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ORIGINAL RESEARCH

Organic mulch sheet formulation as an effort to help plants adapt to climate change

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Abstract

Purpose This study aimed to discover the precise material composition and thickness (water hyacinth, rice straw, and banana pseudostem) of organic mulch sheet.

Methods This current research was conducted by means of a number of treatments with various material compositions and thickness of organic mulch sheet. Several tests were administered such as chemical analyses on organic mulch sheet, tensile strength, and Vilensky test.

Result Various compositions of materials resulted in various chemical analyses of organic mulch sheet. Organic mulch with the strongest tensile strength was during the treatment of 60% water hyacinth, 20% rice straw, and 20% banana pseudostem, reaching 3.28 N/m^2. The highest sunlight intensity of mulch composition was during the treatment of M4 (50% water hyacinth, 40% rice straw, and 10% banana pseudostem) with no hole and absorbing.

Conclusion The result showed that water hyacinth, rice straw, and banana pseudostem could be used as the materials for organic mulch sheets. They could add organic matters into the soil, have endurance and strength to apply as mulch in crop cultivation, as well as help plants adapt to climate change.

Keywords Organic mulch sheet · Organic matters · Tensile strength · Vilensky · Climate change

Introduction

Mulch is a soil cover that functions to maintain soil temperature and humidity, inhibit the growth of weeds, also lessen soil erosion (Díaz-Pérez and Batal 2002; Kar and Kumar, 2007; Ekinci and Dursun, 2009; Sinkevičienė et al. 2009; Ibarra-Jiménez et al. 2011; Dvořák et al. 2012). In horticulture plantation, both organic mulch and inorganic mulch have been into a common use (Dvořák et al. 2001; George Hochmuth et al. 2002; Kasirajan and Ngouajio 2012; Cowan 2013; Lakkenborg et al. 2014; Azad et al. 2015). Specifically, in this unstable climate and global warming condition (Wai et al. 2007), mulch is utilized to help plants adapt to climate change by modifying microclimate around the growing plants (Dvořák et al. 2001; Ibarra-Jiménez et al. 2011; Kasirajan and Ngouajio 2012). The following concern would be on the environment modification to optimize the growth of plants so as to improve potential production (Scholes et al. 1997; Peng et al. 2004; Widiatningrum and Pukan 2010; Kalra et al. 2013). The growth and productivity of plants generally are affected by rainfall, temperature, humidity, and soil fertility (Pereira and Nova 2008; Ayinde et al. 2011; Mahmood et al. 2012; Iriany et al. 2013; Nakano et al. 2013; Yaghi et al. 2013). Some previous studies have found that mulch usage increases plant productivity (Siwek et al. 2007; Miles et al. 2012; Haapala et al. 2015).

Mulch has been into a common use in crop cultivation, yet with a number of drawbacks, such as the use of environmentally unfriendly synthetic materials that are hard to degrade (transparent plastic, PHP, etc.), apart from their high price that are less affordable for farmers (O'Brine and Thompson 2010; Coolong 2012; Kasirajan and Ngouajio

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2012; Miles et al. 2012). However, the use of organic mulch from rice straw, litter, and others are unstable at the time. Accordingly, it is urgent to come up with alternative organic materials from the accessible surrounding environment to be made for organic mulch for the farming field with simple technology. Organic mulch requires modification into more effective and efficient forms in usage by modifying it into sheet forms. Besides, the use of paper as mulch has been developed in some patents such as using cellulose fibers with additional materials, cellulosic pulp with biodegradation-retarding agent and addition of fertilizer to optimize mulch function (Wright 1936; Pratt and Medford 1955; Yoko et al. 1986; Peter. F et al. 2003). Most of these patents still used additional materials that are inorganic and relatively expensive to increase satisfactory mechanical strength.

