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Influence of mulch and plant spacing on yield of *Solanum tuberosum* L .cv. Nadiya at medium altitude

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Abstract

Potato (*Solanumtuberosum* L.) is an important horticultural crop in Indonesia that has a high economic value. Development of potato crops at medium altitude is currently facing several constraints. The main constraint is environmental exposure to high temperatures. To maintain potato supply, there is a constant need for a cultivation technology to manipulate the environment where the plant grows using a mulching technology that affects the temperature of the soil. The purpose of this study is to describe the most suitable mulch combination with plant spacing in order to increase potato yields at medium altitude. The results showed that the potatoes grown with a plant spacing of 60 × 30 cm on rice straw mulch had the highest growth component at 8WAP. The plant height, stem diameter, and leaf area were 110.40 cm, 13.20 mm and 3,959.90 cm^2, respectively. The growth rate was 2.36 gram/day, the dry weight was 660.73 grams and the yield was 66.30 tons ha^{-1}. To grow potato in medium altitude is recomended using straw mulch and plant spasing 60 × 30 cm.

Introduction

Potato (*Solanum tuberosum* L.) is a type of tuber contained high carbohydrate and other nutrients, and is expected to become an alternative source of carbohydrate. The national productivity of potato is increasing due to increasing demand of potato by the consumer. Between 2009 and 2012, the productivity of potato was 66,531 ha^{-1}, 59,882 ha^{-1}, and 65,989 ha^{-1} and the areas resulting 15.94 tons ha^{-1}, 15.96 tons ha^{-1}, and 16.58 tons ha^{-1}respectively (the National Statistics Bureau and Directorate General of Horticulture, 2010). The national potato consumption keeps increasing with the projection of 1.68% per year until 2014. In 2002, the potato consumption was 0.82 million tonsand it increased to 0.88 million tonsin 2006 and 0.93 million tons in 2007 (FAO, 2012). The total area of potato plantation in 2013 was 62,900 Ha with the total production of 1,124,282 tons (the National Statistics Bureau and Directorate General of Horticulture, 2015).

In Indonesia, the potato is generally grown in the highlands, an area located more than 1,000 meters above sea level because it has to grow at low temperatures. The main reason why the potato was grown at medium altitude was the lack of area for potato cultivation in the highlands. Therefore, both intensification and extensification are needed to increase production of potato. Extensification strategy is to if for increase the potato growth on the lower land and medium plans (300 to 700 meters above the sea level) because there is a vast area of the medium altitude in Indonesia. One method of exploring potato cultivation is by selecting a suitable variety of potato that adapts well to the medium plains, produces high yield and is resistant to plant disease (Lehar, 2012; Rosyidah *et al*., 2013; Wulandari, 2014). Having selected 5 varieties of potato, it is apparent that there are two which are the most suitable varieties for potato cultivation at medium altitude, these are the Nadiya and the DTO 28 types (Lehar *et al*., 2016).

Another problem that occurs with potato plants is that they cannot adapt to high temperatures, especially during the night. Consequently, the production of potato in tropical areas is limited (Levy and Richard, 2007). An area in which the maximum temperature reached is 30°C and the minimum air temperature is 15°C is suitable for growing potatoes, rather than an area where the average constant temperature is 24°C (Ashandhi and Gunadi, 2006). As required by the conditions, treatments should also be applied to provide the optimum growing environment for the potato. Manipulating the growing environment with mulch and by varying the plant spacing will, in particular, affect the soil temperature and as a result, the growth and yield of potatoes will also be affected. Mulch has various advantages through its biological, physical and chemical effects on the ground. Mulch

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can physically stabilize the soil temperature and maintain moisture around the plant roots. Doring *et al.* (2006) reported that mulch would influence soil temperature. It is important to select the most appropriate mulch and plant spacing for fruit and vegetable plants. Furthermore, Ibarra *et al*. (2011) stated that mulch color influenced photosynthesis and eventually affected growth and development of plants, such as leaves and stem, especially during the vegetative phase.

Doring *et al*. (2006) explained that rice straw mulch had higher reflectance than plastic mulch. Fang *et al.* (2011) reported that straw mulch or mulch made from other crop residue had low thermal conductivity so that less heat touched the surface of the ground compared to having no mulch or mulch with high thermal conductivity such as plastics. Hence, different types of mulch have different abilities to maintain temperature, humidity and water content. Temperature affects photosynthesis and respiration rates; when the temperature is higher than 30°C, potato assimilation falls to zero and potato yields will also decrease (Levy and Richard, 2007). The porpose of this study was to obtained low soil temperature to induce plant growth and tuber formation in the medium altitude.

