves that have been cut earlier to facilitate the filling the container as described in figure 5a and 5b.

(a) (b)

Figure 5. Oil palm water content measurement samples.

Moisture content measurement begins with the weighing of aluminum foils containers, followed by weighing the aluminum foils container that has been filledwith oil palm leaves. Weight measurement using a digital scale was performed at before and after drying using the oven (figure 5a). Oven wassetata temperature of 105°C and carried out for 24 hours (figure 5b). Mechanical characteristic was represented by shear strength measurement of oil palm leaf. Scissors method was used to determine the maximum shear strength of oil palm leaf.

As the name implies, scissors method is a shearing strength testing methods that use the scissors tool as the main test. Scissors method using 15 samples of oil palm leaves that entirely is the base of the leaves. The base of the leaves chosen because the base of the leaf is the part which has leaflets bone diameter larger than the other parts of the leaf. The method uses scissors tool vise, wire, an iron plate with the adjusting the size of the vise jaws, large scissors, lift and balance with the maximum lifting capacity of 50 kg and 0.1 kg smallest precision measurement.

Figure 6. Measurement of friction by scissor method.

During measurement, scissors were placed on a vise and left hand-held of the scissors to hold in a static position, and so only force that occurs between the fulcrums. Blade tip was pulled down with the digital scale. The wirewas tied to the tip of the scissors so that can connect to digital scale until a force systemis formed.

4.2. Procedure of measuring physical and mechanical characteristics of FFB stalks

Physical characteristics of FFB stalks was measured using four samples of FFB stalks with relatively uniform moisture content. The measurement includes length, the diameter of stalks, and moisture content. Moisture content data is important to support hardness analysis [5, 6].

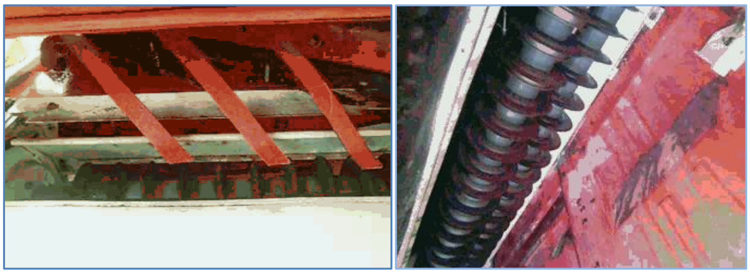
Mechanical characteristics were measured using Yamanaka Penetrometer. Penetrometer tip (cone) was vertically pushed down to the FFB stalk and data can be read on the scale available in the penetrometer. Data obtained from this measurement was penetration depth and hardness. Material hardness measured by penetrometer will indicate how much force/energy needed to break the stalk and so be the basis to selectappropriate method for chopping and shred the stalk to be used as bio-mulch [7]. All the measurement of mechanical characteristics were conducted on newly harvested FFB at three points i.e.base (6-9 cm fromfruitless, middle (4-5 cm from fruitlets) and tip parts (2 cm from fruitless).

(a) (b)

Figure 7. Length measurement (a) and hardness of FFB stalks (b).

4.3. Field test on effectiveness of oil palm leaf as bio-mulch

Field test to observe the effectiveness of oil palm leaf as bio-mulch was conducted at Leuwikopo farm using plot with 1x1 m^2. Three experiment plots were used: 1) control plot, 2) bio-mulch plot, and 3) synthetic mulch plot. 20 kg of oil palm leaves were chops using combine harvester bladesand4 kgused for five replication experiment plots. Bio-mulch materials were spread out on the surface of plotsup to 10 cm thickness, while the synthetic plastic sheets used to cover the plots. The observationwas conducted every weekfor 77 days on temperature andmoisture content of soil at surface layers. The effectiveness of bio-mulching was observed by comparing the results of the three treatments.



(a) (b)

Figure 8. Cutting blades of combine machine, (a) front view (b) bottom view.