An organic material as a renewable resource contains wood or natural fiber called as cellulose. Organic mulch sheet made from fiber can be processed from natural cellulosic source such as kenaf, pineapple leaf fiber, banana fiber, coir, paddy straw, sugarcane, water hyacinth, corn cobs, and many more (Azubuike & Okhamafe 2012; Bhatnagar et al. 2015; Indriyati et al. 2016; Salleh et al. 2015; Main et al. 2014; Sarika et al. 2014; Teygeler 2000). These materials contain fiber waste similar to the materials for this current research. The use of organic fiber waste such as banana pseudostem, straw, and water hyacinth for the organic mulch sheet will improve soil properties as the combination of papermaking and organic fertilizer (Mawlana et al. 2014; Vidya and Girish, 2014). Natural organic mulch eventually breaks down and adds organic materials to the soil. Degradation or decomposition of organic mulch increases the amount of soil organic carbon (Bajorien et al. 2013). Hence, microbial activity in the soil will increase, especially microbial biomass supporting any enzymatic process in the soil (Jodaugienė et al. 2010; Moreno et al. 2011). The issue about the use of water hyacinth that has the ability to absorb heavy metal and will harm soil microorganism and the crop is not true. Metals such as iron, manganese, chrome, and cadmium were highly concentrated at the roots than other parts of the plant like leaves and stem. Commonly, the highest concentration of heavy metal in water hyacinth plant is in root, followed by leaves and stem, respectively (C.N et al. 2014; Das et al. 2016; Saha et al. 2017). Water hyacinth can be used as fertilizer, fish or animal feed and for mushroom cultivation. It means that water hyacinth can be used as an organic matter added into the soil. Previous researches showed that organic fertilizer from contaminated heavy metal water hyacinth and cow dung (mass ratio 1:5 and 1:1) did not exceed the limit of quantities of heavy metal and can be applied. Besides, compost of water hyacinth has a positive effect on the formation of macro-aggregates of the soil, water holding capacity, cation exchange capacity and non-significant changes in pH occurred (Khan and Sarwar 2002; Nyawira 2016; Sindhu et al. 2017).Water hyacinth commonly used as bio-absorption of heavy metal does not contain heavy metal on high proportion that will damage or affect the soil (Gavrilescu 2004).

With simple technology, this organic mulch sheet is cheaper in price as it recycles wastes, more practical and effective in usage, using simpler technology, environmentally friendly, and in long-term increases soil fertility. Accordingly, it is necessary to discover the precise material composition of organic mulch sheet.

Methods

The experiment was conducted in the laboratory of the University of Muhammadiyah Malang and in the farming field in Batu, East Java, in the altitude of 1670 meters above sea level. The experiment was done from March to July 2014.

Material

The making of organic mulch sheet requires the following materials: water hyacinth, rice straw, and banana pseudostem. The tools were: organic mulch sheet molds, a digital scale, scissors, knife, measuring cup, blender, sieve, stove, pan, and caliper.

Experimental design

This research was conducted by employing a completely randomized design. The treatment experiment included compositions of organic mulch sheet materials with six variations and two thickness (twelve combinations), then repeated three times. The variation of organic mulch sheet compositions included M_1 = 40% water hyacinth:40% Rice straw:20% banana pseudostem; M_2 = 50% water hyacinth:20% Rice straw:30% banana pseudostem; M_3 = 50% water hyacinth:30% Rice straw:20% banana pseudostem; M_4 = 50% water hyacinth:40% Rice straw:10% banana pseudostem; M_5 = 60% water hyacinth:20% Rice straw:20% banana pseudostem; M_6 = 0.60%water hyacinth:30% Rice straw:10% banana pseudostem. There are two levels of organic mulch sheet thickness, T_1 = 0.5 mm and T_2 = 1 mm.

Implementation of the study

Making of mold

Preparing Styrofoam and cloth; one hole was made on the Styrofoam with the size of 30 cm × 50 cm; the upper part of Styrofoam was covered by the cloth.

