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The Effect of NPK Fertilizer on the Growth and Yield of Sweet Corn (*Zea mays Saccharata* Sturt.) with Various Planting Arrangements

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Abstract**—** *Planting layout arrangements greatly influence the sweet corn population and crop yields per unit area. Planting layout arrangements are related to plant spacing, plant spacing that is too wide causes too little population, while plant spacing that is too tight results in competition between plants. Fertilization of macronutrients such as NPK is needed to meet the needs of plants in the maximum population. The research was carried out from May to July 2023 in Jetis Village, Jetis District, Ponorogo Regency, East Java Province, Indonesia. The experiment used a split-plot design with NPK fertilizer dosage as the main plot and planting pattern as a subplot. The NPK dosage consists of three levels, namely 200 kg ha^{-1}, 300 kg ha^{-1} and 400 kg ha^{-1}, while the planting pattern consists of four levels, namely single row, jajar legowo 3:1, jajar legowo 2: 1 and ring pit pattern. The research results show that differences in planting layout influence the microclimate around sweet corn plants which includes temperature, relative humidity and sunlight intensity. The ringpit planting layout shows a higher population and yield compared to other planting patterns. The single row planting pattern showed the lowest growth and yield of sweet corn. NPK fertilization with doses of 300 kg ha^{-1} and 400 kg ha^{-1} can increase the growth and yield of sweet corn plants.*

Keywords**— *Fertilizer, NPK, Planting system, Population density, Sweet corn***

I. INTRODUCTION

Sweet corn (*Zea mays saccharata* Sturt.) is a type of plant that is harvested young and widely cultivated in tropical areas. Not only in tropical regions, sweet corn is a popular vegetable in the USA, Australia and Canada. Sweet corn is very popular among people because it has a 25-30% sweeter taste than normal grain corn (Bhatt, 2012; Ugur and Maden, 2015). Sweet corn is a source of carbohydrates, protein, vitamins, minerals, phenolic acids, carotenoids and fiber. Regular consumption of sweet corn can reduce the severity of chronic diseases such as cardiovascular disease, eye disease, obesity, diabetes and digestive diseases (Sheng *et al*., 2018). Sweet corn also has an important role in meeting the nutritional needs of celiac sufferers, because sweet corn kernels do not contain gluten which is usually provided in the form of corn flour (Baranowska, 2023).

In Indonesia, the average sweet corn production is around 8.31 tons ha^{-1} and has a value that is very far from the potential yield of 14 tons ha^{-1} to 18 tons ha^{-1} (Pratama *et al.*, 2022). Low production can be caused by various aspects, including cultivation factors, biotic factors and abiotic factors. Improvement efforts that can be made to increase production are expanding cultivation areas (extensification) as well as increasing land productivity and improving cultivation techniques (intensification) (Magezi *et al.*, 2023). Intensification can be done by regulating planting patterns and managing adequate nutrition.

Setting planting patterns is related to plant spacing, plant population per hectare which will then influence the production produced per hectare (Bernhard and Below, 2020). Increasing population in a unit area can increase yields, but plant density that is too high reduces yields and quality due to competition for environmental resources such as light, temperature, water and nutrients (Xue *et al*., 2016). As a C4 plant, corn is very susceptible to light stress and low temperatures (Bilska and Sowiński, 2010; Bellasio and Griffiths, 2014).

At maximum population conditions, nutrient management is needed so that plant nutrition is sufficient. Macro essential fertilizers that must be met for plant growth are N, P and K (Gul *et al*., 2015). N plays an important role in the synthesis of proteins, enzymes, DNA, RNA and chlorophyll (Hayat *et al*., 2010). P is needed in the formation of proteins and carbohydrates, DNA, RNA, forms ATP as an energy source and is important in the photosynthesis process, while K plays a role in osmoregulation, photosynthesis and induces sucrose content, soluble sugar content and starch content in corn plants (Pettigrew, 2008; Duncan *et al*., 2018; Yang *et al*., 2021). This research aims to obtain a model for proper plant layout and NPK fertilization to increase the productivity of sweet corn plants.

