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Analysis of the impacts of technological implementation on the productivity and quality of seed potato tubers

Y. Setiyo[1,3]*, I.B.W. Gunam[1], B.A. Harsojuwono[1] and K.A. Yuliadhi[2]

*[1]Agriculture Technology Faculty, Udayana University, Bali, Indonesia, [2]Agriculture Faculty, Udayana University, Bali, Indonesia. [3]Agriculture Technology Faculty, Udayana University, Bukit Jimbaran, South Kuta, Badung, Bali (80361), Indonesia. *E-mail: yohanes@unud.ac.id*

Abstract

Potato is one of the most vulnerable crops to climate change in terms of various physiological processes. The implementation of technology in seed potato cultivation was done by installing clear plastic shade on crops and installing black plastic mulch on raised beds. The plastic shade helped in reducing the amount of sunlight intensity received by plants in the range of between 651-1435 lux; maintaining the temperature between 21-28 °C and the relative humidity of the environment between 55-82 %. On the other hand, the plastic mulch helped in controlling the growth of weeds and controlling the amount of water in the soil, especially in the root zone at field capacity, and maintained soil temperature at the fixed root zone at 12-24 °C. Plant growth was influenced by seed quality, soil temperature, and soil moisture content. The combination of plastic shade and plastic mulch technology on potato seed cultivation increased the quality of plant growth measured from the total biomass weight of 17.2 %. The rate of plant growth directly influenced the productivity of the tuber, which increased by 3.3 %.

Key words: potato tuber, plastic mulch, shading, productivity

Introduction

People eat potato (*Solanum tuberosum*) tubers because they are high in nutrition and carbohydrates (Wustman and Struik, 2008) and cultivated worldwide, including Indonesia. Potatoes can be grown in hot climates in cold seasons with low soil fertility if the field elevation is between 1100 and 1500 m above sea level. However, potato is not tolerant to high temperatures and humidity. Its cultivation is best when the temperature is between 15 and 18 °C and the soil pH is 5.5 and 6.0. (Muthoni *et al*., 2015).

Potato growth necessitates specific environmental conditions for crops to develop optimally and produce tubers that meet the standards as seeds [(base seed or G0 (zero generation), G1 (first generation), and G2 (second generation), primary seed or G3 (third generation), and spread seed G4 (fourth generation)]. Temperature, light, humidity, and drought, as well as management practices (pruning, thinning, protection, irrigation, and fertilisation), can all have an impact on plant sensitivity (Charrier *et al*., 2015). Potato quality and productivity suffer as a result of global climate change. The Intergovernmental Panel on Climate Change has stated that global warming is a natural phenomenon (IPCC, 2007). The increase in global temperature in 2100 will be 1.8-4 °C has been predicted by Lobell and Burke (2010).

Potato tuber quality is influenced by mulching and plastic mulch. Production was 20-30 % higher yield than the crop without plastic mulch (Setiyo *et al*., 2016). The use of a Low External Input Sustainable Agriculture (LEISA) system on potato cultivation has improved the soil's physical, chemical, and biological quality while also increasing the productivity and quality of potato tubers (Petr and Jaroslav, 2011; Setiyo *et al*., 2017). In potato cultivation using the LEISA system, a fertilising dose of 10-20 tons/ha compost has several effects, including soil porosity of 56-63 %, water availability of 34.53-40.69 % w.b., soil temperature of 26-29 °C, soil pH of 6.8-6.9, soil organic matter content of 5.60 %, and cation exchange capacity (CEC) of 27.61.2 me (100 g^{-1}). Compost improved soil water-holding capacity by about 17 %, increased soil porosity by about 12 %, and increased CEC by 2.1-3.2 me (100 g^{-1}).

Using the LEISA system in conjunction with fertilising techniques that use 20 tons/ha chicken manure compost can boost crop production from 17 tons/ha to 31.33 tons/ha. The increase in production is also accompanied by a grade shift in potatoes, with 46.87 % of total potato tubers produced, weighed up to 100 g (Raymundo *et al*., 2018; Machuca *et al*., 2015; Setiyo *et al*., 2017).