Preparation of tools and materials

Preparing water hyacinth, rice straw, banana pseudostem, and necessary tools.

Cutting and weighing

The total weight of mulch for each combination was 1000 g. Water hyacinth, rice straw, and banana pseudostem were weighted based on the set composition in each treatment before finally being cut into the size of 1 cm.

Pulping

Water hyacinth was blended for 15 min and banana pseudostems were blended for 20 min by the addition of water before being squeezed to take the pulp.

Molding

Molding process started by pouring and flattening the hot pulp into the prepared mold. Then, the pulp in the mold was dried while being steadily pressed to eliminate the water.

Measured variables and data analysis

The following tests were conducted: chemical analysis of the organic materials (C organic, N total, C/N ratio and organic matter), organic mulch sheet tensile strength by Brazilliant test (N/cm^2), Vilensky and sunlight exposure intensity tests. Tabulation was then conducted before statistically being analyzed by means of F Test. To detect the differences among the treatments, BNJ Test in the level of 5% was conducted. The data were analyzed by means of Minitab version 17 software.

Results and discussion

The organic mulch sheet was made of water hyacinth, banana pseudostem, and tannery waste. It produced a compact and strong structure (Li et al. 2010; Sutyasmi 2012; Sahari and Buku 2015). The high cellulose content in the water hyacinth and banana pseudostem (over than 60%) and low lignin content (lower than 5%) through the delignification process are used to remove the lignin contained in the materials (Li et al. 2010; Tumolva et al. 2013; Ramesh et al. 2014).

Chemical analysis

The results are shown in the following Table 1 about chemical analyses on organic materials for organic mulch sheet in various treatments. From various treatments, it could be seen that treatment M3 (50% water hyacinth: 30% rice straw, 20% banana pseudostem) and M1 (40% hyacinth: 40%rice straw, 20% banana pseudostem) showed the highest N total of contents compared to that of other treatments. Previous study showed 50% water hyacinth and 30 and 20% straw organic mulch sheet composition increased C-organic, N-total, and organic matter compared with 60% water hyacinth and 30% straw composition (Iriany et al. 2016). Besides, the nitrogen content of banana pseudostem is the highest than other raw materials. Nitrogen content of water hyacinth, straw, and banana pseudostem in dry matter, respectively, are 0.28%; 0.5–0.8%; and 0.93–1.87% (Dobermann and Fairhurst 2002; Abdullah et al. 2014).

Table 1 The results of chemical analyses on organic materials for organic mulch sheet

Treatment	C-organic (%)	N-total (%)	C/N ratio	Organic matter (%)
M_1 (40:40:20)	27.69	10.16	3	47.90
M_2 (50:20:30)	29.67	7.96	4	51.32
M_3 (50:30:20)	31.41	11.93	3	54.33
M_4 (50:40:10)	32.78	5.73	6	56.71
M_5 (60:20:20)	32.89	7.8	4	56.91
M_6 (60:30:10)	31.03	2.04	15	53.68

Table 2 The results of tensile strength analyses on composition treatment for organic mulch sheet

Treatment	Tensile strength (N/m^2)
M_1 (40:40:20)	28.1
M_2 (50:20:30)	23.2
M_3 (50:30:20)	27.5
M_4 (50:40:10)	18.8
M_5 (60:20:20)	32.8
M_6 (60:30:10)	22.1

Tensile strength

Based on the test of the mulch tensile strength, it resulted in the following numbers as shown in Table 2. Table 2 showed that the highest tensile strength was during the treatment of M5. Previous researches have shown that 60% water hyacinth, 20% straw, and 20% banana pseudostem composition gained the highest tensile strength value than other treatments (Djojowasito et al. 2007; Indriyati et al. 2016). Water hyacinth has a compact, short, and soft fiber than others, therefore, it contributes more effects on the tensile strength of organic mulch sheet. Besides, the tensile strength of organic mulch sheet is higher than biodegradable paper made (patented) by Peter. F et al. (2003)