II. MATERIALS AND METHOD

2.1 Experimental detail

The research was carried out from May to July 2023 in Jetis Village, Jetis District, Ponorogo Regency, East Java Province, Indonesia. The research was carried out using a split-plot design, the main plot was the NPK fertilizer dose and the plant layout method was the subplot

The main plot is the NPK fertilizer dose which consists of three levels:

N1: NPK 200 kg ha^{-1}

N2: NPK 300 kg ha^{-1}

N3: NPK 400 kg ha^{-1}

The subplot consists of a plant layout method which consists of four levels:

P1 = Single row (95 plants per plot)

P2 = Jajar legowo 3:1 (246 plants per plot)

P3 = Jajar legowo 2:1 (270 plants per plot)

P4 = Ring pit (280 plants per plot)

This treatment combination was repeated 3 times to obtain 36 experimental plots.

Data were analyzed using ANOVA (Analysis of Variance) and carried out with the F test was at the 5% error level, if there is an effect continued HSD (honest significant difference) test at the 5% error level.

2.2 Field experiment

The experimental site is situated at an altitude of approximately 146 meters above sea level (masl), average air temperature of 21-31°C, and with Alluvial soil type. Planting sweet corn seeds is carried out using 4 plant layout methods according to treatment: a) Single row planting uses spacing 20x70 cm (population of 95 plants per plot), b) Jajar legowo 3:1 with a planting distance of 30x30x90 cm (population 246 plants per plot), c) Jajar legowo 2:1 with a planting distance of 20x30x90 cm (population 270 plants per plot), d) ring pit pattern, in one circle there are 8 planting holes with a planting distance between the circles of 60x70 cm (population 280 plants per plot). An illustration of the plant layout is presented in Figure 1.

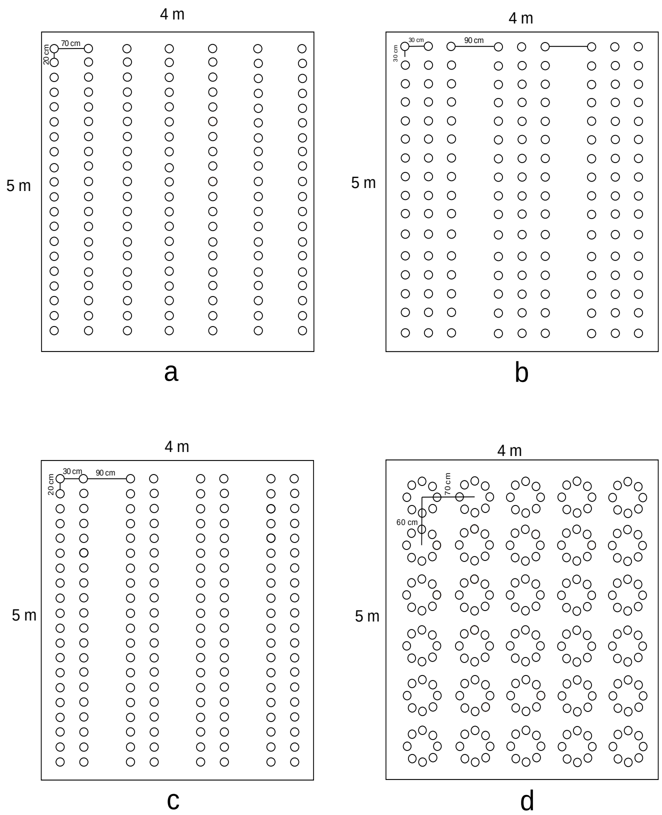

Fig.1: Sweet corn planting pattern: a. Single row, b. Jajar Legowo 3:1, c. Jajar Legowo 2:1, d. Ring pit pattern

Fertilizer application uses compound NPK 16:16:16 according to the dosage of each treatment. Maintenance activities include replanting, irrigation, weeding, hilling and controlling pests and diseases. Sweet corn harvesting is carried out 18-24 days after pollination. The age of a sweet corn plant is between 60-70 days at physiological maturity which is marked by the color of the corn hair starting to turn brown and drying out, the tip of the cob starting to be filled with corn kernels.