(a) (b)

Figure 9. Size reduction of leaves by combine machine blades (a) mixed cuttings (b) cutting size variation.

5. Results and discussion

5.1. Physical characteristics measurement of oil palm leaf

Measurement results of Oil palm leaf size was 14,5-100,4 cm length, 0,1-7,0 cm width, 0,01-0,12 thickness and diameter of leaf bone 0,01-0,9 cm. As explained in methodology that the leaf was stored (atroom temperature) to identify moisture changes. The results shown in the following tables.

Tabel 2. The moisture content of oil palm leaflets(<5 years plant) on various stored days.

Fresh level (store days)	Moisture Content (%)			
	Bottom	Middle	Tip	Average
0	65.8	68.7	54.8	63.1
3	34.9	49.8	43.7	42.8
5	62.2	34.0	26.1	40.7
7	34.8	38.3	38.0	37.0
9	11.7	21.4	27.3	20.1

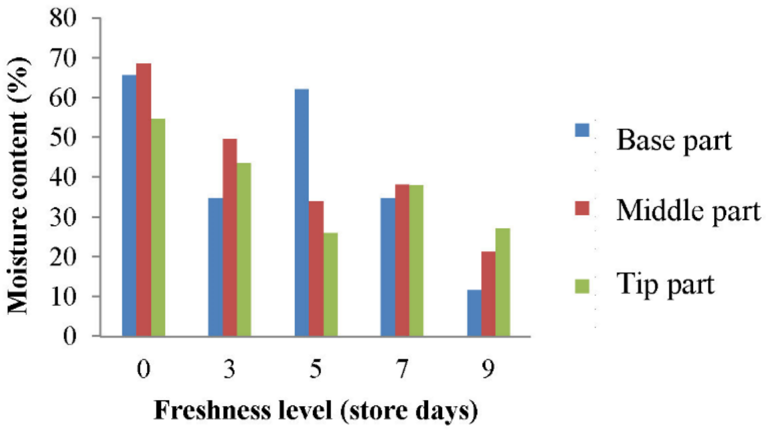


Figure 10. The moisture content of oil palm leaflets (<5 years plant) on various stored days.

Data from at the above table and trend are shown in figure 10 indicates that for the young plants, the moisture content of leaflets at the base part except at 5th days was lower than that of leaves at middle and tip parts of the frond. The decrease of moisture content was very fast, from 0 to 9th stored days which was from average 63.1% to 20.1%.

Tabel 3. The moisture content of oil palm leaflets (> 20 years plant) on various stored days.

Fresh level (store days)	Moisture Content (%)			
	Bottom	Middle	Tip	Average
0	44.5	65.3	66.6	58.8
3	38.5	45.2	42.1	41.9
5	47.3	46.2	48.3	47.2
7	38.3	33.2	30.5	34.0
9	30.0	27.2	39.9	32.4

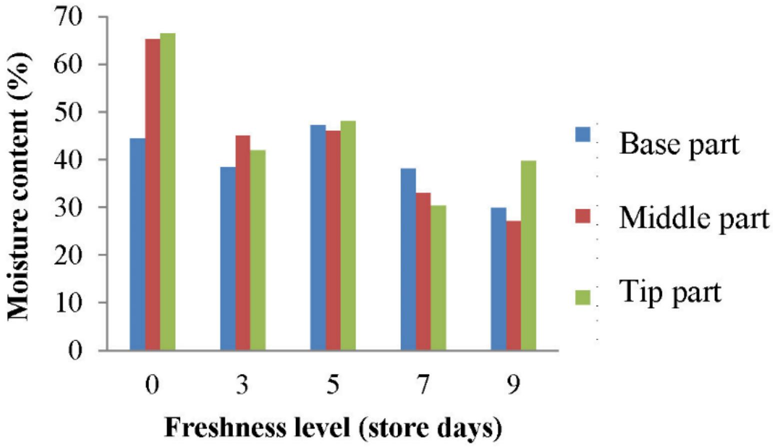


Figure 11. The moisture content of oil palm leaflets (>20 years plant) on various stored days.