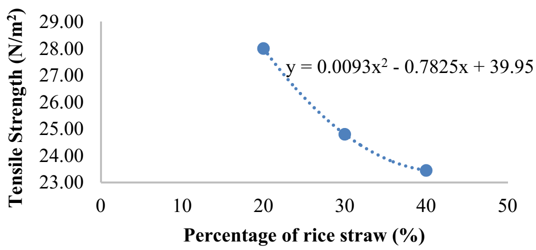

Fig. 1 The correlation between tensile strength and the percentage of rice straw contents in organic mulch sheet

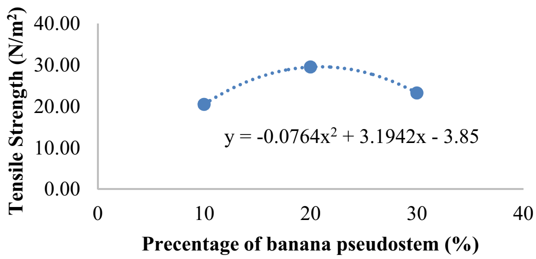

Fig. 2 The correlation between tensile strength and the percentage of banana pseudostem contents in organic mulch sheet

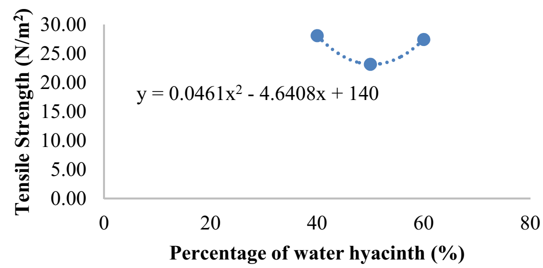

Fig. 3 The correlation between tensile strength and the percentage of water hyacinth contents in organic mulch sheet

although it is still lower in tensile strength compared to that of fiber composite made from kenaf and pineapple (J, M.K and W.S 2015).

Figure 1 shows that the increase of rice straw proportion resulted in the decrease of tensile strength. Figure 2 shows the parabolic correlation between the proportion of banana pseudostem and tensile strength and the optimum proportion is shown to be 20%. The correlation between tensile strength and water hyacinth proportion displays an inverse manner from the correlation between tensile strength and banana pseudostem proportion (Fig. 3). The optimum proportions of water hyacinth are 40 and 60%. In each material, the maximum tensile strength was gained from rice straw proportion of 20%, banana pseudostem proportion of 20%, and water hyacinth of 60%. It is similar to the previous study revealing that the highest tensile strength has been gained from 20–30% banana pseudostem (Djojowasito et al. 2007); also, the other paper exhibited the highest tensile value of the sample at 15 wt% composition of fiber than 5 and 10 wt% (MdRadzi et al. 2015). Another paper has shown that the proper comparison of hyacinth plant and coconut coir was 88 and 12% (Nugroho et al. 2013) also the additional treatment to increase tensile strength was by alkali and enzyme treatments (Tumolva et al. 2013). For pulp from straw, tensile strength could gain 153.10^5 N/m^2 (Saragi, 2008). Each type of fiber source has its different characteristics as well as its effects on tensile strength of organic mulch sheet. Accordingly, it is crucial to find the proper combination of materials.

Table 3 The result of vilensky test of various organic mulch sheet composition

Treatment	Sunlight intensity			Note
	Before	After		
		Wet	Dry	
M_1 (40:40:20)	15	190	14	Without hole, absorbing
M_2 (50:20:30)	19	45	22	Without hole, non-absorbing
M_3 (50:30:20)	28	238	20	Without hole, absorbing
M_4 (50:40:10)	33	298	40	Without hole, absorbing
M_5 (60:20:20)	8	92	3	Without hole, absorbing
M_6 (60:30:10)	25	194	24	Without hole, absorbing