Because seed potato cultivation is a process for producing high-quality seed potatoes, it must adhere to a set of rules. Optimising the condition of the potato root zone, optimising the microclimate, and controlling weeds and potato pests are all part of the seed potato cultivation procedure. Seed potato cultivation necessitates several conditions, including a controlled environment, because microclimate changes can affect pest population and disease occurrence, host-pathogen interactions, insect distribution and ecology, and potato quality deterioration. Because their climate requirements are appropriate for various physiological processes, potatoes are the most vulnerable to climate change then any vegetable (Laux *et al*., 2010; Van Oort *et al*., 2012).

To improve seed potato cultivation, technology is being implemented by installing clear plastic shade on the cultivation and installing black plastic mulch on the raised beds. The plastic shade can (1) reduce the amount of sunlight intensity received by plants in the range of 651-1435 lux, (2) control the environmental temperature in the range of 21-28 °C, and (3) control the environmental humidity in the range of 55-82 percent. Plastic mulch, on the other hand, has the ability to (1) control weed growth, (2) control soil water content, particularly at the root zone at field capacity, and (3) control soil temperature at the fixed root zone at 12-24 °C. (Muthoni *et al.*, 2015; Rykaczewska, 2015). This study aimed to see how different technologies affected various aspects of potato seed production.

Materials and methods

Material: This study of G0 group Granola variety potatoes was carried out by farmers who are certified as potato seed extractors. The seed potato tubers had the following characteristics: average weight size of 12.3±1.2 g, specific gravity 0.97±0.01 $g.cc^{-1}$, growing 1-3 apical buds, with 0.5±0.02 cm apical shoot height in average.

Research design: The experiment was designed with a two-factor factorial design. The first factor was the use of black plastic mulch to close raised beds, and the second factor was the use of clear plastic shade to control the microclimate around the plant. Two models were used in the first factor: cultivation with plastic mulch and cultivation without plastic mulch. In the second factor, three types of cultivation were used: greenhouse cultivation, plastic shade cultivation, and no plastic shade cultivation. The treatments totaled 12 units, and each experimental unit was repeated three times for 36 experimental units. This research was conducted according to Wang *et al.* (2015) to optimise (1) potential yield (PY), (2) meteorologically possible yield (MPY), (3) actual possible yield (APY), and (4) real yield under commercial conditions (CY). PY denotes the yield under ideal soil and meteorological conditions, such as species or varieties and solar radiation influx. MPY is the maximum yield achieved through soil fertility and agrotechnology manipulation. The maximum yield that can be obtained by modifying existing meteorological and soil conditions is referred to as the APY. CY is the field yield.

Research procedure: The elevations of the location were: 900 m d.p.l., 110 m d.p.l., and 1300 m d.p.l. To prepare a bed area measuring 80 cm x 10 m, a drainage channel with a width of 50 cm and a depth of 30 cm was created between the beds. The bed was completely covered with black plastic mulch. The experiment used a 20 cm x 25 cm spacing, resulting in four planting grooves on each bed. In addition, 20 tonnes of chicken manure compost and 250 $kg.ha^{-1}$ of compound NPK fertiliser were applied (Setiyo *et al*., 2016). Plastic shade was created after the plastic mulch on raised beds was installed and planting holes were dug. This was done to make it easier to plant potato seeds.

The shade frame was constructed from 2.24 cm PVC pipes, and the height of shade used for all treatments was 1 m and 5 m long. Microclimate (sunlight intensity, ambient temperature, soil temperature, and air humidity), plant growth (total plant mass, height, and weight of tubers from each tree), and productivity were the variables studied in the experiment (potato tuber weight and tuber quality). Every 7 days, the microclimate was observed at 07.00, 12.00, and 16.00. Microclimate data was collected at random from 5 points on each experimental unit. Every 7 days, growth measurements were taken from each of the ten trees chosen at random for each experimental unit. When potato tubers were harvested from each of the 20 plants that were randomly assigned to each experimental unit, productivity was measured. The potato tubers from group G1, which had the potential to become seed potatoes, were then stored for three months in a dark room at a temperature of 24-29 °C. After storage, the number of damaged tubers was counted, *i.e.*, tubers that grew only one apical bud, tubers that grew 2-3 apical shoots, and tubers that grew more than 3 apical shoots.

