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The Influences of Organic Mulches on Soil Moisture Content and Temperatures

-A Case Study of Tapioca Wastes Application-

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Abstract: The aim of this study was to investigate the influence of organic mulching on soil temperature and moisture content. An experiment was conducted in a pineapple plantation at Lampung province, Indonesia from July 2001 to September 2002 using tapioca wastes and rice husk. There were 5 treatments namely: control/no mulch, rice husk mulch, cassava bagasse mulch, cassava peel mulch, and black polyethylene film mulch. The results showed that the soil temperatures of the surface layers under cassava bagasse and black polyethylene film mulches slightly increased with the increase in air temperature, while rice husk and cassava peel mulches decreased the heat convection into soil surface by retaining the incoming solar radiation heat within mulches layers. However, soil temperature regimes were greatly ameliorated by the mulching materials and that enhanced water absorption by pineapple, therefore the total wet biomasses and yields were improved. Cassava bagasse mulch enhanced effective rainfall during rainy season, better than the other mulching materials.

Keywords: *Organic mulching; Cassava bagasse; Cassava peel; Indonesia; Pineapple; Soil moisture; Soil temperature*

1 Introduction

Indonesia is one of the countries that experience tropical monsoon climate with average annual rainfall ranging between 2,500 and 3,000 mm. The mean daytime and nighttime air temperatures are 32°C and 22°C respectively, with mean annual relative humidity between 80% and 90%. High air temperature and high solar radiation intensity in tropical countries cause high evaporation as they strongly correlate each other (Ferraris, 1992). In dry season, plants require intensive irrigation application, but operational cost for irrigation is high, thus farmers have to prepare and add supplemental irrigation for crops or, if irrigation is not available, reduce water losses such as evaporation from soil.

Application of organic amendments to the soil surface is widely used in order to ameliorate topsoil physical conditions, especially with respect to temperature, evaporation and soil moisture content.

Unger and Parker (1976) showed that wheat straw was about twice as effective as grain sorghum stubble and more than four times as effective as cotton stalks for reducing evaporation. Laboratory study by Benoit and Kirkham (1963) proved that water loss in unmulched soil column was 1.25 to 5 times higher than that of mulched soil column in 600 hours.

Surface mulch application presents opportunities for utilizing a range of organic matter wastes that may benefit crop, soil and water relations (Mohavedi Naeni and Cook, 2000a; Parkinson *et al.*, 1999; Sellers *et al.*, 2001). The using of organic mulches may increase the quality of wheat (Sharma and Acharya, 2000), white yam (Olasantan, 1999), maize (Ghuman and Sur, 2001) and tomato (Srivastava *et al.*, 1994), by conserving soil moisture. The ability of mulch in minimizing evaporation also helps to maintain soil temperature. Organic mulch can act as an insulating material for soil layers, since it can lower the soil temperature during high air temperature and warm the soil during low air temperature (Begum *et al.*, 2001a). If topsoil temperature is excessive, mulching can reduce temperature for a more optimal germination and root development.

Cassava (*Manihot esculenta*), which is the raw material for tapioca production, is one of the most important food crops cultivated in Indonesia. Due to the increased demand of cassava by tapioca industries, lands for cassava cultivation have increased over the years. Lampung Province is one of the main areas for cassava cultivation in Indonesia, and consequently produces a high amount of tapioca. Due to the high production of tapioca, large volumes of cassava wastes are generated by the tapioca industries, and may lead to a big environmental problem. Thus, there is an urgent need to find suitable applications and disposal of these wastes. One alternative for its economic utilization is to use it as substrate in fermentation processes for the production of value added products like enzymes and biomass (Vandenberghe *et al.*, 2000). However, no information regarding

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the use of tapioca wastes (cassava bagasse and cassava peels) as organic mulching materials is available in literatures. Hence, the application of these industrial tapioca wastes as organic mulching materials to support plant growth requires investigation and evaluation.

Therefore, the objective of this study was to investigate the influence of tapioca wastes and rice husk on soil temperature and soil moisture, under pineapple (*Ananas comosus*) production.

2 Materials and Methods

The investigation was conducted from July 2001 to September 2002 in a pineapple plantation owned by a private company known as the Great Giant Pineapple Company (GGPC), located at Lampung province, in Indonesia. The site lies on latitude 4°59'S and longitude 105°13'E. The mean annual rainfall is 2,541 mm with diurnal mean air temperature of 21-34°C and diurnal mean humidity of 84-91% within the last ten years: 1990-2000 (Great Giant Pineapple Co., 2001). The whole cropping area was planted with the 'Smooth Cayenne' pineapple variety.

The site consisted of *Red-Yellow Podzolic* soil with sandy clay loam texture (clay 0.32-0.35 kg kg^{-1}, sand 0.52-0.59 kg kg^{-1} and silt 0.08-0.13 kg kg^{-1}), soil particle density of 2.67×10^3 kg m^{-3}, soil bulk density of 1.22×10^3 kg m^{-3} and available water content (-10 to -1500 kPa) of 0.09-0.13 m^3 m^{-3}.

