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The Correlation Model between Microclimates and Potato Plant Growth

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Abstract*— Mulch in vegetable crops will provide a good growing environment for plants because it can reduce evaporation, prevent direct exposure to excessive sunlight to land, and maintain soil humidity for the plant to absorb water and nutrients optimally. The use of plastic mulch, especially silver, black plastic mulch in vegetable production with high economic value, is continuously increasing in line with the increasing needs and consumers' demand for vegetable products. Various studies have shown that mulch can increase crop yields, improve crop quality, and ultimately improve farming efficiency. This study aimed to determine the relationship between microclimate and potato growth due to the use of different mulch types. The research method uses an experimental design using a random group design. The study was conducted in the District of Bumiaji, Batu city, East Java, Indonesia. Observations were made for climate components, namely air temperature, soil temperature, the radiation received by a crop canopy, and reflected radiation by the soil's surface. Simultaneously, the measured growth variables were the plant's height, the number of leaves, the leaves' width, stem diameter, and the stover's dry weight. This study showed that silver-black-plastic mulch provides the highest growth of potato compared to other treatments. The use of silver-black plastic mulch lowers the soil's temperature, maintains soil moisture, and increases the PAR above the plant canopy.

***Keywords*— Correlation; microclimates; potato plant growth.**

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I. INTRODUCTION

Mulch can be defined as any material that is spread to cover some or the entire soil surface and affect the ground's microenvironment. Mulching produced beneficial effects on root depth, plant height, leaf area index, and yield [1]. The materials of mulch could be derived from the remains of plants or plant parts, which are then classified as organic mulch, and synthetic materials such as plastic that is classified as non-organic mulch [2]. The use of plastic mulch has become common in producing vegetable crops with high economic value, both in developed and developing countries, including Indonesia.

The provision of organic mulch, such as straw, provides a suitable environment for plant growth because it reduces evaporation, prevents direct exposure to excessive sunlight to land, and maintains soil moisture so that the plant can absorb water and nutrients well. Some studies also reported that organic mulch, i.e., straw, significantly increased soil organic carbon (SOC), total N, available N, available K than non-mulch [3]–[5]. On the other hand, organic (degradable) mulch lowers the recycling system's cost because it does not need to be cleaned or disposed of agricultural land [6]. Differences in using mulch materials will have different effects on plants' growth and yields [7], [8].

The use of plastic mulch, especially silver, black plastic mulch in vegetable production with high economic value, is continuously increasing in line with the increasing needs and consumers' demand for vegetable products. The use of silver, black plastic mulch has become an integral part of the production process of vegetables, e. g., potatoes [9]. Various studies have shown that the proper use of several types of mulch on the different types of plants can increase the plant's early yields and the total yields of various crops. It can also improve the quality of crop yields and ultimately increase farming efficiency [10]; [11]. Furthermore, mulch also contributed to controlling pest and diseases by modification of microclimates [12].

FAO suggests a link between crop yields and water use, which satisfies the equation, where the relative decline of its products is associated with decreased relative evapotranspiration (ET) [13]. Some researchers have also made calculations to estimate potential evapotranspiration (PET) with some variables, including temperature, barometric pressure, relative humidity, saturated air pressure, solar radiation, latitude (length of the day), and wind speed [14]. Meteorological factors directly affect potential crop production by setting up transpiration, photosynthesis, and respiration as physiological mechanisms that affect plant growth and development. The main environmental factors affecting plants' physiological processes are a flux density of solar radiation, air temperature, and soil water content availability. Potatoes are sensitive to both water and heat stress. Heat stress affects both plant growth and development. The effects of plastic-film mulch on radiative and thermal conditions are dominated by plastic-film mulch's thermal and optical properties [15]. Knowledge of the needs of the potato crop climate and physiological responses to the environment is fundamental to help farmers produce high yields of quality tubers under the appropriate atmospheric environment.

The effect of temperature on PET can be directly related to the intensity and solar radiation duration. The temperature that affects PET is the leaf temperature and not the air temperature around the leaf. The effect of wind on the PET is through removing water vapor out of the leaf pores. The stronger the wind speed, the greater the rate of evapotranspiration. Compared with the effect of the solar's heat radiation, the wind effect on the rate of ET is less significant.

