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Effect of Fertilizer Application and Plant Density on Physiological Aspect and Yield of Taro (*Colocasia esculenta* (L.) *Schott* var. *Antiquorum*)

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ABSTRACT

A research was conducted to study the effect of nitrogen and potassium (NK) fertilizers and plant density on the growth and yield of taro (*Colocasia esculenta* (L.) *Schott* var. *Antiquorum*). The field experiment was carried out at Brawijaya University experimental field station located at Jatikerto, Malang, Indonesia. The experimental treatments consist of three plant density (18,000, 24,000 and 30,000 ha^{-1}) and three levels of NK fertilizer (62.50 kg N, 81 kg K_2O, 125 kg N, 162 kg K_2O, 187.50 kg N, 243 kg K_2O ha^{-1}). These treatments were arranged in a split plot design; fertilizer in the subplot and plant density in the main plot with three replications. The F-value ($p = 0.05$) was used to test the treatment effect and Least Significant Different (LSD) ($p = 0.05$) was used to test the difference between treatments. The results showed that there was no interaction between NK fertilization and plant density for most of the parameters. Plant density only significantly influenced the number of tubers per plant and starch content. The optimum application rate of NK fertilizers was obtained as 127.04 kg N ha^{-1} and 164.64 kg K_2O ha^{-1} with the tuber yield of 16.72 t ha^{-1}. The highest starch content (28.36%) achieved at the application rate of 127.84 kg N ha^{-1} and 162.08 kg K_2O ha^{-1}.

Key words: Cocoyam, plant arrangement, plant nutrient, chlorophyll, starch content

INTRODUCTION

Taro (*Colocasia esculenta* (L.) *Schott* var. *Antiquorum*) can be found in any part of Indonesia. It is believed that taro was originated from South and Southeast Asia (Kolchaar, 2006). Its underground root, known as corm, possesses a high nutritional value. The data presented by USDA shows that every 100 g of dry tuber contain: 142 kcal energy, 34.6 g carbohydrate, 5.1 g fiber, 0 g cholesterol, 5 mg vitamin C, 2.93 mg vitamin E, 484 mg potassium, 76 mg of phosphorus, 18 mg calcium and 30 mg magnesium (Wills *et al*., 1983). Therefore, taro has a good prospect to be used as one of the staple food to support government food security program. In fact, taro is one of the popular edible root vegetables in large parts of West Africa, Pacific Island and South America (De la Pena and Plucknett, 1971).

Unlike other tuber crops, such as cassava and sweet potato, in Indonesia taro has only received little attention. Most of them grow wild in unused land or forest land. If it is cultivated, usually this crop is grown naturally in the yard with no specific attention. As a consequence, the yield of taro is very low, only 5 t ha^{-1} while with proper cultivation technique the yield could reach 50 t ha^{-1} in lowland and 25 t ha^{-1} in dry land (De la Pena and Plucknett, 1972).

Taro does not need special requirements to grow. It can grow in any environmental conditions. Therefore, a simple technology such as improving planting materials or increasing plant population would be enough to increase tuber yield (Tsedalu *et al*., 2014). Liou (1984) observed that increasing plant population from 26,600-83,300 plants ha^{-1} increased corm yield from 17-56 t ha^{-1}. However, to minimize plant competition, improving plant population should be followed by plant arrangement (Ogbonna *et al*., 2015). With plant spacing of: 50×100, 40×100 and 30×100 cm, Ogbonna *et al*. (2015) found that increasing plant population from 20,000 plants ha^{-1} (plant spacing of 50×100 cm) to 25,000 plants ha^{-1} (plant spacing of 40×100 cm) resulted an increase in plant population at harvest but there was a decline in plant population for further decreased in plant spacing (30×100 cm).

With the high biomass harvested, there would be high plant nutrition removed from the soil. Therefore, fertilization should be employed, either to obtain high yield or to maintain soil productivity. Generally tropical soils are low in nitrogen content (Pardales and Belmonte Jr., 1984). Tadesse and Tesfaye (2010) found that tuber yield increase up to 150 kg N ha^{-1}, then decrease when nitrogen rate increase to 200 kg N ha^{-1}. The effect of NPK application on taro yield has been studied by Villanueva *et al*. (1983) and Ogbonna and Nweze (2012). Ogbonna and Nweze (2012) found that the highest yield was obtained with application of 200-250 kg ha^{-1} NPK fertilizer (NPK; 15, 15, 15). A further increase application rate decreased taro yield.