Five mulching treatments, namely: control (no mulch), rice husks, cassava bagasse, cassava peel, and 0.5mm-black polyethylene film were applied. Each treatment consisted of two 0.6m×15m size plots, which was the standard size for pineapple culture in the study site.

Rice husks are the hard protecting coverings of rice grains that are removed during post harvest and are commonly used for organic mulching material around the study site. Cassava peel is the cortex of cassava tuberous root that is removed in the tapioca processing industry. Then, when the central part of the cassava tuberous root is ground and pressed under high pressure to extract the juice, the solid waste remaining is the cassava bagasse. The characteristics of the organic residues used as mulching materials are shown in Table 1.

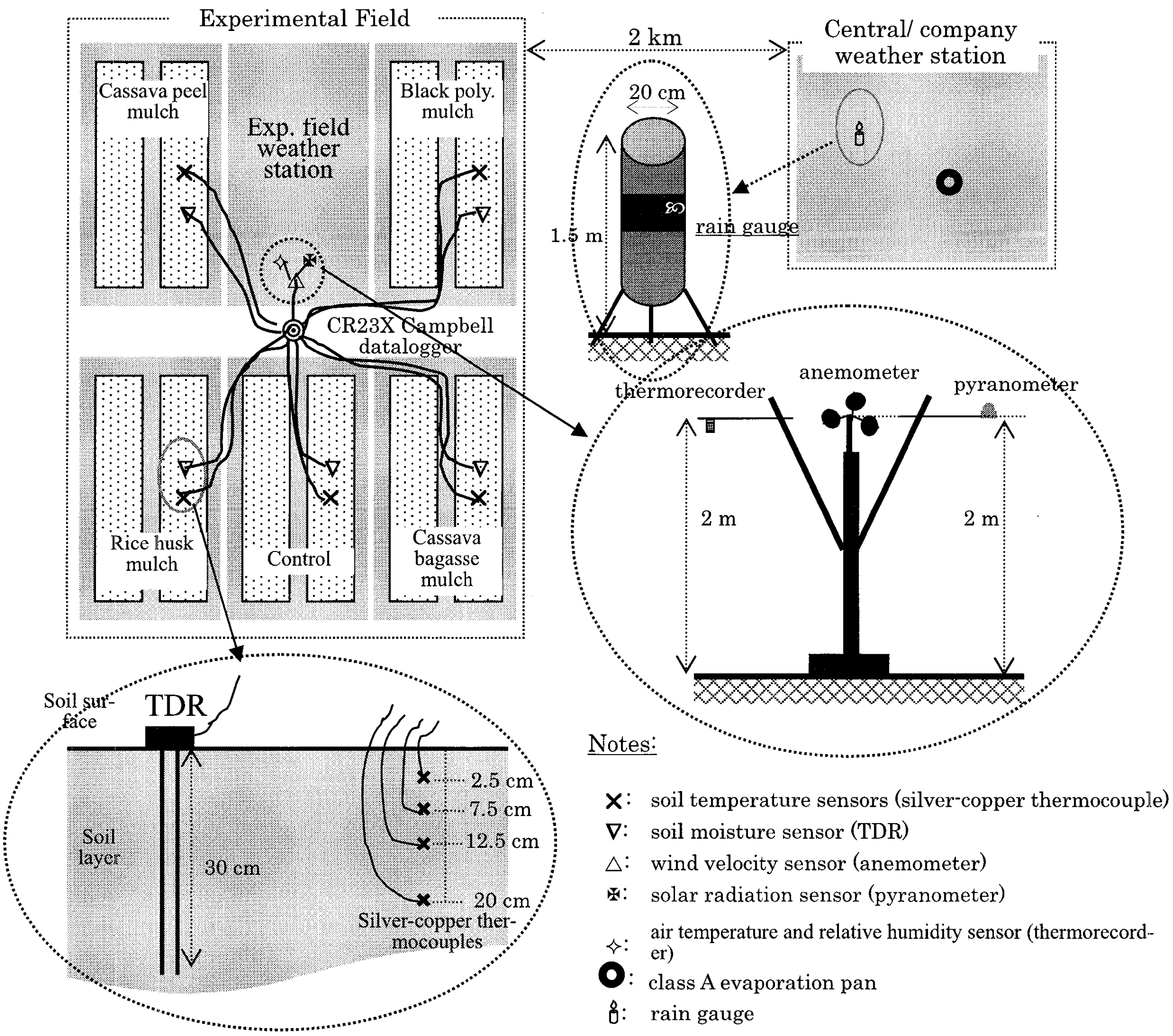

Figure 1: Schematic description of sensors' location and placement in the experiment field

Table 1: Application rate, water content and thickness of the organic mulches

Organic residues	Water Content (g kg^{-1})	Application rate dry weight (ton ha^{-1})	Mulch thickness (cm)
Rice husk	12.6	262.2	3 – 5
Cassava peel	14.1	257.7	3 – 5
Cassava bagasse	20.0	240.0	2 – 4

Pineapple seedlings were transplanted in June 2001 and mulching application was completed at late July 2001. Two rows of the seedlings were planted on each plot, the distance between each plant in a row was 25 cm, and a total of 120 plants occupied each plot.