Measurement of moisture content at the different level of freshness was intended to identify the condition of leaflets as similar as possible to the real condition in the field whereas the oil palm frond are normally left at the field for several days before collected them to *gawanganmati*. Data from at the above table and trend are shown in figure 11 indicates that for the old plants, the moisture content of leaflets at the base part was always lower than that of leaves at middle and tip parts of the frond. The decrease of moisture contentwas fast, from 0 to 9th stored days which was from average 58.8% to 32.4%. The decrease of the moisture content of leaflets of old plant was not as fast ofthe young plant.

Data from the above table 3 shows that changes in moisture content of oil palm leaflets for both stages of oil palm trees, indicating that the oil palm leaflets were very porous and so sensitive to surrounding temperature. The changes in moisture content will affect the mechanical characteristics of leaflets. This also indicates that when leaflets remain in the moist condition, then the moisture content will increase very fast.

5.2.Mechanical characteristics (shear strength) of oil palm leaflets

Shear strength data will be used to find proper method and how much force needed to chop and shred the leaves. Reducing the size of leaves were intended to make the material easily distributed to the surface, and so increase the effectiveness of mulching.

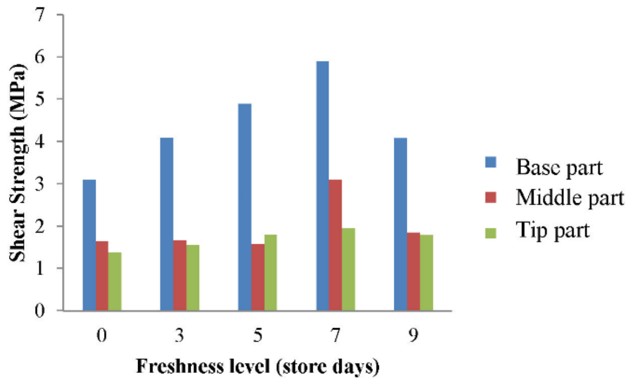


Figure 12. Shear strength of oil palm leaflets by scissor method.

Shear strength is influenced by moisture content up to freshness level 8 (stored until 8 days). The highest was found at 8 store days with 6 MPa shear strength, meaning that the lower the moisture content the higher the shear strength. At higher moisture content, the pore space of leaves were filled with waterand at low mositure content the water in pore space was dried out and so the density of material was high that makes more difficult to cut the materials. At freshness level 9, the moisture content was the lowest, howeverthe materialget rotten and so the shear strength turned to lower stage.

5.3. Physical and mechanical characteristics of oil palm ffb stalks

As explained in the methodology that the physical characteristics of FFB stalks were measured using 4 samples of FFB stalks with relatively uniform moisture content. The results of moisture content of FFB staks at the very fresh stage ranged from 44,62 to 48,46 % db.The result of the shear strength of FFB stalks at various positions shown in the following Figs. At the same moisture content the sample no 2 has the lowest hardness compared to the other samples with diferent hardness. It means that at the same ripeness stage of oil palm fruits, the FFB stalks may have different mechanical characteristics. The implication of these characteristics are to cut or chop the stalks for a bio-mulch needs different method and needs different cutting force.