Soil humidity also affects the occurrence of evapotranspiration. Evapotranspiration took place when the vegetation had no shortage of water supply. In other words, evapotranspiration (potential) occurred when soil moisture conditions ranged between wilting point and field capacity. Since the availability of water in the soil is determined by the type of soil, indirectly, PET is also affected by possible potential factors. This study aimed to observe the growth and yields of potatoes in the provision of various mulches.

The model that can be used to know the growth and yield of potatoes in the provision of various mulches is Partial Least Square (PLS). Structural partial least square modeling explains the relationship between latent variables and their measurement components (indicators) and the weight relation used to estimate latent variables' case value [16]. According to Kwong and Wong [17], the PLS model can predict relationships with weak theories. This study aimed to determine the correlation between microclimates and the growth as well as productivity of potato.

II. Material And Method

A. Field Plot Establishment

The study was conducted in farmers' fields at four different location altitudes. The attempted treatments were kinds of mulch that consisted of 4 levels, namely: M_0 = without mulch, M1 = straw mulch, and M2 = silver-black-plastic mulch. The environment design applied a randomized block design and repeated up to three times.

Observations were made when the plant sample was 35 days after transplanting (dat) with the intervals of 10 days up to the age of 65 dat. Harvesting was done at the time the plant was 120 days after planting, whereas the measured yield variables were the number of tubers per plant, the diameter of the tuber, and the weight of fresh roots. The number of sample plants was four in each treatment (experimental unit)

B. Microclimate Measurement

Observations were conducted to the climate components, such as air temperature, humidity, the radiation received by a crop canopy, and radiation reflected by the soil's surface. At the same time, the measured growth and yield variables consisted of plant height, leaf number, leaf width, stem diameter, dry weight of stover, the number of tubers, the diameter of tubers, and crop harvest yields.

In this research, intake radiation is an exogenous latent variable, while temperature, reflective radiation, temperature, and humidity are endogenous latent variables. Humidity indicators in plant growth are a dry weight of stover, stem diameter, number leaves, leaf width, and plant height. Simultaneously, the humidity indicators on tuber yields are the result, tuber number, and tuber diameter. The correlation between microclimates and plant growth has eight structural models:

$$Stover\_BK = \gamma_{h1} humidity + \gamma_{t1} temperature + \gamma_{r1} reflective + \varepsilon_1$$
$$Stem\_Diameter = \gamma_{h2} humidity + \gamma_{t2} temperature + \gamma_{r2} reflective + \varepsilon_2$$
$$Leaf\_Number = \gamma_{h3} humidity + \gamma_{t3} temperature + \gamma_{r3} reflective + \varepsilon_3$$
$$Leaf\_Width = \gamma_{h4} humidity + \gamma_{t4} temperature + \gamma_{r4} reflective + \varepsilon_4$$
$$Plant\_Height = \gamma_{h5} humidity + \gamma_{t5} temperature + \gamma_{r5} reflective + \varepsilon_5$$
$$Humidity = \gamma_{t6} temperature + \gamma_{r6} reflective + \gamma_{i1} intake + \varepsilon_6$$
$$Temperature = \gamma_{r7} reflective + \gamma_{i2} intake + \varepsilon_7$$
$$Reflective = \gamma_{i3} intake + \varepsilon_7$$

C. Data Analysis

The analysis technique with component-based SEM is also called the Partial Least Squares (PLS) method, a free distribution method. The primary purpose of modeling with PLS is considered for prediction [18]. Estimation of parameter in the Partial Least Square (PLS) model includes three things, i.e.:

- Weight estimate is to determine the weight to calculate the latent variable data.
- Path estimate is the path coefficient estimation between latent variables and between latent variables with indicator.
- The mean estimate is parameter estimation based on resampling.