Irrigation was given manually from August to September 2001 to support the initial stage of seedlings growth. The irrigation rates calculated from the potential evapotranspiration (ETo) and crop coefficient (Kc), were 4.68 mm d^{-1} during August 2001, 5.31 mm d^{-1} in September 2001 and 1.72 mm d^{-1} in July 2002, with the interval of 3 days.

Soil temperatures at the depth of 2.5, 7.5, 12.5 and 20 cm from soil surface were measured by using silver-copper thermocouples. Mean soil moisture content from soil surface to the depth of 30 cm was measured with probes of a TDR (Time Domain Reflectometer). Five units of silver-copper thermocouples and a unit of TDR were set in the middle of each treatment and connected to a unit of CR23X Campbell data logger for measurement at 10 minutes interval. A unit of pyranometer to measure solar radiation was placed at a height of 2m above the ground surface. A rain gauge was placed at a height of 1.5m, while an anemometer for measuring wind velocity and a thermo recorder for measuring air temperature were also positioned at a height of 2m from ground surface. Finally, a class 'A' evaporation pan for measuring evaporation rate was located at the site. The solar radiation data was also recorded by the CR23X Campbell data logger. The schematic description of sensors' location and placement is presented in Fig.1.

One hundred fruits of pineapple [*Ananas comossus* (L.) Merr.] from each treatment were sampled randomly and weighed to determine the fruit yield during harvest. Total wet biomass of pineapple was determined from 10% of total plants by destructive method, approximately 24 plants from each treatment. Also, fruit quality tests were performed to determine the brix and acid of fresh fruits using the RHB90 refractometer and chemical titration from 10% of total harvested fruits at each treatment. The data were processed statistically using Duncan's Least Significant Difference (LSD) test at 95% probability level.

3 Results and Discussion

3.1 Climate

The climatic data were divided into three periods as shown in Table 2. The evaporation rates of August and September in 2002 dry season were higher than in 2001 dry season, due to El Nino, the weather anomaly that hit Indonesia in 2002. The differences between maximum and minimum air temperatures during El Nino (August and September 2002) were lower than the corresponding months in 2001. This showed that El Nino engendered high air temperature by increasing the minimum air temperature. However, mean daily solar radiations were nearly the same within the 2001 and 2002 dry season.

Table 2: Monthly climatic data for the study period

Month	Rainfall	Evaporation	Air Temperature (°C)			Solar Radiation (MJ m^{-2} d^{-1})	Wind velocity (m s^{-1})
	Total (mm)		Max	Min	Mean	Mean	Mean
2001 Dry season							
Aug.	114	143	37.2	22.2	28.2	15.4	†
Sep.	170	116	43.0	20.8	28.0	17.3	†
Oct.	143	114	41.8	21.7	27.8	15.3	1.0
2001-2002 Rainy season							
Nov. 2001	245	107	45.3	22.9	31.2	15.3	1.1
Dec.	450	105	42.4	22.3	28.3	14.5	1.0
Jan. 2002	422	116	45.8	23.0	29.9	16.7	1.3
Feb.	282	102	44.7	21.5	31.1	13.7	1.4
Mar.	345	115	44.8	22.7	30.4	17.1	0.9
Apr.	333	94	43.2	22.6	28.6	15.5	0.8
2002 Dry season							
May	143	121	39.6	21.5	28.4	16.3	0.9
Jun.	118	138	46.5	19.2	31.0	14.4	1.0
Jul.	102	135	41.1	20.5	28.1	14.9	1.1
Aug.	5	185	42.5	17.1	28.9	17.0	1.4
Sep.	11	191	43.8	19.4	29.3	16.8	1.5

Note: † error in measurement
Solar radiation was measured at a height of 2m from soil surface