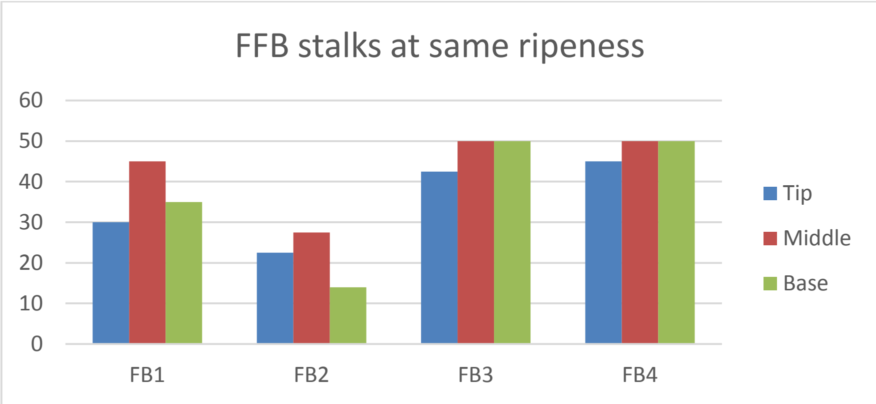


Figure 13. The hardness of 4 samples of FFB stalks.

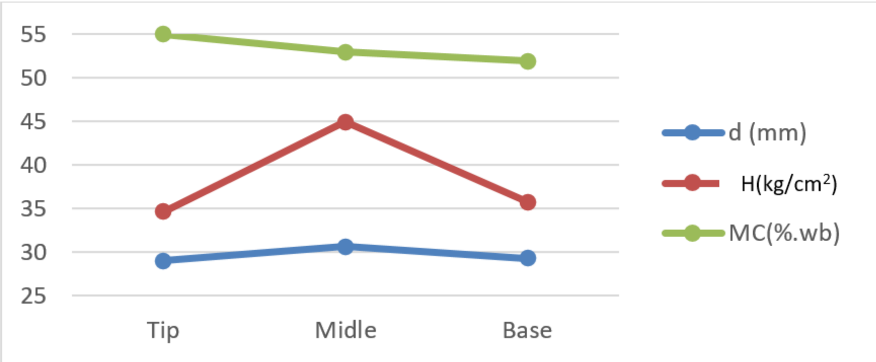


Figure 14. Hardness and moisture content of FFB Stalks.

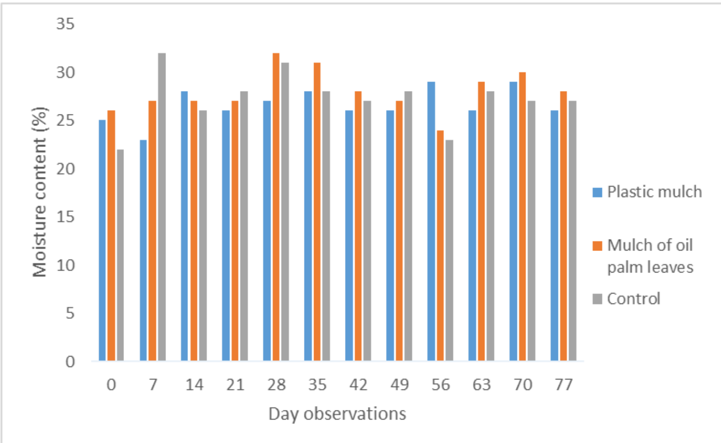
The moisture content of FFB stalks ranges from 52 to 55% wb., while the hardness ranges from 30 to 39 kg/cm^2. Based on the data, the middle part of FFB stack has the highest hardness, meaning that to cut the stalks at this position needs more cutting force. The base part which the closest to the tree stem has a lowest moisture content. So it is recommended to harvest the FFB at the base part of the stalk. The hardness data can be used to estimate the proper method to chop the stalks to be used as bio-mulch. As mentioned in methodology that the experiment on the effectiveness of FFB stakes as bio-mulch is still on going, so the result will not be reported in this paper.

5.4. Field test on effectiveness of oil palm leaf as bio-mulch
As explained in the methodology, the oil palm leaflets were chopped by combine harvester blades into 6 cm length and distributed to the surface of plots with 10 cm thickness. The experiment was conducted up to 77 days, but the effectiveness of bio-mulch was observed every week by measuring moisture content and soil temperatures at surface layer at 0-5 cm and 5-10 cm.