According to Sanchez [19], PLS's latent variable is estimated as a linear combination of the indicator. Data of the latent variable is derived from the sum of the weighted multiplication by the indicator, denoted by

$$\widehat{LV}_{jk} = \hat{Y}_{jk} = \sum_k w_{jk} X_{jk} \quad (1)$$

After obtained the latent score, then estimate the path coefficient with the Ordinary Least Square (OLS) method between interrelated latent variables

$$\beta_{ij} = (Y_i'Y_i)^{-1}Y_i'y_j \quad (2)$$

The test of parameter significance is performed by the bootstrap resampling method developed by Geisser [20]. The statistical test being used is the t-test. According to Solimun (2010), the goodness of fit in the structural model is as follows:

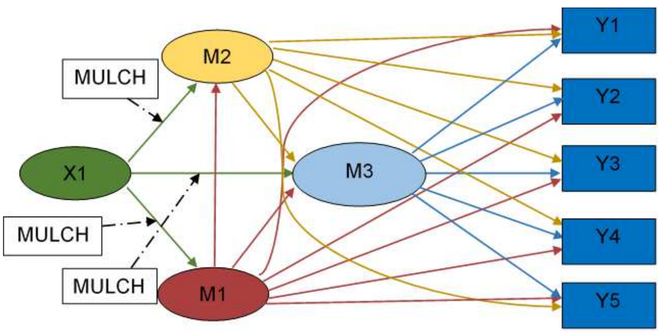
$$Q^2 = 1 - (1 - R_1^2)(1 - R_2^2)\ldots(1 - R_p^2) \quad (3)$$

Analysis Partial Least Square in this research uses SmartPLS software. This software can calculate parameter estimation and the goodness of fit model.

III. Results And Discussion

A. The Correlation between Microclimates and Plant Growth

The structural correlation model between microclimates and potato plant growth, in general, can be portrayed as seen in Figure 1. The examined elements of microclimate included received radiation, temperature, reflected radiation, and humidity. The microclimate elements are essential factors in the processes of metabolism and photosynthesis of plants [21].



X1: Intake Radiation
M1: Reflective Radiation
M2: Temperature
M3: Humidity
Y1: Stover BK
Y2: Stem Diameter
Y3: Leaf Number
Y4: Leaf Width
Y5: Plant Height

Fig. 1 Structural Correlation Model between Microclimates and Potato Plant Growth

The use of different mulches resulted in differences of reflected radiation, the temperature under the canopy, and humidity. Indirectly, these different mulches also have shown some impacts on the growth of potato plants. The growth of potato plants was measured based on the dry weight of stover, stem diameter, the number of leaves, leaf width, and plant height. The correlation model of microclimates related to the growth of potato plants was analyzed by using the Partial Least Square (PLS) method. The followings are the results of the correlation modeling between microclimate and the potato plant growth:

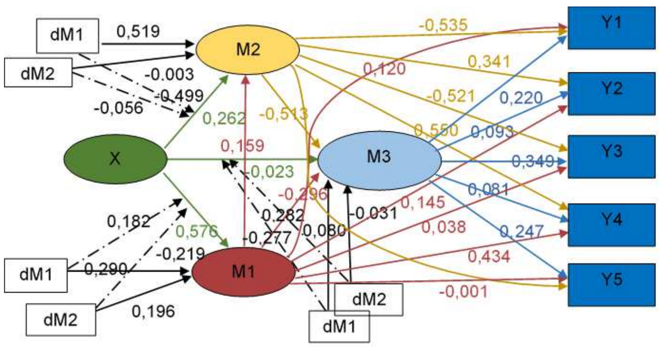


Fig. 2 The Parameter Estimation Result of Structural Model on the Correlation between Microclimate and Potato Growth

Before its usage to explain the correlation between microclimate and potato plant growth, the structural models were tested to find the models' goodness and fit by using predictive coefficient relevance (Q^2). Based on its endogenous variables, the structural models can be divided into six models. The followings are the division of the models along with the coefficient of determination (R^2) and the results of coefficient predictive relevance (Q^2) calculation of the structural models:

TABLE I
The Goodness of Fit Test for the Structural Models

Models	Endogenous Variables	R^2	Q^2
Model 1	A dry weight of stover	0.471	
Model 2	Stem Diameter	0.157	
Model 3	Leaves Number	0.637	
Model 4	Humidity	0.649	0.997
Model 5	Leaf Width	0.602	
Model 6	Reflected Radiation	0.475	
Model 7	Temperature	0.217	
Model 8	Plant Height	0.685	

Q^2 = 1 – (1 – $R1^2$) (1 – $R2^2$) .... (1- Rp^2)
Q^2 = 1 – (1 – 0.471)(1 – 0.157) .... (1 – 0.685)
= 1 – (0.529 x 0.843 x .... x 0.315)
= 1 – 0.003
= 0.997

The calculation result displayed the predictive value-relevance (Q2) of 0.997 or 99.7%. Relevance predictive value of 99.7% indicated that the diversity of data that could be explained by the model amounted to 99.7%, or in other words, 95.4% of the information contained in the data might be explained by the model; while the remaining 0.3% was explained by other variables (which were not mentioned in the model) and error. Thus, the built structural models were best used to describe the correlation between microclimates and potato plant growth.

Different mulch influenced the microenvironmental e. g soil moisture and temperature [22], [23]. Different mulch contributed to the different microenvironmental which significantly affected potato growth [23] e. g plant height [15], [24], [25]; stem diameter [25]; number of leaves [24], [25]; leaf area and leaf area index [26]; and plant dry weight [24], [26].

B. The Effects of Mulch Provision on Temperature Reflected Radiation and Humidity

To test the effect of mulching on temperature, reflected radiation, and humidity, mulch variables must be formed into a dummy variable, as mulch is a qualitative variable. The treatment of the mulch types used in this experiment was the medium without mulch (M0), straw (M1), and silver-black plastic (M2). Therefore, the dummy variable was formed by developing two variables, namely dM1 and dM2. In calculation, M0 was used as a reference to explain the effect of mulching on temperature, the reflected radiation, and humidity. Here are the results of testing the effects of mulching on the temperature, the reflected radiation, and humidity:

TABLE II
TESTING OF THE EFFECTS OF MULCH

Effect Lines	Coefficient	T-Statistic	p-value
Dummy 1			
dM1 ->Temperature	0.519	0.989	0.324
dM1 ->Reflected Radiation	0.290	1.048	0.296
dM1 ->Humidity	0.080	0.328	0.743
Dummy 2			
dM2 ->Temperature	-0.003	0.011	0.991
dM2 ->Reflected Radiation	0.196	0.626	0.532
dM2 ->Humidity	-0.031	0.166	0.868

On the effect line of dummy 1 (DM1) with temperature, the obtained path coefficient was 0.519. The coefficient indicated that the use of straw mulch produced a higher temperature than without mulch. By investigating the effect line of the reflected radiation effect, it was found that the path coefficient was 0.290. A positive coefficient showed that the use of a straw to produce reflected radiation was higher than without mulch. If it was seen from the effect line of humidity, the obtained coefficient was 0.080. As a previous explanation, this positive coefficient projected that straw's use affected higher humidity than without one. The use of straw mulch produced higher soil temperature, reflected radiation, and humidity than without mulch. Straw mulch generated significantly higher soil moisture than without one [25], [27].

On the other hand, it was reported that straw mulch decreased soil temperature [27]. The value was close to or even lower than bare soil at the early growing potato season, and the difference became smaller as time passed from early until late growing days [28]. The P-value can explain it on each line that was more than 0.05, which means that the difference is not significant at the 5% error level.

On the effect line of dummy 2 (DM2) towards temperature, the obtained line coefficient was -0.003. The negative coefficient indicated that the use of silver-black plastic mulch resulted in lower temperatures than without mulch. By observing from the reflected radiation line, the obtained path coefficient was 0.196. A positive coefficient showed that the use of silver-black plastic produced reflected radiation higher than without mulch. If seen from the humidity line, the obtained coefficient was -0.031, which means that the use of silver-black plastic produced lower moisture than without one.