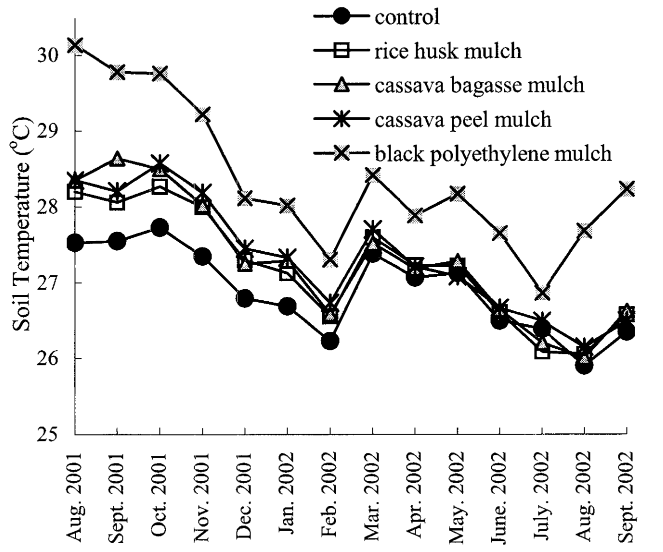

Figure 2: Mean monthly soil temperature at 0-25cm depth

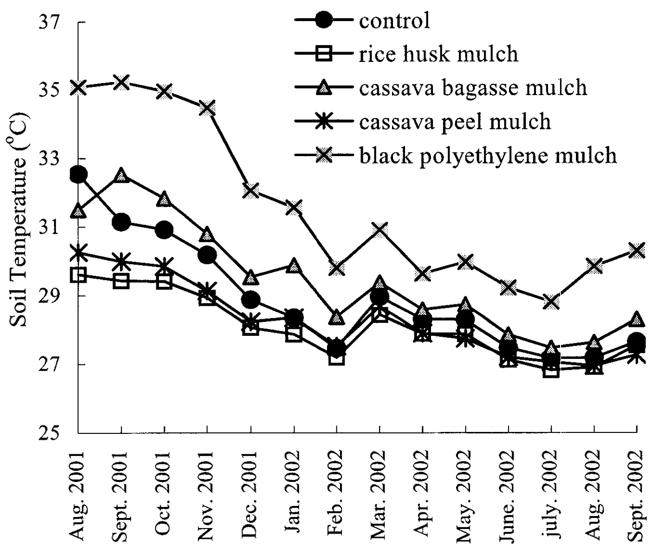

Figure 3: Mean daily maximum soil temperature at 2.5 cm depth per month

3.2 Soil Temperature

The mean soil temperatures from 0 to 25cm depth were observed with the silver-copper thermocouple at every 10 minutes are shown in Fig.2.

The mean soil temperatures tended to decrease from the initial to final stage, because heat absorption by the mulches was further suppressed by standing crops as the canopy progressively increased shading of the soil surface (Dekker and Ritsema, 1997).

The soil temperature under black polyethylene mulch was the highest of all the treatments during the whole period, because the black polyethylene film absorbed most of the heat from solar radiation and it also has the lowest albedo. Also the latent heat flux from ground surface was the lowest due to the interception of evaporation from soil surface. Meanwhile, the mean soil temperatures were similar under the organic mulches, but higher than control and lower than the black polyethylene mulch. Covering soil surface with organic mulches to decrease evaporation from soil surface resulted in a lower latent heat flux compared to control. On the other hand, from March 2002, the average soil temperatures of organic mulches were close to the control, because the organic materials had been decomposed and their thicknesses had shrunk.

Figure 3 shows the monthly mean daily maximum soil temperature at 2.5cm depth. It can also be seen that the maximum soil temperatures under the black polyethylene film mulch were the highest of all. On the other hand, the organic mulches decreased the heat conduction into the soil surface by retaining the incoming solar radiation heat. Thus, maximum soil temperatures under the organic mulches, especially the rice husk and cassava peel were lower than control. But despite cassava bagasse also being an organic material, the maximum soil temperature beneath it was higher than control. That happened because cassava bagasse is a material that can readily undergo fermentation process. Therefore, the increased maximum soil temperature under cassava bagasse mulching was caused by heat released through its fermentation process.

On the other hand, rice husk and cassava peel were slowly decomposed, possibly due to the cellulose contained in these materials. The gradual decomposition of rice husk and cassava peel rather afforded longer period of mulching existence. Hence, rice husk and cassava peel provided better protection than cassava bagasse.

Figure 4 shows the comparison of soil temperature profiles of each treatment in the three periods, i.e.: August 18, 2001, September 26, 2001 and August 22, 2002. Each profile is the hourly soil temperatures at 4 depths (2.5, 7.5, 12.5 and 20 cm) in a single day; therefore there are 24 lines for each treatment.

The reasons of choosing the periods are as follow: 1) August 18, 2001 represents the initial period when the mulching materials were still fresh and the canopy of plants was minimal; 2) it was assumed that in September 26, 2001 the canopy of plants was extending, therefore soil temperatures were affected by both mulch and canopy; and 3) August 22, 2002 was chosen because more than one year after the application, it was assumed that organic materials hadbeen decomposed and the canopy of plant had already completely covered soil surface. On the chosen days, there was no rainfall and the weather conditions were almost the same. The mean air temperature was 28.2, 28.4 and 29.2°C and total solar radiation was 16.2, 15.2 and 16.6 MJ m^{-2} d^{-1} at August 18, 2001, September 26, 2001 and August 22, 2002, respectively. It can be noted from Fig.4 that generally, soil temperature fluctuation gradually decreased in all treatments from the soil surface towards the deeper layers.

Soil temperatures of black polyethylene film mulch were higher than the control, and soil temperature profile showed a wider range for both minimum and maximum soil temperatures during the whole period.