Based on Indonesian National Standard Sunlight intensity, environmental temperature, soil temperature, environmental humidity, crop productivity and tuber quality were recorded.

Data analysis: The data were analyzed according to regression and the variant (ANOVA) and continued with Duncan's multiple comparison test. In the data analysis software program of SPSS 25 was used.

Results

Sunlight intensity: The intensity of sunlight on the soil surface or on parts of potato crops ranged from 266 to 1158 lux. Potato tissue culture needs 3000-4000 (average 3500) lux light intensity (Rehana *et al.,* 2018). The amount of light intensity was good enough to support the metabolism of potato plants such as evapotranspiration, photosynthesis and respiration. The intensity of sunlight received by the soil surface for all cultivation treatments had a tendency to decrease with the increasing age of potato plants. The average decrease of sunlight intensity was 67±6 $lux.week^{-1}$. The pattern of changes in light intensity received by soil surface or plants in potato cultivation is illustrated in Fig. 1.

Environment temperature: The environmental temperature of the potato seed cultivation experiment was recorded between 22.5-29.2 °C. This temperature is still tolerable for the growth of potato of Granola varieties. The optimum temperature for potato photosynthesis is 25 °C, above this temperature, the rate of photosynthesis of potato plant decreases due to non-stomata factors (Muthoni *et al*., 2015) and, the ambient environmental temperatures of day time is 30 °C and the ambient temperature of night day time is 23 °C. The environmental temperature at night day time is 18-20 °C, and the average environmental day-time temperatures is 25 °C. Total of biomass, potato tuber weight, and final yield were all decreased because of the environmental temperature more than 30 °C during the period (Wang *et al.,* 2015).

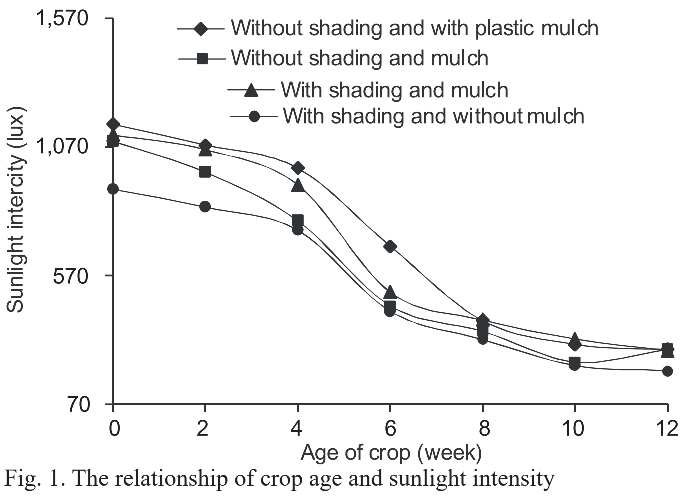

Fig. 1. The relationship of crop age and sunlight intensity

As shown on Fig. 2, it can be seen that the decrease in air temperature occurred every week for all treatments of the seed potato cultivation. The average decrease of temperature was 0.55±0.1 °C week^{-1}, the decrease in temperature in the vegetative growth phase was recorded at 1.0±0.1 °C week^{-1} and in the generative growth phase was recorded at 0.1±0.05 °C week^{-1}. At vegetative growth phase, the environmental day-time average temperature on potato cultivation was 26 °C, which is near the optimal for photosynthesis process. But for generative potato growth phase, the environmental temperature is lower than 25 °C. The lowering of temperature happened as a result of the intensity of sunlight being absorbed by the plant mass for photosynthetic activity. Because of the increasing age of plants, the photosynthetic activity of plants also increased. At a temperatures environment between 25-29 °C when fewer tubers per plant are formed, larger tubers are obtained (Muthoni *et al.*, 2015).