The use of silver-black plastic mulch produced higher reflected radiation, also lower temperature, and moisture than without mulch. It can be explained by the negative relation between reflected photosynthetically active radiation (PAR) and root zone temperature (RZT). The mean RZT under the plastic mulch decreased with increasing percentages of reflected PAR. PAR's percentage reflected from the silver mulch surface was higher than the black and white mulch [22]. The P-value on each line was more than 0.05, which means that the difference is not significant at the 5% error level. As reported by a previous study that silver-on-black mulch could increase [26], [28], or decrease soil temperature either significantly or insignificantly [22].

C. The effects of Temperature on the Growth of Potato Plants

In addition to a direct effect on humidity, the temperature factor has also directly affected potato plants' growth. Here are the results of testing the effects of temperature and humidity towards potato plant growth:

TABLE III
TESTING ON THE EFFECTS OF TEMPERATURE

Effect Lines	Coefficient	T-Statistic	p-value
Temperature ->Humidity	-0.513	2.033	0.043
Temperature -> Stover Dry Weight	-0.535	5.447	0.000
Temperature ->Stem Diameter	0.341	1.469	0.143
Temperature ->Leaf Number	-0.521	5.414	0.000
Temperature ->Leaf Width	0.550	3.344	0.001
Temperature ->Plant Height	-0.632	7.250	0.000

On the effect line of temperature to humidity, the obtained line coefficient was -0.513. This coefficient portrayed that temperature increase gave a negative impact on humidity. The increase in temperature resulted in a decrease in humidity. Furthermore, on the effect line of temperature to crop yields, the obtained line coefficient was -0.535. The negative coefficient indicated that an increase in temperature affected negatively on the dry weight of the stover. The increase in temperature was likely to reduce the dry weight of the stover. On the effect line of temperature on stem diameter, the coefficient was 0.341, which means that the increase in temperature impacted the increase in stem diameter. However, the p-value was higher than 0.05, which indicated that these effects are not significant at the 5% error level.

On the effect line of temperature towards the number of leaves, the line coefficient was -0.521. The negative coefficient means that an increase in temperature has an impact on decreasing the number of leaves. On the effect line of temperature on leaf width, the obtained line coefficient was 0.550. A positive coefficient indicated that an increase in temperature has an impact on the increase in leaf width. Also, the effect line of temperature on plant height received an -0.632 coefficient. This negative coefficient showed that an increase in temperature results in a decrease in plant height. Temperatures negatively affect the growth of all variables except the variable leaf width.

In summary, temperature directly affected the growth of the potato, i.e. negatively affected the dry weight of stover, number of leaves, and plant height; and positively affected stem diameter and leaf width. A previous study reported that temperature above 3ºC of ambient temperature negatively impacts plant dry weight of potato [29]. Furthermore, RZT has negative linearity with plant height, stem diameter, the leaf dry weight, stem dry weight, and shoot dry weight of potato [22]. Besides growth, total and tuber dry matter was significantly reduced with the increase of mean air temperature [30]. Temperature increase caused increased respiration rates, and thus the plant may suffer from stress despite the high soil humidity. High respiration indicates photosynthate assimilation demolition that should be directed to the growth; in fact, its use is diverted for respiration [31].

The negative effect of mean air temperature may be attributed to some factors, including four aspects [30]. Firstly, the rise of temperature was decreasing CO2-level on net photosynthesis so that assimilation for the growth and development of plants reduced. Secondly, the temperature was affecting respiration, which increases with increasing temperature—consequently, net photosynthesis and dry matter accumulation decrease. Maintenance respiration was much more sensitive than gross photosynthesis to temperature. Thirdly, a high vapor pressure deficit at elevated temperature was increasing stomatal resistance, resulting in reduced photosynthetic rate. Fourthly, the negative effect of high temperature may be associated with the proportion of diffuse radiation because the high temperature often in agreement with sunny weather and thus a high proportion of direct radiation.