Material and Methods

The study was conducted from July to November 2015 in Poncokusumo, a municipality located in Malang, East Java, Indonesia. The area is categorized as medium altitude and is located at 700 meters above sea level with an average temperature of 28°C.

Samples

The study used Solanumtuberosm L.cv. Nadiya with plant spacings of 70 × 30 cm and 60 × 30 cm. The mulch was either silver, black plastic mulch (MPHP) or rice straw mulch or no mulch was used, while the biological agents used were Trichodermaviride, Pseudomonas fluorescence and Streptomyces sp., 20 ton ha^{-1} of chicken manure, (Nitrogen, Phosphorus, Potassium) NPK fertilizer (16:16:16) of which dosage the was 1 ton ha^{-1}, fungicide in which the active substances were propinab 70% and metalaxyl 30% and insecticide in which the active substances were carbofuran 3% and pyridaben.

Research design

The study used a split-plot design consisting of 6 treatments and 4 replications. The main plot used 70 × 30 cm and 60 × 30 cm planting spacing's while the sub plot used silver black plastic and rice straw mulch, as well as no mulch. Based on the two factors, the researchers obtained six (6) combinations of treatments; each treatment was replicated (4) four times to obtain 24 plots for testing. The mulch and biological agents were given two weeks prior to planting the seeds. The biological agents were poured onto the soil which had previously been given organic fertilizer. The biological agents had the same concentration, 20 milliliters/L of water. The concentration of the biological agents was 10^9CFU/mL^{-1} for *Trichodermaviride* (Lehar, 2012) and10^8 mL^{-1} for *P. fluoresensi* and *Streptomyces* sp. (Rosyidah *et al*., 2014; Lehar *et al.*, 2016).

Statistical analysis

The data analysis was facilitated by the 2010 version of Microsoft Excel using variance analysis (F-test with a 5% standard error) followed by a least significant difference (LSD) approach.

Results and Discussion

The mulch and plant spacing treatments showed interaction during the observations in terms of the plant height, stem diameter and leaf number of the potato plants at 6 WAP, 8 WAP, and 10 WAP. The interaction between the type of mulch and plant spacing impacted the height of the plant, the diameter of the stems, the number of leaves (Table 1) and the size of the leaves (Figure 1). In terms of the growth of the plants, there was an interaction between the type of mulch and the plant spacing observed in the height of the plants, the diameter of the stems and the number of leaves (Table 1). During the 8 WAP and 10 WAP, there was a significant difference between the potato plants grown on the rice straw mulch, the spacing of which was 60 × 30 centimeters, and both the plants grown in the same planting space but without any mulch and the potato plants grown with the rice straw mulch, for which the planting space was 70 × 30 cm. However, there was no difference observed with the potato plants grown on the silver, black plastic mulch. In terms of the stem diameter, there was a significant difference between the potato plants grown on the rice straw mulch and those grown with no mulch for which the planting space was 60 × 30 cm compared to those for which the planting space was 70 × 30 cm at 6 MST, 8 MST and 10 WAP. The number of leaves on the potato plants grown in the rice straw mulch and those grown with no mulch for which the planting space was 60 × 30 cm was higher than those where the seeds were planted with a spacing of 70 × 30 cm while there was not much difference in the number of leaves when the mulch

Table 1. Height, diameter and number of leaves of potato plant as the result of the mulch and plant spacing treatment at 6 WAP, 8 WAP, and 10 WAP

Treatment	Plant Height (cm) at					
	6 WAP		8 WAP		10 WAP	
	70x30 cm	60x30 cm	70x30 cm	60x30 cm	70x30 cm	60x30 cm
Silver, black plastic mulch (*PHP*)	11.89 a	13.96 ab	50.39 a	51.88 a	50.76 a	52.64 a
Rice Straw mulch	37.73 de	50.02 e	105.18 d	110.40 e	105.44 d	110.45 e
No mulch	36.40 cde	35.53 bcde	78.65 b	88.03 c	79.41 b	88.17 c
LSD 5%	21.79		3.08		2.94	
	Diameter of Plant (mm) at					
Treatment	6 WAP		8 WAP		10 WAP	
	70x30 cm	60x30 cm	70x30 cm	60x30 cm	70x30 cm	60x30 cm
Silver, black plastic mulch (*PHP*)	5.93 a	6.51 b	6.38 a	7.01 b	6.40 a	7.59 b
Rice Straw mulch	10.07 e	12.70 f	10.59 e	13.20 f	10.85 e	13.32 f
No mulch	8.51 c	9.88 de	9.26 c	10.05 d	9.35 c	10.15 d
LSD 5%	0.42		0.33		0.14	
	Number of Leaves at					
Treatment	6 WAP		8 WAP		10 WAP	
	70x30 cm	60x30 cm	70x30 cm	60x30 cm	70x30 cm	60x30 cm
Silver, black plastic mulch (*PHP*)	52.18 a	64.00 a	76.43 a	80.18 a	76.77 a	80.50 a
Rice Straw mulch	98.37 bc	124.12 c	128.62 c	154.19 d	129.55 c	161.19 d
No mulch	57.11 a	73.12 ab	91.76 a	100.06 b	91.76 a	101.21 b
LSD 5%	28.24		2.51		23.47	