It can also be seen from Fig.4 that minimum and maximum soil temperatures in cassava bagasse mulch were 0.5

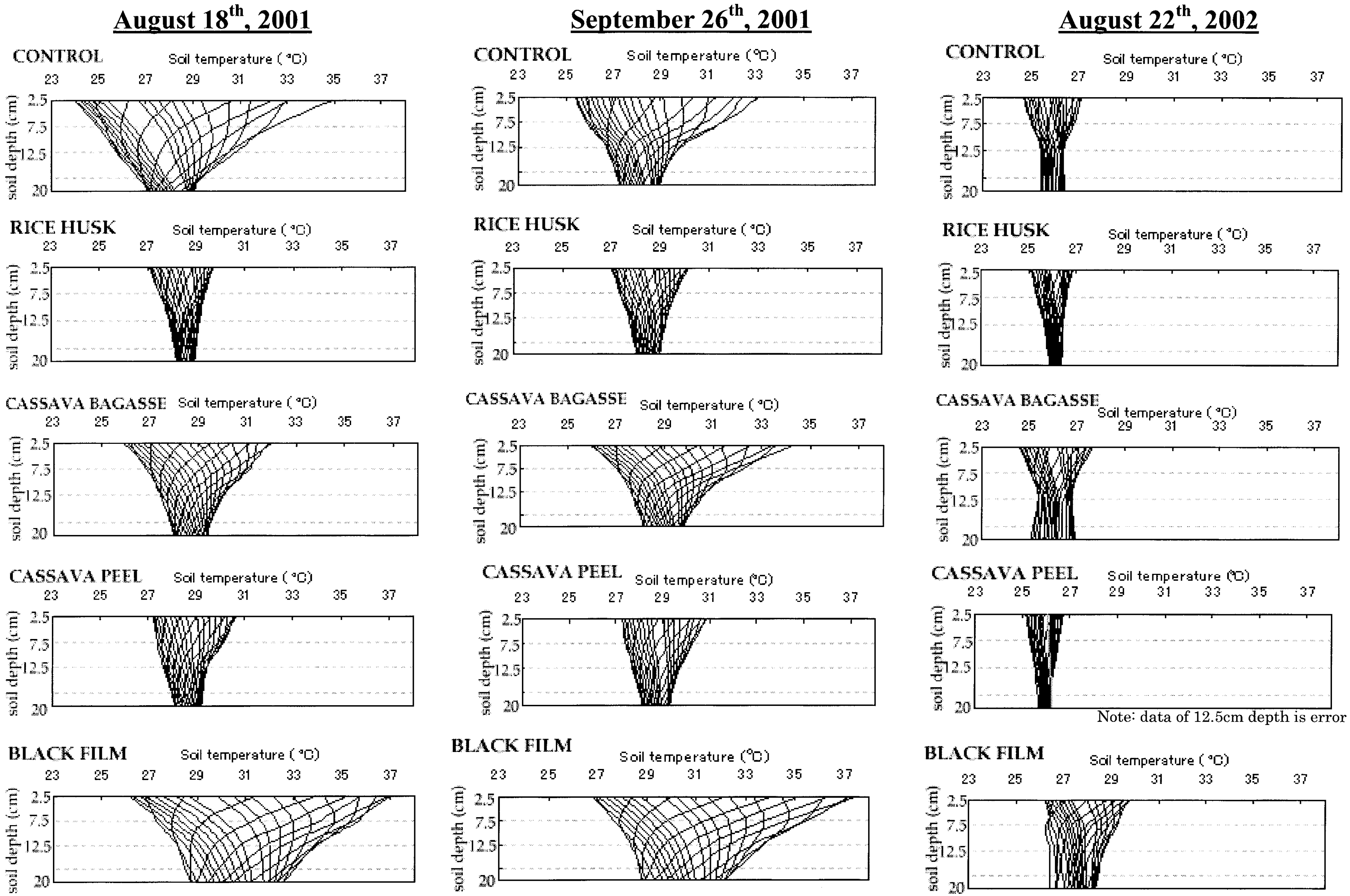

Figure 4: Soil temperature profile of each treatment measured on August 18th, 2001, September 26th, 2001 and August 22nd, 2002