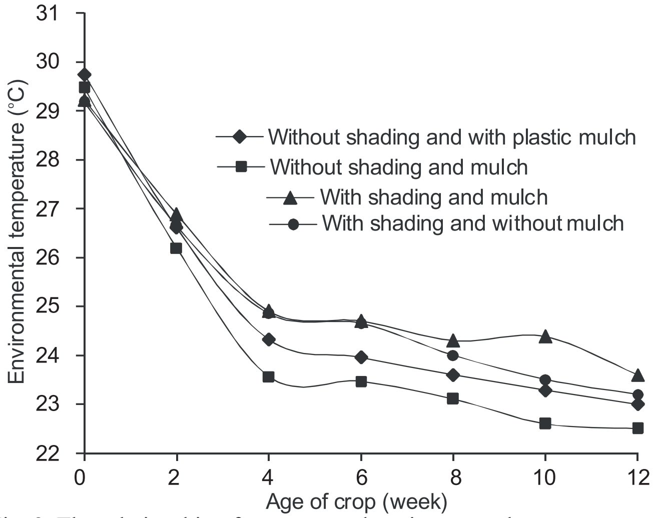

Fig. 2. The relationship of crop age and environmental temperature

Soil temperature: Air temperature and solar radiation control the soil temperature in potato cultivation. The drier the soil, the closer the soil temperature to air temperature. More frequent irrigation can reduce high soil temperatures to provide evaporative cooling. The soil temperature at the root zone of the potato plants varied between 21.43-21.8 °C. At this temperature, the growth of potato plants was still good because the soil temperature fluctuation is less than 5 °C.

The results of this study are very close to the findings of Rykaczewska (2013) that shows the optimum soil temperature as 20 °C. Soil temperature, especially at the potato root zone, impacts the value of potato evapotranspiration, soil CEC, soil pH, and potato tuber formed. Soil temperature affected root concentration with depth but did not influence root distribution lateral direction. Most plants that grew under the plastic mulch had higher yields than plants that grew on land without plastic mulch. In addition, soil temperature showed a very significant effect on plant photosynthesis.

Fig. 3 shows a decrease in soil temperature for all cultivation treatments when the plant age increases. The relationship between plant age and average soil temperature at the root zone makes a pattern of second-degree polynomial. The average decrease in soil temperature at the root zone was 0.02±0.001 °C week^{-1}. The decrease in temperature was due to the absorbance of sunlight

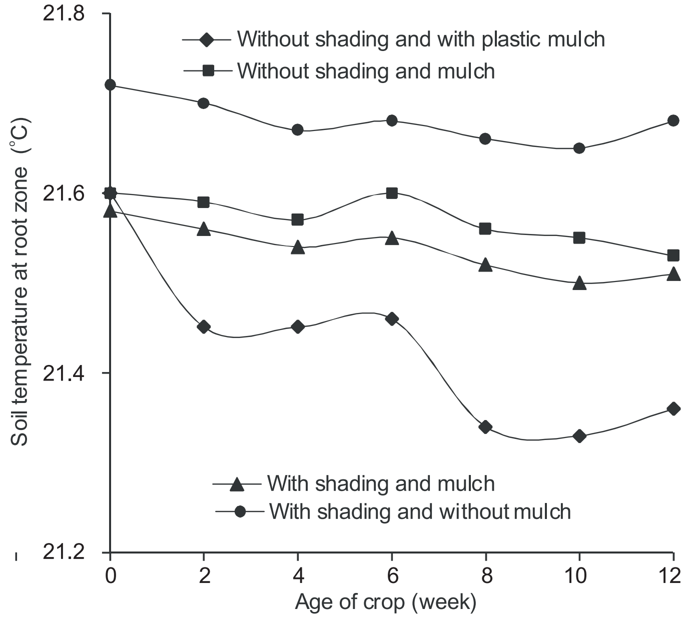

Fig. 3. The relationship of crop age and soil temperature at root zone

intensity by the plant mass due to photosynthetic activity. Along with the increasing age of plants, the photosynthetic activity of plants also increases. But, soil temperature from research by Petr and Jaroslav (2011) on potato planting by plastic mulch reached 0.8 °C lower than without plastic mulch.

Environment humidity: The relative humidity of air or environment in the potato cultivation with Granola varieties is shown in Fig. 4. Relative air humidity during potato cultivation varied between 71.98-83.0 %. Potato plant growth at RH more than 90 % is impacted by late blight epidemic caused by *Phytophthora infestans*, but, if environment RH is less than 50 %, potato or sweet potato growth is inhibited (Olanya *et al.,* 2006).