Notes: The valuefollowed by the same letters in the same column are not significantly different based on the LSD 5%. cm = centimeter, WAP = (number of weeks after planting).

used was the silver, black plastic mulch. The potato plants grown on the rice mulch with a 60 × 30 cm planting space had the largest leaf size compared to the other treatments during the entire observation period (Figure 1). This demonstrated that the type of mulch was highly influential in the improvement and refinement of the plants growth and yield. Doring *et al*. (2006) explained that rice straw mulch has higher reflectance than plastic mulch. Fang *et al*. (2011) reported that straw mulch, or mulch made from other crop residues, has a low thermal conductivity so that less heat touches the surface of the ground compared to having no mulch or a mulch with a high thermal conductivity such as those made with plastics. Hence, different types of mulch have different abilities to maintain the temperature, humidity, and water content of the soil, as well as the level of weeds.

Novak *et al.* (2011) stated that organic mulch or mulch made from plant residue, that entirely covers the surface of the ground would protect the ground from intensive rainfall and high temperatures. Organic mulch could affect the physical and chemical substance of the ground and trigger the growth of plants (Govaertset *et al*., 2007) as well as increase the nitrogen level in the soil that makes the plants grow well (Fang *et al*., 2011; Dvorak *et al*., 2015). Darmawan (2014) reported that several studies revealed that vegetables have different responses

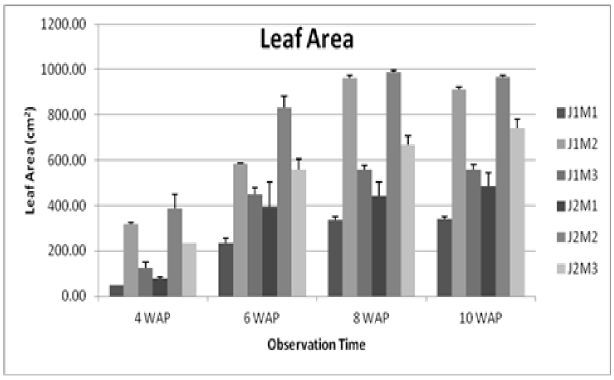

Figure 1. Leaf area as the result of the mulch and plant spacing treatment.
Description: J1: 70x30 cms, J2: 60x30 cms, M1: silver black plastic, M2: rice straw, M3: control

towards mulch with certain colors. Plastic, colored mulch determines the amount of radiation energy being accepted and affects the microclimate around the plants and mulch with a specific color increases the temperature of the mulch surface and the soil under the mulch (Prayogaet al., 2016).

Rice straw mulch with a closer planting space reduced the soil temperature, 20.98°C (July), 21.19°C (August), 21.21°C (September), 22.08°C (October). On the other hand, silver, black plastic mulch with a wider planting space increased the soil temperature, 28.06°C (July), 28.09°C (August), 29.32°C (September), 30.05°C (October). Mulch

Table 2. Weight of dried potato as the result of the mulch and plant spacing treatment at 6 WAP, 8 WAP, and 10 WAP

Treatment	Weight of Dried Potato (g)							
	4 WAP		6 WAP		8 WAP		10 WAP	
	70x30	60x30	70x30	60x30	70x30	60x30	70x30	60x30
Silver, black plastic mulch (*PHP*)	89.98 a	115.74 b	95.47 a	148.02 b	136.86 a	191.69 b	132.68 a	121.70 a
Rice Straw Mulch	192.97 d	367.56 e	228.58 d	625.31 f	327.56 e	660.73 f	283.86 c	412.62 d
No mulch	106.66 b	169.29 c	179.05 c	267.21 e	216.32 c	320.55 de	135.18 a	219.08 b
LSD 5%	7.86		17.89		22.32		25.10	

Notes: The value followed by the same letters in the same column are not significantly different based on the LSD 5%.g = gram, WAP= (number of weeks after planting).