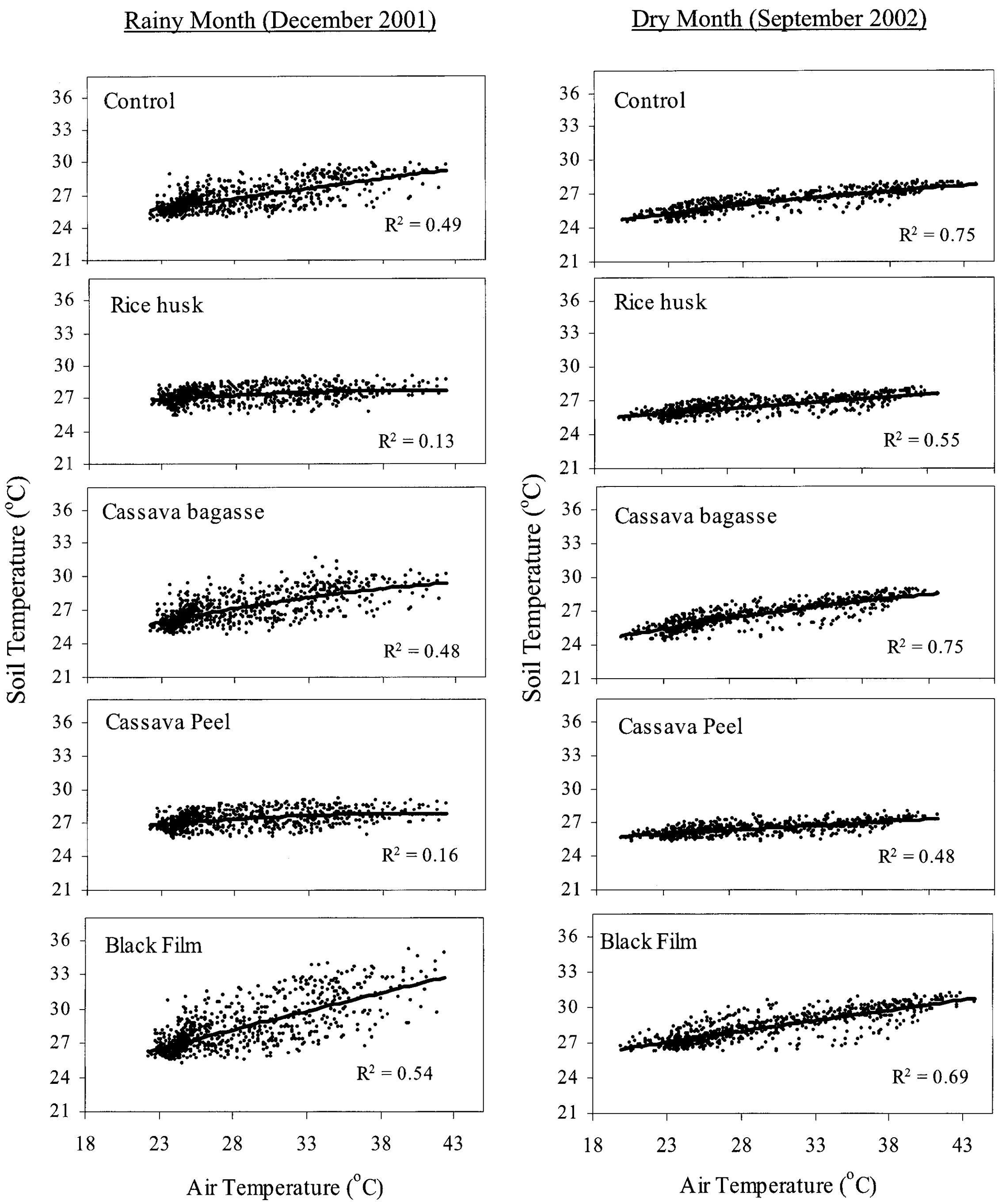

Figure 5: Relationship between air and soil temperatures under the various mulches at 2.5 cm depth

to 1.5°C higher than control at surface layer, especially during September 26, 2001. This may be attributed to the fermentation process of cassava bagasse as explained earlier from Fig.3 where the maximum soil temperatures beneath it were always higher than control and other organic mulching materials. The soil temperature fluctuation (the difference of the lowest and the highest soil temperature) shown in Fig.4 was also high under cassava bagasse mulch, although fermentation occurred, while the fluctuations were lower under rice husk and cassava peel mulches. That is probably due to the characteristic of cassava bagasse mulch that did not restrain the heat beneath it during nighttime when surrounding temperature was rather low. Hence the heat released to the air, and thus soil temperature was also rather low. But during daytime when surrounding temperature was also high, the fermentation process of cassava bagasse generated distinct high soil temperature.

On the other hand, the fluctuations of soil temperature under rice husk and cassava peel mulching were smaller than control. Under these organic mulches, minimum soil temperature rose and maximum soil temperature dropped, which shows that rice husk and cassava peel maintained soil temperatures by retaining incoming solar radiation heat within the mulch layers during daytime, and also restraining heat release from soil layers to the air during nighttime.

Figure 5 shows regression curves of the hourly air temperature and soil temperature at 2.5cm depth for December 2001 rainy season and September 2002 dry season. The relationships between soil and air temperatures of each treatment at each month were determined with the regression values.

It is shown in Fig.5 that generally, air temperature and soil temperature correlated better during dry season than rainy season. During dry month, less energy is required to raise soil temperature while much more energy is required to raise soil temperature during rainy month, because the specific heat of dry soil is smaller than that of moist soil.

The regression lines for rice husk and cassava peel mulches showed a stable condition with nearly horizontal lines, which indicated that air temperature did not affect soil temperature, hence these mulches were good at insulating the soil. On the other hand, soil temperatures under cassava bagasse and black polyethylene film mulches slightly increased with the corresponding increase in air temperature. Their regression values were higher than those of rice husk and cassava peel mulches. This suggests that cassava bagasse and black polyethylene film mulches are not very good heat insulating materials.