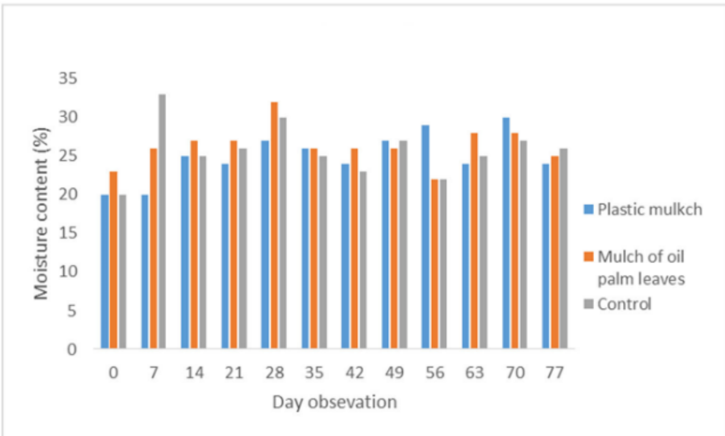
(a) (b) (c)

Figure 15. Observation plots: Control (a), Bio-mulch treatment (b), synthetic mulch (c).

Based on figure 15 the highest moisture content soil at 0-5 cm depth was found at the plot with bio-mulch and the lowest found at the plot with plastic mulch, while the lowest temperature was found in the plot of plastic mulch. The higher moisture content of the soil surface was influenced by the moisture content of the bio-mulch, while low temperature at soil under the plastic mulch was because of the evaporated water was trapped by plastic mulch and protect the temperature at the soil lower than the others.



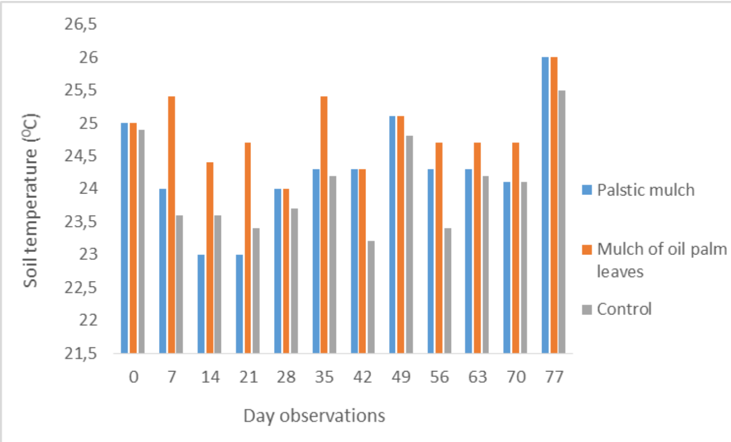
(a)



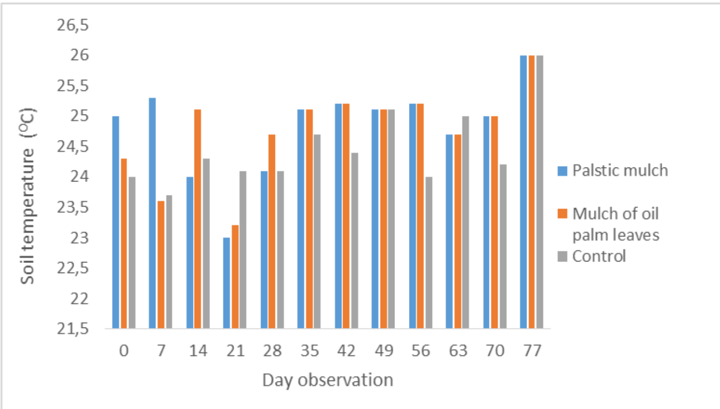
(b)

Figure 16. The moisture content of soil at 0-5 cm depth (a) and 5-10 cm depth (b).