The rise followed the increase of plant life in air humidity around the potato cultivations, where every week, the air humidity increased by an average of 1.21±0.2 %. The age increase of potato plants increased the evapotranspiration of plants (0.1 to 0.6 cm.day^{-1}). The rate of potato evapotranspiration showed a direct impact on the humidity of the air around the plants.

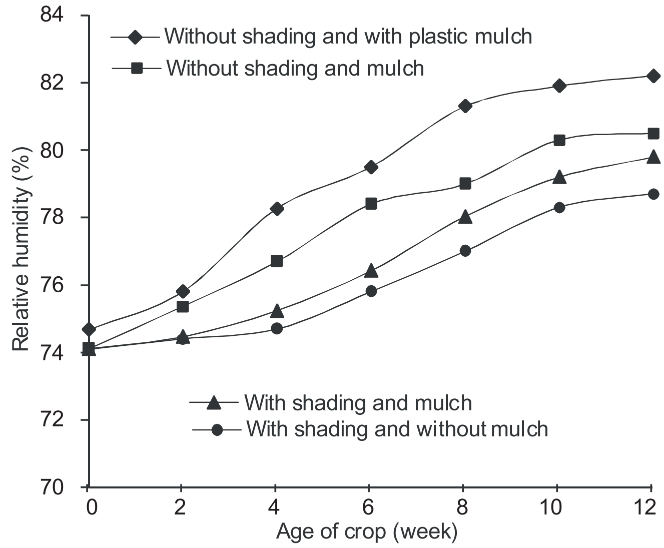

Fig. 4. The relationship of crop age and relative air humidity

Crop productivity: The productivity of potato cultivation of the G0 Granola variety with different treatments, *i.e.*, with and without plastic shade and with raised beds, closed or not closed with plastic mulch, is shown in Table 1. The average production of tubers per plant was 5.1±0.3 to 6.0±0.5, this result has met the standard of seedling for Granola varieties with a number of 5-8 tubers per plant. The weight of potato tubers produced in the G1 group was 29.4-35.4 g. The treatment of potato cultivation with clear plastic shade and plastic mulch is significant to potato crop productivity. Crop production efficiency can be increased by using plastic mulching. Implementation of plastic mulching on potato cultivation is to modify root zone temperature and plant growth. In addition, it reduces pest damage and enhance production in cultivated plants (Machuca *et al.,* 2015). This research is close with the study by Ghosh *et al.* (2001) who reported increasing shading intensity consistently decreased dry matter production and marketable tuber weight and reduced the tuber yield.

Tuber quality: The quality of potato tubers of the G1 Granola variety produced from the four treatments is shown in Table 2. The number of potatoes that can be used as seed increased (P<0.01) when clear plastic shade and plastic mulch were used. The total number of potato tubers that could be classified as seed (weight of potato tuber 10-60 g) was 82.77-85.85 percent, with 7.05-10.5 percent of tubers being too small for seed (less than 10 g weight) and 10.56-14.31 percent being too large for seed (more than 60 g weight). When the average daily temperature was 16 to 18 °C, tuber weight increased rapidly (Wang *et al*., 2015).

Discussion

Sunlight intensity: The age increase of potatoes caused a rise in the sunlight absorbed by parts of the plants during photosynthetic and synthesis activities. In the vegetative growth phase, the photosynthetic activity of plants increased sharply as the sunlight intensity received by plants also reduced sharply by 103±3 lux week^{-1}. Meanwhile, the decrease of intensity of sunlight received by the soil surface at the generative growth phase was 53.3±1.3 lux week^{-1}. Reduction in light intensity of sunlight by artificial shade reduced the level of NR activity in leaves of both cultivars (Ghosh *et al.,* 2001). The intensity of sunlight on potato cultivation with the installation of clear plastic or transparent plastic with a thickness of 0.2 mm was lower than the intensity received by cultivation without plastic shade (8.87±1.2 lux). In the case of cultivation with plastic shade, there was 1.37 % absorption of light intensity by the shade, where the shade reflected 13.33±1.2 %, and the shade transmitted 73.7 % of the intensity of sunlight to the environment around the plant. The ability of plastic shade technology to control the intensity of sunlight dynamically in the range of 266-1158 lux is vital in cultivating seed potatoes. The