Therefore, the present experiment was aimed to study the effect of NK fertilization at three different plant densities on the physiological aspect of taro plant, especially its chlorophyll content and Net Assimilation Ratio (NAR). The study was also investigated the effect NK fertilization on the yield of taro planting at three different plant densities.

MATERIALS AND METHODS

Location: The study was conducted at experimental field of Brawijaya University at Jatikerto, approximately 30 km to south from Malang. This field station located 303 m above sea level; the soil is a silty clay loam, with soil pH of 6.5; C-organic content of 0.63%; N-soil content of 0, 10% and K-soil content of 1.0 mmol.

The annual rainfall is about 2000 mm with distinct dry-wet season. Wet season starts from November and ended in April the following year. Minimum temperature ranges between 18-21°C and maximum temperature ranges from 30-33°C.

Experimental treatment: The experimental treatments consist of three plant density (18,000; 24,000 and 30,000 ha^{-1}) and three levels of fertilizer application (62.50 kg N ha^{-1}, 81 kg K_2O ha^{-1}; 125 kg N ha^{-1}, 162 kg K_2O ha^{-1}, 187.50 kg N ha^{-1}, 243 kg K_2O^{-1}). These treatments were arranged in a Split Plot Design with fertilizer application in subplot and plant density is placed in the main plot and all treatments were replicated three times.

Taro seedling with 2-3 leaves was planted on experimental plot of 16.75×43.9 m. Prior to planting the chicken manure was applied to the soil at a rate of 9 t ha^{-1}. Nitrogen was applied as Urea (46% N) and potassium as potassium chloride (50% K_2O). Potassium and nitrogen fertilizer was applied in two installments: 1/3 at 30 Day After Planting (DAP) and the rest (2/3) at 60 DAP. Fungicides Dhitane M-45 and Antracol WP 70 were used to control plant diseases and insecticide Winder 100 EC and Furadan 3G were used to control insect pests.

Data was collected on leaf area, chlorophyll content, Net Assimilation Rate (NAR), the number of tubers $plant^{-1}$, weight of tubers $plant^{-1}$, tuber yield ha^{-1} and starch content of tubers. To obtain these data, two plants from each plot were harvested at 70, 105 and 140 Days After Planting (DAP). The plant was harvested at 175 days after planting. Soil sample was taken before fertilizer application, soon after fertilizer application and at harvesting for nitrogen and potassium. Chlorophyll content was determined by spectrophotometer method (Hidema *et al*., 1992), soil nitrogen by Kejldahl methods (AOAC., 2002) and soil potassium was extracted with ammonium acetate 1 N and then the K concentration in the solution was read with spectrophotometer (SPAC., 1980). The NAR describes the rate of increase in total plant dry matter per unit leaf area per unit time, determined by using the formula (Evans, 1972):

$$NAR = \frac{W2 - W1}{LA2 - LA1} \times \frac{InLA2 - InLA1}{T2 - T1} \text{ g cm}^{-2} \text{ day}^{-1} \quad (1)$$

where, W1, W2 is total dry matter at the time of observation 1 and 2, T1, T2 is observation time 1 and 2 and LA1, LA2 is leaf area on observation 1 and 2.

The F-test at p = 0.05 was used to test the effect of the treatments. If there is a significant effect, statistical analysis followed by Least Significant Different (LSD) test at p = 0.05 to test the difference between treatments (Gomez and Gomez, 1984). Regression analysis is used to explore relationship between the variables.

RESULTS AND DISCUSSION

Chlorophyll content: Chlorophyll content of taro plant was not significantly influenced by Interaction between NK fertilization and plant density but only influenced by NK fertilization (Table 1).