3.3 Soil Moisture Content

The two main factors that influence soil moisture content are water inflow (precipitation) and outflow (evaporation/ evapotranspiration). Therefore, an important practice for rain-fed agriculture is to increase effective rainfall and decrease evaporation from soil surface. Mulches prevent soil water evaporation and thus help to retain soil moisture. The effects of organic mulches on soil moisture content depended on the climate (dry/rainy season) and the type of organic materials.

Figure 6 shows the mean monthly soil moisture contents at 0-30 cm depth measured with TDR. The monthly fluctuations of soil moisture content were almost similar for all treatments. The increases of soil moisture from August to

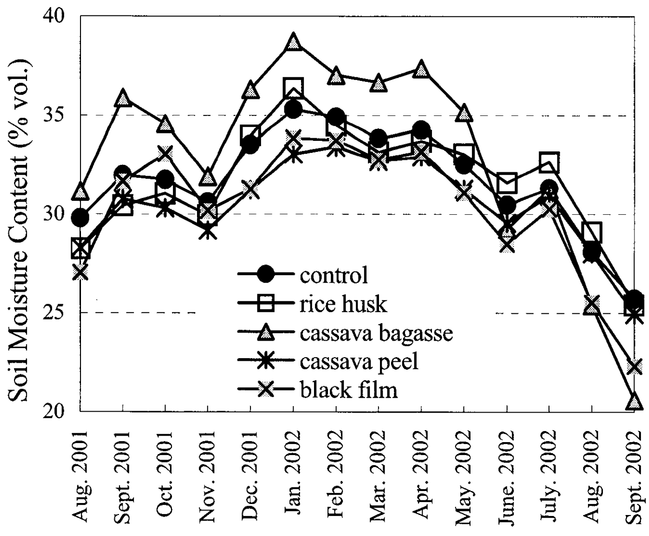

Figure 6: Mean monthly soil moisture content at 0-30cm depth (using TDR)

September 2001 and from June to July 2002 were due to the irrigation applied during these periods. Pineapple is a drought-tolerance plant, but low rainfalls could be harmful to the plant growth during critical stages such as the initial stage of seedling (Aug.-Sept.2001) and initial stage of fruit development (June-July 2002). High rainfalls from December 2001 to April 2002 resulted in high soil moisture contents. As a result of low rainfall and high evaporation from May 2002, soil moisture content started to decrease.

As shown in Fig.6, the cassava bagasse mulching maintained the highest soil moisture contents compared to the control until May 2002. Next, soil moisture under the rice husk mulch was nearly similar to the control and finally, the soil moistures under the cassava peel mulch as well as the black polyethylene film mulch were both lower than the control.

From September 2001 to May 2002 when the total rainfall was higher than evaporation (Table 2), soil moisture contents under cassava bagasse mulch were the highest. This may indicate that cassava bagasse mulch layer absorbed rainwater, which infiltrated into soil layers gradually and continuously and thus more water could be conserved during precipitation. Therefore, cassava bagasse enhanced the effective rainfall. However, from May to September 2002 when there was low rainfall, Fig.6 shows that soil moisture contents under cassava bagasse and black polyethylene film mulches decreased sharply. This may be due to the better plants' growth in those treatments, which are shown by their higher wet biomasses in Table 3. Bigger plants in cassava bagasse and black polyethylene film mulches promoted higher transpiration rates than smaller plants in other treatments, and hence soil moisture content decreased sharply under these treatments during dry season 2002 than others.

Meanwhile, the soil moisture content remained low under cassava peel and black polyethylene film mulching in spite of high rainfalls from Dec. 2001 to April 2002. The impervious polyethylene film material completely covered and protected soil surface from water infiltration into layers beneath it. During this experiment, cassava peel behaved just like the polyethylene film mulch.

3.4 Pineapple [*Ananas comosus* (L.) Merr] Production and Quality

There were no significant differences in yield and fruit quality parameters ($P \leq 0.05$) in all the treatments as shown in Table 3. In descending order, the total wet biomass and fruit yield weights were as follows; black polyethylene film>cassava bagasse>cassava peel>rice husk>control.

Table 3: Pineapple wet biomass, fruit yield, and fresh fruit quality

Mulching Treatment	Wet Biomass (g plant^{-1})	Fruit yield (t ha^{-1})	Brix	Acid
Control	3,037	123.4	14.45	0.43
Rice husk	3,089	129.5	14.70	0.45
Cassava bagasse	3,217	139.3	14.44	0.43
Cassava peel	3,169	134.7	14.45	0.42
Black film	3,541	144.3	14.34	0.43
Significance	**NS**	**NS**	**NS**	**NS**

*Significant at $p \leq 0.05$ using LSD

Pineapple is in the group of succulent plants, which is water-retaining plant and adapted to arid climate condition. The succulent plants including pineapple use a specialized photosynthesis pathway called Crassulacean Acid Metabolism (CAM). CAM plants open their stomata during night, and close during the day. Hence, the transpiration and also the water uptake from root to the stem, leaves, and fruits, occur at night. During this stage, soil temperature plays an important role in the physiological process, since low soil temperature results in decreasing absorption of water by plants (Kramer, 1934). Hence, maintaining soil temperature in the pineapple culture would enhance water absorption by plants and thus improve production and yield.