Experiment plots were set at the area without direct radiation of sunshine, meaning that all the plots received low solar intensity. The temperature at control plot more fluctuative compared to the plots with mulch treatments. This is because,during the experiments, there were few days raining which may affect the moisture content and temperature of soil especially at the control plot with no mulching. At the soil with clay texture, the water holding capacity is high and that is the main reason why the control has more fluctuative soil temperature. Soil covered by bio-mulch was more stable on both moisture content and soil temperature as well as bio-mulch has more ability to keep the water at the surface layer. Average difference moisture content and temperature of soil covered by bio-mulch was 3.258% dan 0.455°C respectively which were the lowest compared to the other plots.



(a)



(b)

Figure 17. Soil temperature at 0-5 cm depth (a) and 5-10 cm depth (b).

Bio-mulch and plastic mulch, in fact, have more ability to maintain the soil temperature at ranges of 24-26°C, while for the plastic mulch ranges of 23-26°C. When it rains, the bio-mulch keep the water for some time and absorb it at a certain level, while the plastic mulch justkeep the water at the surface until it evaporates. Both materials can keep the moisture content at certain level. The effectiveness of bio-mulch was shown only on the moisture content during the observation period, while for the temperature no effect shown at this experiment. As explained above that the oil palm leaflets were cut to 6 cm length. This size was considered as the optimum size for bio-mulching, meaning that the size may be kept for at least two months before the materials be decomposed naturally. In the field, mulch material was placed under the oil palm trees with the wide canopy, and

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so the rain fall and sunshine will not attack directly to the soil surface. With this condition bio-mulch has potential to protect the surface from evaporation and at the certain period the mulch will be decomposed and become compost material which may increase the fertility of soil.

6. Conclusions

The decrease of moisture content of leaflets from young plant was very fast, from 0 to 9th stored days which was from average 63.1% to 20.1%, while for the leaflets from old trees the decrease ranges from 58.8% to 32.4%. The decrease of the moisture content of leaflets of old plant was not as fast ofthe young plant. Shear strength is influenced by moisture content up to freshness level 8 (stored until 8 days). The highest was found at 8 store days with 6 MPa shear strength, meaning that the lower the moisture content the higher the shear strength. The results ofthe moisture content of FFB staks at the very fresh stage ranges from 44,62 to 48,46 % wb., with the hardness ranges from 30 to 39 kg/cm^2.Scissor method is considered as a proper method to chop the oil palm leaflets and the cutting force should be greater that the strength of the leaflets.

References

[1] Fauzan A 2002 *Pemanfaatan Mulsa dalam Pertanian Berkelanjutan Pertanian Organik.* Malang. *H* 182-7
[2] Aholoukpé H, Dubos B, Flori A, Deleporte P, Amadji G, Chotte J-L and Blavet D 2013 Estimating aboveground biomass of oil palm: allometric equations for estimating frond biomass *Forest Ecology and Management* **292** 122-9
[3] Fauzi Y, Widyastuti Y E, Satyawibawa I and Hartono R 2006 *Kelapa Sawit: Budidaya, Pemanfaatan Hasil dan Limbah, Analisis Usaha dan Pemasaran* (Jakarta: Penebar Swadaya)
[4] Khalid H, Zin Z and Anderson J 1999 Quantification of oil palm biomass and nutrient value in a mature plantation. I. Above-ground biomass *Journal of Oil Palm Research* **11** 23-32
[5] Lisyanto 2002 Mekanisme Pemotongan Rumput dengan Menggunakan Pisau Pemotong Rumput Tipe Reel. Master Thesis. (Bogor: Institut Pertanian Bogor)
[6] Sakai J, Inoue E and Oduori M F 1993 Combine Harvester Reel Stagger-I. Principle of Determination of Reel Stagger Based on Reel Kinematics and Crop Stem Deflection *Agricultural Mechanization In Asia Africa And Latin America* **24** 27-32
[7] Martin G H 1985 *Kinematika dan Dinamika Teknik* (Jakarta.: Erlangga)