Table 3. Weight of potato tuber per plant and the weight of tuber for plot as the result of the mulch and plant spacing treatment

Treatment	Weight of fresh tuber			
	Weight per plant (gr)		Weight per plot (kg)	
	70x30	60x30	70x30	60x30
Silver, black plastic mulch (*PHP*)	1,907.50 a	2,227.50 a	76.30 a	89.10 b
Rice Straw Mulch	8,398.75 bc	1,0470.00 c	335.95 e	418.80 f
No mulch	3,270.00 a	3,842.50 ab	130.80 c	153.70 d
LSD 5 %	4,626.53		7.40	

Notes: The value followed by the same letters in the same column are not significantly different based on the LSD 5%.

has various physical and chemical advantages for the soil. It stabilizes the temperature of the soil and keeps the area around the roots moist. A lower soil temperature as an effect of the rice straw mulch and a 60 × 30 cm planting space (J2M2) increased the plant height, stem diameter, the number of leaves (Table 1) and leaf area (Figure 1).

Not only did the soil temperature influence the yield, but it also influenced growth rate, Initiation came from buds formed into stolon, followed by the growing tuber, leaf shape, the number of leaves and branching structure. Doring *et al.* (2006) Fahrurrozi *et al*. (2006) and Hamdani (2009) described that at lower temperatures, the morphological characteristics of the plants are large-sized leaves, more branches, and a higher stem diameter. This was in line with the findings of Timlin *et al.* (2006) who found in their study that at higher temperatures, the plants were smaller, had smaller leaves, the branches were upright and fewer in number and their diameter was reduced.

Organic mulch had low thermal conductivity. Franquera (2015) reported that rice straw mulch could suppress evapotranspiration, lowering the temperature and soil temperature so that reducing the loss of water from the surface of the soil. As the result, it minimizes risk for drought. According to Doring *et al*. (2006) rice straw mulch or mulch made from crop residue had low thermal conductivity so that less heat touched the surface of the ground than no mulch or mulch with high thermal conductivity such as plastic mulch. The silver, black plastic or PHP mulch had higher soil temperature compared to no mulch. Mulch that had high thermal conductivity would result in escalating soil temperature because it had lower reflectivity than no mulch (Jodaugiene *et al.* (2006).

Mulch affects soil temperature because it blocks direct sunlight (Doring *et al.*, 2006; MutetwaandMtaita, 2014). The maximum soil temperature under rice straw mulch at a 5-centimeter depth was 10ºC lower than when no mulch was used while the minimum temperature was 1.9°C higher (Zhao *et al*., 2012; Azad *et al.*, 2015). Hamdani (2009) revealed the influence of the type of mulch on soil temperature and moisture and showed that there was no difference in the soil temperatures between no-mulch and rice straw mulch treatments in the morning, but that the silver, black plastic mulch showed a higher soil temperature. In the late afternoon, the soil temperature with the rice straw mulch was lower than that with nomulch and the silver, black plastic mulch.

Table 4. Potato yield per hectare as the result of the mulch and plant spacing treatment

Treatment	Weight (t/ha)
70 x 30 cm Planting Size	31.11 a
60 x 30 cm Planting Size	31.16 a
5% BNT	5.28
Silver, black plastic mulch (*PHP*)	18.22 a
Rice Straw Mulch	66.30 c
No mulch	33.96 b
LSD 5%	4.24

Notes: The value followed by the same letters in the same column are not significantly different based on the LSD 5%.

Samiati *et al.* (2012) suggested that the mulch affects the microclimate in west Sumatra by forwarding and reflecting the sunlight, temperature and humidity below and above the mulch, as well as the level of soil moisture so that the rate of net assimilation and the growth of Barsisicajuncea using organic mulch was better compared to an inorganic one.

The mulch and planting space treatment showed an interaction in terms of dried potato weight at WAP, 6 WAP, 8 WAP and 10 WAP (Tabel 2). The rice straw mulch with a 60 × 30cm planting space showed a significant difference in the dried potato weight at 4 WAP, 6 WAP, 8 WAP and 10 WAP. The mulch and plant spacing treatment showed that the potato plants grown on the rice straw mulch with a 60 × 30 centimeter planting space gave better results than the potato plants grown on the same mulch but with a 70 × 30 centimeter planting space.

The rice straw mulch increased the growth of the plants; the plants kept growing until 8 WAP or 8 weeks after being planted and then the growth decreased at 10 WAP or 10 weeks after being planted due to senescence. The rice straw or organic mulch could accelerate the growth of the plants, making a significant contribution to their tuber growth, while the plastic mulch resulted in a higher heat conductivity that slowed down the growth of the plants (Sinkeviciene, 2009; Zhao *et al*., 2012; Azad, 2015). There was an interaction between the mulch and plant spacing treatment in terms of the tuber weight. Table 3 illustrates the weight of the tubers for each potato plant and e each plot.