D. The Effects of The Reflected Radiation on The Growth of Potato Plants

In addition to its direct effect on temperature and humidity, the reflected radiation factor has also directly affected the growth of potato plants. Here are the test results of the effect of the reflected radiation to humidity and the growth of potato plants:

TABLE IV
TESTING ON THE EFFECTS OF REFLECTED RADIATION

Effect Lines	Coefficient	T-Statistic	p-value
Reflected Radiation ->Humidity	-0.296	1.315	0.190
Reflected Radiation ->Temperature	0.159	0.952	0.342
Reflected Radiation ->Stover dry weight	0.120	0.877	0.381
Reflected Radiation ->Stem Diameter	0.145	0.970	0.333
Reflected Radiation ->Leaf Number	0.038	0.259	0.796
Reflected Radiation ->Leaf Width	0.434	2.455	0.015
Reflected Radiation ->Plant Height	-0.001	0.011	0.992

On the effect line of reflected radiation to humidity, the coefficient was -0.296. The negative coefficient indicated that an increase in the reflected radiation reduced the humidity. On the effect line of reflected radiation to temperature, the line coefficient was 0.159. A positive coefficient explained that an increase in the reflected radiation impacted on the increasing temperature. The prior study stated that mean global radiation was positively correlated to mean temperature [30]. Decreasing light intensity followed by increasing air humidity, decreasing average air, and soil temperature [32]. Also, mulch surface temperature is associated with the daily integral net radiation (Rn), which resulting in longwave radiation on the canopy emitted from the mulch surface [15]. The effect line of reflected radiation to dry weight of stover showed a coefficient of 0.120. This positive coefficient portrayed that an increase in the reflected radiation gave a positive impact on the dry weight of the stover. Whereas for the stem diameter, the obtained line coefficient was 0.145, indicating that an increase in the reflected radiation resulted in a positive effect on stem diameter. For the number of leaves, the derived line coefficient was 0.038. This number indicated that there was an increased number of leaves.

For the effect line of reflected radiation on leaf width, the coefficient was 0.434, showing a positive impact on leaf area. For the plant height, the line coefficient was -0.001, reflecting a negative impact on plant height. Based on the results of the analysis, p-value on all lines of more than 0.05 indicated that the reflected radiation has no significant effect on the growth of potato plants except the leaf width. Regarding this result, it was also reported that radiation level did not significantly influence the total dry matter of potato [30]. The decreasing solar radiation in the form of heat received by the surface of the soil will decrease the evaporation rate so that soil humidity can be maintained [33]. The low intensity of light received by the leaf surface caused low energy available to combine CO_2 with H_2O. This situation led to a low rate of photosynthesis. The low rate of photosynthesis will be followed by a low rate of growth and development; thus, the yielding results are also low [34].

E. The effects of humidity on the growth of potato plants

The following is the test result of the humidity effect on the growth of potato plants:

TABLE V
TESTING ON THE EFFECTS OF HUMIDITY

Effect Lines	Coefficient	T-Statistic	p-value
Humidity ->Stover dry weight	0.220	1.127	0.261
Humidity ->Stem diameter	0.093	0.519	0.604
Humidity ->Leaf Number	0.349	1.467	0.144
Humidity ->Leaf Width	0.081	0.528	0.598
Humidity ->Plant Height	0.247	1.272	0.205

As seen from the effect line of humidity on the stover's dry weight, the derived coefficient was 0.220. This value indicated that an increase in humidity has a positive impact on the stover's dry weight. As for the trunk diameter, the resulting coefficient was 0.093, showing that an increase in humidity has a positive impact on the stem diameter.

Further, the effect of humidity on the number of leaves showed the coefficient line of 0.349. It reflected that an increase in humidity correlated positively with the number of leaves. For humidity, the obtained coefficient was 0.081. This positive coefficient displayed a positive impact on the leaf width; as for the plant height, the coefficient was 0.247, proof that an increase in humidity created a positive impact on leaf width. The P-value of humidity, which was greater than 0.05, had no significant effect on potato plants' growth. Soil humidity is generally proportional to all the variables of plant growth though not significantly. High soil humidity has shown high water content in the soil; therefore, the transport of mineral nutrients that plants need are equally fulfilled [34].

IV. CONCLUSION

Silver-black-plastic mulch provides the highest growth of potato compared to other treatments. So, farmers can use silver-black-plastic mulch in planting potatoes. Compliments to BMKG and the head of Bumiaji district that assist researchers conducted this research.

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