The result in Table 1 show that the lowest content of chlorophyll a, b and total chlorophyll was found in fertilizer NK doses of 62.5 kg Nha^{-1}, 81.0 kg K_2O ha^{-1} and showed an increase with its increased dose of fertilizer NK from 62.5 kg Nha^{-1}, 81.0 kg K_2O ha^{-1}, into 125.0 kg Nha^{-1}, 162.0 kg K_2O ha^{-1} and 187.5 kg N ha^{-1}, 243.0 kg K_2O ha^{-1}. The lowest content of those chlorophyll is due to the lower levels of availability of NK soil (after application of the entire fertilizer NK) as well as lower plant uptake estimation, respectively 0.17 and 52.94% for N and 0.55 and 55.36% for K fertilizer. While the level of availability of NK soil and plant uptake estimate of 0.22%, 65% for N and 0.60 and 60% for K fertilizer occurred in fertilizer NK doses of 125.0 kg N ha^{-1}, 162.0 kg K_2O ha^{-1} and 0.33 and 73.64% for N and 0.73 and 68.06% for K doses of 187.5 kg N ha^{-1}, 243.0 kg K_2O ha^{-1}. The increase of chlorophyll content with increasing nitrogen rate is reasonable because nitrogen is play important role in chlorophyll compound (Tadesse and Tesfaye, 2010). However, a further increase in dose of NK fertilizers did not significantly increase the chlorophyll content. It is suspected that the higher N absorbed by plants is not only for the formation of chlorophyll but also used for the formation of other compounds such as amino acids or proteins that are not identified in the observations (Prawiranata *et al*., 1981). Faozi and Wijonarko (2010) also reported that the increase in urea than 150-300 kg ha^{-1} were not followed by an increase in the content of chlorophyll a and b, respectively (10.5 and 11.2 mg g^{-1})[a] for chlorophyll a and (14.6, 16.8 mg g^{-1})[a] for chlorophyll b.

Leaf area and Net Assimilation Rate (NAR): Interaction between NK fertilizers and plant density did not significantly influence on leaf area and Net Assimilation Rate (NAR) of taro plants (Table 2). These leaf area and NAR were only influenced by NK fertilization but not by plant density.

Table 1: Effect of NK fertilization (kg ha^{-1}) on average content of chlorophyll a, b and total chlorophyll at three levels of plant density

Treatments	Average content of chlorophyll (μg 2 g bs^{-1})		
	a	b	Total
62.5 N; 81.0 K_2O	2750.48^{a}	1364.11^{a}	4114.59^{a}
125.0 N; 162.0 K_2O	3096.13^{b}	2188.76^{b}	5284.89^{b}
187.5 N; 243.0 K_2O	3153.03^{b}	2304.91^{b}	5457.94^{b}
F-value	17.59*	14.94*	35.97*

Means followed by the same letter in each column are not significantly different (p = 0.05), *Significance at 5% level

Table 2: Effect of NK fertilization (kg ha^{-1}) on average leaf area at 140 DAP and NAR at 105-140 DAP

Treatments	Leaf area (cm^2)	NAR (mg cm^{-2} day^{-1})
62.5 N; 81.0 K_2O	2005.28^{a}	1.29^{a}
125.0 N; 162.0 K_2O	2647.00^{b}	1.90^{b}
187.5 N; 243.0 K_2O	2188.94^{a}	1.57^{ab}
F-value	6.08*	5.67*

Means followed by the same letter in each column are not significantly different (p = 0.05), *Significance at 5% level, NAR: Net assimilation ratio, DAP: Days after planting

Leaf area is increased with increasing fertilizer application. The widest leaf area (2647.00 cm^2 $plant^{-1}$) was obtained at 125.0 N; 162.0 K_2O treated taro but further increase in fertilizers rate will decrease the leaf area. Wider leaf area is strongly associated with a higher content of chlorophyll, either a, b and total chlorophyll in the treatment. Chlorophyll *a* acts as the reaction center (P700), which plays a role in converting radiation energy into chemical energy (Evans and Poorter, 2001). Whereas chlorophyll b, act as photosynthetic antenna or as an energy collector. Therefore, if the level of N availability is low, it can cause delay in the synthesis of carbohydrates. Carbohydrate is an energy and the energy will be converted into lipid, proteins, nucleic acids and other organic molecules in the formation of plant organs, including leaf area (Evans and Poorter, 2001). However, wider leaf area is not always followed proportionately by total dry weight. This is a result of the mutual influence among leaves shade formed. Consequently, assimilates production is low, especially on shaded leaves. The relationship between Leaf Area (LA) and Total Dry Matter (TDM) follows a quadratic model (Fig. 1):

$$TDM = -7.97\ LA^2+34.46\ LA+138.68 \qquad (2)$$

Based on this equations, it can be calculated that the optimum leaf area on taro plants was 2186.78 cm^2 to obtain optimum total dry matter as much as 175.93 g $plant^{-1}$.