There was no interaction between the planting space or the type of mulch in terms of the weight of the potatoes per plant. The weight of the potatoes grown in the rice straw mulch and with a 70 × 30 cm planting space was similar to the potatoes grown on the same media but with a 60 × 30 cm planting space, even though these potatoes were heavier than the ones grown on the plastic and with no mulch. The lowest yield, 1,907.50 gram per plant, was the result of the potato plants grown on the plastic mulch with a planting size of 70 × 30 centimeters. Each plot of the potato plants grown on the rice straw mulch with a planting space of 60 × 30 centimeters resulted in 418.80 kilograms of potatoes. The lowest yield per plot, 76.30 kilograms, resulted fromthe plastic mulch and a 70 × 30 cm plant spacing.For the non-mulch and 60 × 30 cm plant spacing treatment, the weight of the potatoes and the weight for each plot of potato plants was higher and significantly different from the 70 × 30 cm plant spacing. The non-mulch treatment was also significantly different from both the plastic mulch with a 70 × 30 cm spacing and the plastic mulch with a 60 × 30 cm spacing treatments.

Based on the observation of each hectare in terms of the potato yield, there was no interaction between the type of mulch and the planting space. Table 4 describes the potato yield per hectare as the result of the mulch and plant spacing treatment. The problems of medium potato and lowlands potato are high soil temperatures that tuber formation was not optimal because carbohydrates that were accumulated in tubers respire back into energy for the growth of leaves. With the technology as the results of this experiment proved that straw mulching and close spacing of influenced led to the ground temperature was lower than without mulch and wider spacing, and also with a low temperature of soil accumulation of carbohydrates in the form of tubers became optimal. The use of a spacing basically to provide space around good plant growth without experiencing competition among plants. According to Akassa *et al.* (2014) study conducted in Western Ethiopia shows that if the minimum spacing of plant density exceeds the limit, then the tubers harvested results will not increase and unfavorable. The use of plant spacing may influence the shade of the leaves for their overhaul of leaf structure, the addition of plant height, leaf number, and leaf area and decreased the number of tillers, and the number of branches (Abrha *et al*., 2014). The use of a more dense spacing can hit the high temperatures that could spur plant growth and optimal results. Laurie *et al.* (2015), using sweet potato in the area of the plateau South Africa showed that in conditions of high-temperature pressure, the more dense spacing can increase a greater leaf area because the soil surface is covered by a canopy of leaves and soil temperature can be lowered during the day. Warnita (2007) studies showed that closer plant spacing resulted in higher plants, more leaves, and larger leaves in several genotypes of potato with the maximum growth happened at 8 WAP in south Sumatra.

According to Dvorak and Hamouz (2010), organic mulch decreases the soil temperature because it decreases the radiation received and absorbed by the soil so that it lowers the temperature of the soil during the day. The high pressure of the soil temperature may reduce the yield due to an increasing photorespiration rate that inhibits the growth of the plants. According to Timlin *et al.* (2006), lower soil temperatures may impede the respiration rate of the roots so that the number of assimilates that function as reserved nutrients increases rather compared to the non-mulch treatment. A suitable soil temperature for the potato plants was between 14.9 and 22.7°C (Doring *et al.*, 2006; Azad *et al*., 2015). Soil temperature was associated with the absorption of nutrients by the roots, photosynthesis, and respiration. Timlin *et al.* (2006) and Doring *et al.* (2006) reported that dry substance accumulation is delayed when the soil temperature is over 24°C.

The size of the leaves affected the dry weight of the plants (Table 3) and the weight of the potatoes and (Table 2). Lakitan (2008) supported this idea indicating that the leaf was the main component of photosynthesis so that a larger leaf would be able to absorb more sunlight and have a higher CO_2 fixation; better photosynthesis produced higher assimilates that were continuously processed during the growth of the potato. The rice straw mulch resulted in larger leaves and higher dry weight and yields compared to the non-mulch and silver, black plastic mulch treatments (Jodaugiene *et al.*, 2006; Hamdani, 2009; Rajablariani and Hassankhan, 2012; Zhao *et al*., 2012; Mutetwa and Mtaita, 2014).

Conclusion

The results showed that the rice straw mulch and a 60 × 30 cm planting space resulted in the highest growth component at 8WAP; the plant height was 110.40 centimeters, stem diameter was 13.20 millimeters and the leaf area was 3,959.90 cm^2. The growth rate was 2.36 gram/day, dry weight was 660.73 gram and the yield was 66.30 tons ha^{-1}.

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