Table 1. The productivity of seed potato crops of G0 group Granola variety

Quality parameter	Without shade and without plastic mulch	Without shade and with plastic mulch	With shade, with plastic mulch	With shade, without plastic mulch
.	367.2±10.1a	356.2±9.2a	417.2±12.1d	378.2±11.2c
Number of tuber per crop	5.3±0.3a	5.1±0.3a	6.0± 0.5c	5.7±0.4b
Weight of tuber per crop (g)	172.7± 18.3b	149.4±12.2a	213.5±17.9d	185.7±17.1c
Average weight of tuber (g)	32.6±2.2b	29.4±3.1a	35.4±2.9c	32.4±1.4b

The same notation behind the mean showed no significant difference at the error level of 5 %

Table 2. The productivity of seed potato crops of G0 group Granola variety

Quality parameter	Without shade and without plastic mulch	Without shade and with plastic mulch	With shade, with plastic mulch	With shade, without plastic mulch
Grouping of tuber weight from harvest				
Tuber weight < 10 g (%)	9.94c	8.26b	7.05a	10.50c
Tuber weight <10 - 20 g (%)	6.17c	8.77d	5.33a	5.96b
Tuber weight 20 - 40 g (%)	39.45b	45.06c	39.46b	38.95a
Tuber weight 40 - 60 g (%)	37.16b	30.02a	40.64c	40.77c
Tuber weight > 60 g (%)	14.31c	11.85b	11.85b	10.56a
Grouping according to tuber's seedling potential				
Tuber too small (%)	9.94a	8.26b	7.05c	10.50d
Tuber too large (%)	14.31a	11.85b	11.85b	10.56b
Tuber appropriate for seedling (%)	82.77a	83.85b	85.43c	85.68c
Grouping of potato tuber quality after 3 months storage				
Rotten tuber (%)	1.2±0.2a	1.1±0.2a	1.2±0.2a	1.1±0.1a
Tuber grows 1 apical shoot (%)	30.3±1.3a	31.2±1.4a	35.5±1.4b	36.2±1.4c
Tuber grows 2 or 3 apical shoots (%)	36.2±1.7a	35.9±1.2a	37.4±1.8b	38.2±1.1c
Tuber grows more than 3 apical shoots (%)	32.3±1.5c	31.8±1.3c	25.9±1.7b	24.5±1.7a

maintenance of sunlight intensity entering the room around the crops was followed by controlling air temperature, air humidity and soil temperature at the root zone. This is consistent with the study conducted by Holcman and Sentelhas (2012). The decrease of light intensity and the amplitude of daily soil temperature due to the application of plastic mulch could reduce the appearance of weeds and control soil water.

Environment temperature: The application of plastic shade technology increased the average temperature by 0.28±0.2 ^{o}C, while the mulch plastic technology application increased environmental temperature by 0.36±0.2 ^{o}C. Increasing environment temperature at the generative phase of potato cultivation near 25 ^{o}C is very good for photosynthesis and forming potato tuber processes.

The technology of clear plastic shade with a height of 1 m above ground level could inhibit air circulation in the shade and inhibit heat transfer from near potato plant to environment. This caused an accumulation of heat due to the radiation of sunlight reflected back and forth from the soil surface to the shade. The plastic mulch, which was installed to cover the raised beds, also caused light reflection from the ground surface. The crop cycle is terminated when the mean daily temperature falls below 7 °C, night frosts start (≤ -2 °C) on the ground surface, or tuber accretion is ended (Saue and Kadaja, 2011).