Vilensky test

Table 3 shows that based on Vilensky test, the highest sunlight intensity of mulch composition was during the treatment of M4 (50% water hyacinth:40% rice straw:10% banana pseudostem). Viewed from the proportion of water hyacinth, the increase in the proportion of water hyacinth could increase sunlight intensity. The picture also portrays that the increase, as well as linear trends, was shown in dry mulch condition. It shows that the increase in the proportion of water hyacinth affects the increase in sunlight intensity (Fig. 4). Fibers from water hyacinth and banana pseudostem that have tied each other prevent the forming of the hole on the mulch (Djojowasito et al. 2007).

Viewed from rice straw proportion used in mulch both with the thickness of 0.5 mm and 1.0 mm, especially for mulch in wet condition, the quadratic curve with the peak/maximum cusp was formed in the proportion of 30%. The same case also occurred in the dry condition of mulch. It indicates that the increase and decrease in rice straw proportion affect the decrease in sunlight intensity (Figs. 5 and 6).

Viewed from banana pseudostem proportion used in mulch both with the thickness of 0.5 mm and 1.0 mm, especially for mulch in wet condition, the quadratic curve tended to decline. In the wet condition, the increase in banana pseudostem proportion affects the decrease in sunlight intensity.

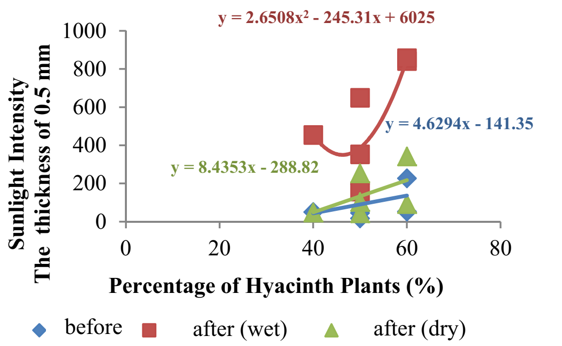

Fig. 4 The correlation between sunlight intensity and the percentage of water hyacinth in 0.5 mm organic mulch sheet

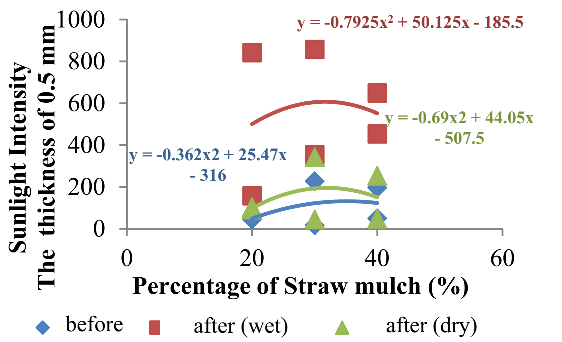

Fig. 5 The correlation between sunlight intensity and the percentage of rice straw in 0.5 mm organic mulch sheet

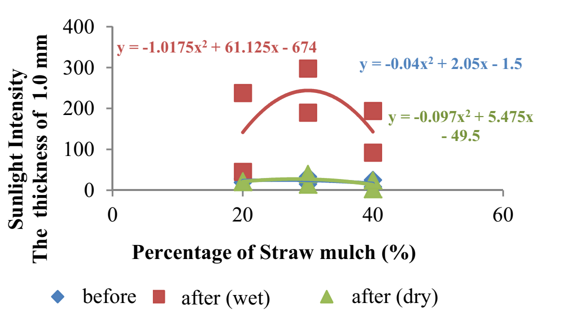

Fig. 6 The correlation between sunlight intensity and the percentage of rice straw in 1.0 mm organic mulch sheet