It is interesting to notice that increasing plant density did not significantly influence the leaf area. One might expect that the increasing density of the plant will be followed by a decline in leaf area. However, it did not occur on taro plants in this experiment. It seems that at higher plant density taro experienced self-sucker (Ogbonna *et al*., 2015), so that plant population is not increase with increasing plant density.

The results in Table 2 also show that increasing doses of NK fertilizer of 62.5 kg N ha^{-1}, 81.0 kg K_2O ha^{-1} to 125.0 kg N ha^{-1}, 162.0 kg K_2O ha^{-1} resulted in the increased value of the NAR. However, a further increase tends to decrease the NAR.

Looking the result given in Table 1 and 2, it is obvious that effect of NK fertilization on NAR is followed by the same pattern with chlorophyll content. This is understandable because NAR is a function of chlorophyll content (Echarte *et al*., 2008). Thus the higher the chlorophyll content, the higher NAR produced.

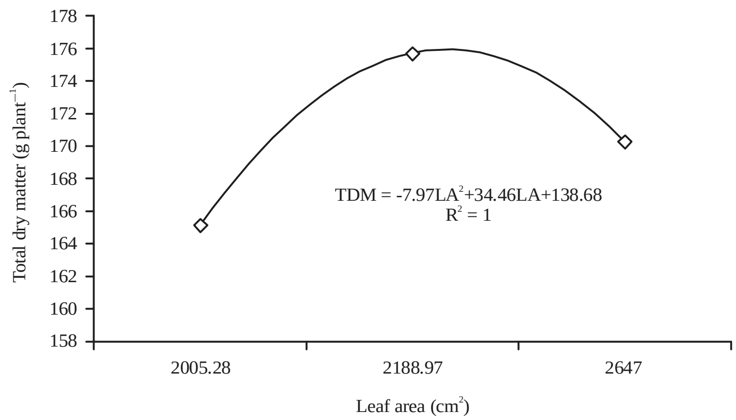

Fig. 1: Relationship between leaf area and total dry matter of taro plant

Table 3: Effect of NK fertilizers (kg ha^{-1}) on average number of tubers $plant^{-1}$, weight of tubers $plant^{-1}$ and tubers yield ha^{-1} at harvest

Treatments	No. of tuber $plant^{-1}$	Tuber weight $plant^{-1}$ (g)	Tuber yield (t ha^{-1})
62.5 N; 81.0 K_2O	26.0[a]	411.04[a]	9.31[a]
125.0 N; 162.0 K_2O	41.0[c]	724.74[b]	16.45[b]
187.5 N; 243.0 K_2O	33.0[b]	610.96[b]	13.88[b]
F-value	12.49*	8.23*	9.61*

Means followed by the same letter in each column are not significantly different (p = 0.05), *Significance at 5% level

Table 4: Effect of plant density (plants ha^{-1}) on average number of tubers $plant^{-1}$ at harvest

Treatments	No. of tubers $plant^{-1}$
18.000	26.0[a]
24.000	32.0[a]
30.000	42.0[b]
F-value	15.93*

Means followed by the same letter in each column are not significantly different (p = 0.05), *Significance at 5% level

Tuber yields and quality

Tuber yields: There was no significant interaction between plant density and NK fertilizer application on the parameters observed. Number of tuber $plant^{-1}$, tuber weight $plant^{-1}$ and tuber yield ha^{-1} was significantly influenced by fertilizer application (Table 3) while plant density only affects the number of tubers $plant^{-1}$ (Table 4).