Soil temperature: The use of plastic shade and black plastic mulch significantly affected soil temperature profile at the root zone. The use of transparent plastic shade increased the soil temperature by an average of 0.1±0.01 ^{o}C, while the use of black plastic mulch could increase the soil temperature by an average of 0.14±0.01 ^{o}C. Plastic mulch prevented heat transfer to the environment, while plastic shade held heat to remain around the plant. Installation of black plastic mulch on raised beds of potato cultivation resulted in (1) the reduction of maximum soil temperature in cultivation without plastic mulch and (2) the increase of minimum soil temperature in cultivation without plastic mulch (Jerry and Prueger, 2015). The average difference between soil temperature and the environmental temperature was 3.2±0.3 ^{o}C. The soil temperature is less than the environmental temperature. Potato plants cultivated with raised beds covered by plastic mulch produced different amounts of tuber with different weights. This is because the soil temperature in the root zone affected plant growth. This is consistent with the result of the study conducted by Jiménez *et al.* (2007).

Environment humidity: The treatments without shade showed the lowest humidity level compared to those with transparent plastic shade. This happened because in the shade-free treatments, the wind could circulate freely and carry water vapour from evapotranspiration. This is in accordance with the opinion that the combination of high temperature and wind speed results in a faster rate of evaporation of water in the air, which will reduce the humidity level. This effect of low humidity suggests that the onset of tuberization involves at least two inductive factors, one of which is not translocated among stolons. Air humidity affected the pressure of water vapor in the air and parts of the plant, which were different. The difference in water vapor pressure impacted the rate of evapotranspiration. Therefore, controlling air humidity by applying mulch plastic combined with plastic shade on potato cultivation can help control plant evapotranspiration and the chance of disease occurring in potato plants.

Crop productivity: The cultivation of seed potatoes with clear plastic shading and raised beds covered by plastic mulch could improve plant productivity. Increasing plant productivity as an impact of plastic shading and mulch resulted 25.9 g potato tuber and increased 3.1g average tuber weight. Plastic shade improved the quality of the environment, especially the environmental temperature, soil temperature, sunlight intensity and relative humidity around the plant so that the condition was optimum for photosynthesis and growth. The weight of crops planted under plastic shade increased by 13.6 %, and the weight of biomass of plants planted with the installation of plastic mulch technology on raised beds increased by 6.2 %. The combination of plastic shade and plastic mulch technology for potato seed cultivation increased the quality of plant growth, measured by the total biomass weight of 17.2 %. The quality of plant growth showed a direct impact on tuber productivity, which increased by 3.3 %. The values of air temperature, soil temperature and vapor pressure deficit (VPD) in cultivation with shade installations affected shading. However, these values did not reduce the total dry matter content of the plants, did not increase the leaf area index, and did not increase the number of tubers per plant or the quality of the tuber. This is consistent with the results of Kittas *et al.* (2012) research on tomato cultivation in greenhouse buildings.

Tuber quality: The use of clear plastic shade and black plastic mulch increased the quality of potato tubers that can become seedlings and reduced the number of potato tuber classes too small and too large. On the other hand, the treatment can increase the average number of potato tuber as seed from 5.1±0.3 become to 6.0± 0.5. These tubers have a roundness of 87.5 %, a density of 0.95 $g.cc^{-1}$, and very fine outer skin. Implementation of clear plastic shade and plastic mulch on potato crop could improve the microclimate required for optimum photosynthesis process and potato tuber development. This research result is very close with Raymundo *et al.* (2018) and Machuca *et al.* (2014) research. Based on the result of the observation that was conducted after 3 months of storage, it is recorded that 1.1-1.2 % of potato tubers were damaged or rotten and the rest grew 1-5 apical shoots per tuber. About 70.2±3.2 % of the tubers grew as many as 1-3 apical buds and the rest grew more than 3 apical shoots. Method of seed potato storage is a significant interaction of light intensity and storage time on the number of apical shoots for each potato tuber (Gachango *et al.,* 2008).

Clear plastic shade can reduce the intensity of sunlight entering the surrounding of potato plants by 25.0±0.3 %. As such,some alteration occurs, namely, the environmental temperature becomes 22.6-26.8 ^{o}C, the soil temperature in the root zone becomes 21.5-21.7 ^{o}C and the air humidity around the potato plant becomes 73.0-82.44 %. Such an environmental condition is still optimal for growing seed potatoes of Granola variety and increasing the quality of potato tubers. Clear plastic shade and black plastic mulch can increase the average number of potato tuber as seed from 5.1±0.3 to 6.0± 0.5.

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