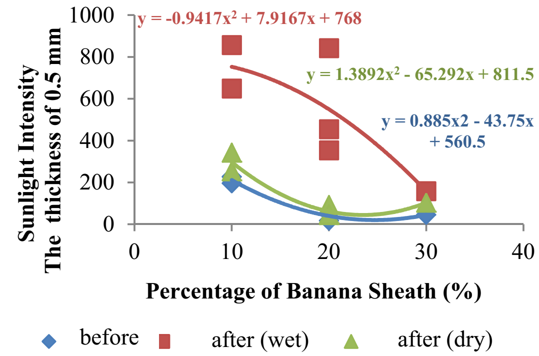

Fig. 7 The correlation between sunlight intensity and the percentage of banana pseudostem in 0.5 mm organic mulch sheet

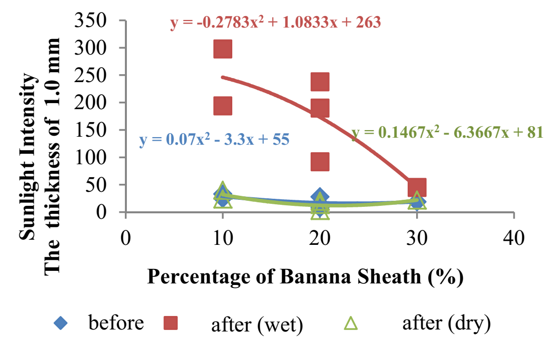

Fig. 8 The correlation between sunlight intensity and the percentage of banana pseudostem in 1.0 mm organic mulch sheet

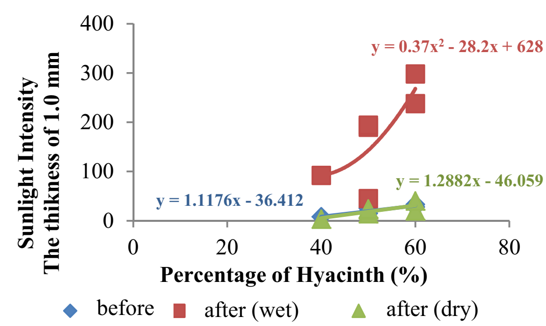

Fig. 9 The correlation between sunlight intensity and the percentage of water hyacinth in 1.0 mm organic mulch sheet

However, in the dry condition, the quadratic curve tended to open upward. It is shown that the minimum cusp of sunlight intensity was formed in the proportion of 20–30%. The higher proportion of banana pseudostem resulted in the increase in sunlight intensity (Figs. 7 and 8).

Viewed from hyacinth proportion used in mulch both with the thickness of 0.5 mm and 1 mm, the quadratic and linear

Table 4 The result of correlation analysis between chemical characteristics of mulch materials and tensile strength of mulch

Chemical characteristics of mulch materials	Correlation	*p* value
C-organic	− 0.113	0.726
N-total	0.072	0.823
C/N	0.032	0.921
Organic materials	− 0.113	0.726

curve tended to ascend along with the increasing proportion of hyacinth. In the wet and dry conditions, the increase in hyacinth proportion affects the increase in sunlight intensity. The higher proportion of hyacinth resulted in the increase in sunlight intensity (Figs. 4 and 9).

The result of correlation test between chemical characteristics of mulch materials and tensile strength of mulch has shown that chemical characteristics of all materials have *p* value more than 0.05. It proves that there is no significant correlation between C-organic contents, N Total, C/N, and organic materials and tensile strength of mulch (Table 4).

Conclusion

The result of this current research has revealed that water hyacinth, rice straw, and banana pseudostem could be used as materials for organic mulch sheet. The best composition has been shown during the treatment of 60% water hyacinth, 20% rice straw, and 20% banana pseudostem seen from tensile strength and endurance towards the water and normal mulch stretch. The best treatment was the composition of 50% water hyacinth, 40% rice straw, and 10% banana pseudostem. Organic mulch with the strongest tensile strength of 32.8 N resulted during the treatment of 60% water hyacinth, 20% rice straw, and 20% banana pseudostem; also the highest C-organic content was during this treatment that accounted for 32.89%.

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