Fig.2 and Fig.3 show that black film mulch maintained the highest soil temperatures, hence the highest wet biomass and fruit yield. Similarly, cassava bagasse also maintained higher soil temperatures and thus resulted in high biomass and yield too.

Regarding the quality of pineapple, there were no significant differences in brix and acidity of fresh fruits for all treatments.

4 Conclusions

Soil temperature regimes were greatly ameliorated by the mulching materials and that enhanced water absorption by pineapple, which is a succulent plant, and thus improved the total wet biomass and yield.

The mean soil temperatures at 0-25cm depths under the mulches were higher than control due to the low latent heat flux that was restrained beneath the soil surface. The fermentation process of cassava bagasse released heat into the surrounding and resulted in the maximum soil temperature increase at surface layer. On the other hand, rice husk and cassava peel retained the heat from solar radiation within the mulches layers and thus contributed in the decreased maximum soil temperatures.

Among all the mulching materials investigated, cassava bagasse enhanced effective rainfall during rainy season.

In areas experiencing limited rainfall and high evapotranspiration due to climatic change, mulching management strategies should consider the influence of each type of mulch available. These considerations include nutrient management, water conservation and soil protection. Consequently, further research on tapioca residue (cassava bagasse and peels) mulch is required in order to identify their contributions to nutrient enhancement of soil and hence potential for different crop yields. Furthermore, Cook et al. (2006) stated that when wheat straw application was increased, water retention increased and temperature decreased. But, it is evident that both water retention and temperature increased under cassava bagasse in this study. Therefore, different rates of application of tapioca residues and their contribution to nutrient enhancement of soil and hence potential for crop yield improvement need further studies.

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References

[1] Begum, S.A., Ito, K., Senge, M., Hashimoto, I., and Asai, O. (2001a): Assessment of selected mulches for reducing evaporation from soil column sand dynamics of soil moisture and temperature, Sand Dune Research, 48(2), pp.49-56.

[2] Benoit, G.R. and Kirkham, D. (1963): The effect of soil surface conditions on evaporation of soil water, Soil Sci. Soc. Am. J. Proceed., pp.495-498.

[3] Cook, H.F., Valdes, G.S.B., and Lee, H.C. (2006): Mulch effects on rainfall interception, soil physical characteristics and temperature under *Zea mays* L, Soil and Tillage Research, 91, pp.227-235.

[4] Dekker, L. M. and Ritsema, C.J. (1997): Effect of maize canopy and water repellency on moisture patterns in a Dutch black plaggen soil, Plant Soil, 195, pp.339-350.

[5] Ferraris, R. (1992): Seedbed factors affecting establishment of summer crops in a Vertisol, Soil and Tillage Research, 23, pp.1-25.

[6] Great Giant Pineapple Co. (2001): The report on climate from 1990-2000. (Unpublished Report-for Internal Use)

[7] Ghuman, B.S. and Sur, H.S. (2001): Tillage and residue management effects on soil properties and yields of rainfed maize and wheat in a subhumid subtropical climate, Soil and Tillage Research, 58, pp.1-10.

[8] Kramer, P.J. (1934): Effects of soil temperature on the absorption of water by plants, Science, 79(2051), pp.371-372.

[9] Mohavedi Naeni, S.A.R. and Cook, H.F. (2000a): Influence of compost amendment on soil water and evaporation, Commun. Soil Sci. Plant Anal., 31(19/20) , pp.3147- 3161.

[10] Olasantan, F.O. (1999): Effect of time of mulching on soil temperature and moisture regime and emergence, growth and yield of white yam in western Nigeria, Soil and Tillage Research, 50, pp.215-221.

[11] Parkinson, R.J., Fuller, M.P., and Groenhof, A.C. (1999): An evaluation of green waste compost for the production of forage maize (*Zea mays* L.), Compost Sci. Util., 17(1), pp.72-80.

[12] Sellers, G., McRae, S.G., and Cook, H.F. (2001): Oilseed rape and field bean production potential on an amended former landfill site stored with London clay, Land Degrad. Dev., 12, pp.487-504.

[13] Sharma, P.K. and Acharya, C.L. (2000): Carry-over of residual soil moisture with mulching and conservation tillage practices for sowing of rainfed wheat (*Triticum aestivum* L.) in north-west India, Soil and Tillage Research, 57, pp.43-52.

[14] Srivastava, P.K., Parikh, M.M., Sawani, N.G., and Raman, S. (1994): Effect of drip irrigation and mulching on tomato yield, Agricultural Water Management, 25, pp.179-184.

[15] Unger, P.W. and Parker, J.J. (1976): Evaporation reduction from soil with wheat, sorghum and cotton residue, Soil Sci. Soc. Am. J., 40, pp.938-942.

[16] Vandenberghe, L.P.S., Soccol, C.R., Pandey, A., and Lebeault, J.M., (2000): Solid state fermentation for the synthesis of citric acid by *Aspergillus niger*, Bioresource Technology, 74(2), pp.175-178.

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