The results in Table 3 shows that the highest yield was obtained at application rate of 125.0 N, 162.0 K_2O ha^{-1}. This is related with the highest tuber number $plant^{-1}$ and tuber weight $plant^{-1}$ obtained by this treatment. Furthermore, the results in Table 3 also shows that tuber yield increased with increasing the rate of fertilizer application from 62.5 N, 81.0 K_2O kg ha^{-1} to 125.0 N, 162.0 K_2O ha^{-1} but decreased when the rate was increased to 187.5 N; 243.0 K_2O kg ha^{-1}. To determine the optimum NK fertilizer dose, fertilizer rate (F) was plotted against tuber yield (Y) and it results a quadratic model (Fig. 2):

$$Y = -4.85\ F^2+21.70\ F-7.54 \quad (3)$$

The optimum rate of NK fertilizer calculated with equation (3) is 127.04 kg N ha^{-1} (282.32 kg of urea ha^{-1}) and 164.64 kg K_2O ha^{-1} (274 kg KCl ha^{-1}) with tuber yield of 16.72 t ha^{-1}. This yield is still far below the yield obtained by Liou (1984) or Ogbonna *et al*. (2015). Liou (1984) could obtain taro yield of more than 57 t ha^{-1}. This difference could be caused by different taro variety. In

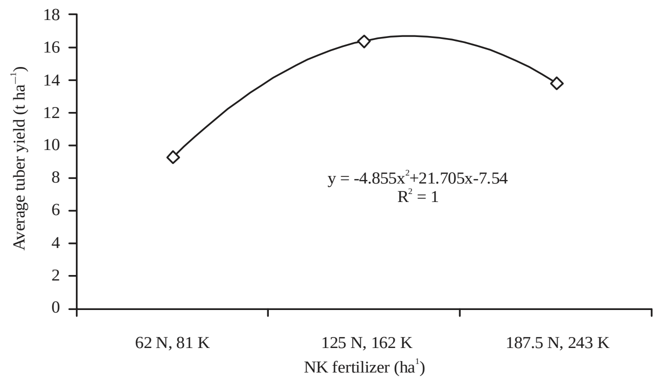

Fig. 2: Relationship between NK fertilizer and tuber yield of taro plant

Table 5: Effect of NK fertilizers (kg ha^{-1}) on starch content of tuber at harvest

Treatments	Average starch content (%) at harvest
62.5 N, 81.0 K_2O	24.99^a
125.0 N, 162.0 K_2O	28.35^b
187.5 N, 243.0 K_2O	25.94^{ab}
F value	7.39*

Means followed by the same letters are not significantly different (p = 0.05), *Significance at 5% level

Table 6: Effect of plant density (plants ha^{-1}) on starch content of tuber at harvest

Treatments	Average starch content (%) at harvest
18.000	29.52^c
24.000	25.56^b
30.000	24.20^a
F value	1082.50*

Means followed by the same letters are not significantly different (p = 0.05), *Significance at 5% level

addition, Liou (1984) planted his taro on lowland, whereas, in this experiment the taro was planted on upland with no irrigation water.

The number of tubers increased with increasing plant density (Table 4). The highest number of tubers obtained at the density of 30,000 plants ha^{-1}. This phenomenon can be understood because the more plants number, the higher the probability of tuber formation.

Tuber quality: Starch content is used to represent the quality of tubers and it was only significantly influenced by individual factor (Table 5 and 6). Starch content increase from 24.39% (application rate of 62.5 N, 81.0 K_2O kg ha^{-1}) to 28.35% (application rate of 125.0 N, 162.0 K_2O kg ha^{-1}). However, increasing application rate to 187.5 N, 243.0 K_2O kg ha^{-1} decreased starch content. This result indicates that NK fertilizer application rate above 125.0 N, 162.0 K_2O kg ha^{-1} is not always followed by high starch formation.

Tuber starch content is also influenced by the level of plant density. The result presented in Table 6 shows the highest starch content (29.52%) was obtained at plant density of 18.000 plants ha^{-1} and decreased as plant density increased. At plant density of 30.000 plants ha^{-1} the starch content is only 24.20%.

The decreased starch content with increasing plant density indicated that increasing plant density of taro plant is not only increasing a competition in tuber development but also significantly influence starch formation.

CONCLUSION

The experimental results being discussed showed that there was no significant interaction between NK fertilizers application and plant density on growth and yield of taro. The NK fertilizer application significantly influenced leaf area, NAR, tuber yield and starch content. Plant density, on the other hand, only significantly influenced the number of tubers per plant and starch content. The optimum application rate of NK fertilizers were 127.04 kg N ha^{-1} (282.32 kg of urea ha^{-1}) and 164.64 kg K_2O ha^{-1} (274 kg KCl ha^{-1}) with tuber yield of 16.72 t ha^{-1}. While the highest starch content (29.52%) was obtained at plant density of 18.000 plants ha^{-1}.

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