2.3 Measurement

The variables were observed in this research include growth variables, microclimate observations and yield variables.

2.3.1 Growth variables observed at age 56 DAP. Growth variables include :

1. Plant height

Observation of plant height is carried out by measuring the height from the base of the stem to the highest growing point of the plant

2. Number of leaves
Counting the number of leaves is done by counting the leaves that have opened completely

3. Leaf area (cm^2)
Leaf area was measured using the ALA method (*Average Leaf Area*) which can be done non-destructively (Widaryanto *et al*., 2019). The method used is to find the average estimated leaf area using a formula :

$$\overline{X} = \frac{(\textbf{Leaf area 1} / \varepsilon\ \textbf{leaf 1}) + (\textbf{Leaf area 2} / \varepsilon\ \textbf{leaf 2})}{2})$$

To find out the average leaf area per plant use the formula:

$$\text{LA per plant} = \overline{X} \times \text{NL}$$

Keterangan:
$\overline{X}$ = Average area per leaf
ε = Number of leaves per plant
LA = Leaf area
NL = Number of leaves per sample plant

4. Stem diameter
Measurements were carried out on the second segment from the bottom of the soil using a caliper

5. Fresh weight per plant
Fresh weight was observed by measuring the total fresh weight of the plant using a digital scale

6. Dry weight per plant
Dry weight is obtained from the weight of samples that have been oven-treated for 48 hours at 80ºC.

2.3.2 Microclimate observations were observed at 14, 28, 42 and 56 HST. Microclimate observations include :

1. Temperature and relative humidity
Temperature and relative humidity are measured using a thermohygrometer. Measurements on plants were carried out in the middle of the plant canopy during the day (12.00 am).

2. Intensity of solar radiation
Measurement of the intensity of solar radiation was carried out at 12.00 am on plants including the top, middle and bottom of the plant canopy using a lightmeter (Sugito., 1999).

2.3.3 Yield variables are observed at harvest time at approximately 60-70 days after planting. Yield variables include :

1. Number of cobs per plot
The number of cobs was calculated by counting all the corn cobs in each treatment plot with an area of 4 x 5 m

2. Length of the filled cob
Measurements are made by measuring the length of the cob from the base to the tip of the cob using a tape measure

3. Cob diameter
Measurements were made at the center of the corn cob using a caliper

4. Weight the cobs with husks
Measurements were made by weighing the corn cobs and husks using a digital scale

5. Weight of cobs without husks
The corn husks were peeled and then the weight of the cobs without the husks was weighed using a digital scale

6. Harvest index
The harvest index is a value that describes the distribution of photosynthesis or plant biomass between the two parts of the plant that have been considered, namely the organs for photosynthesis and the organs of economic value. The harvest index using a formula :

$$\text{Harvest index} = \frac{\textit{Weight of cobs}}{\textit{Total biomass}}$$

III. RESULTS

3.1 Growth Observations

The effect of administering NPK fertilizer doses and planting layout methods on sweet corn plant growth variables is presented in Table 1. There is no interaction between the two treatments, but each factor has its own influence.

Table 1. Effect of NPK dosage and planting layout method on sweet corn plant growth components

Treatment	Plant height (cm)	Number of leaves (sheet)	Leaf area (cm^2)	Stem diameter (cm)	Fresh weight (g tan^{-1})	Dry weight (g tan^{-1})
NPK fertilizer dosage						
N1(NPK 200 kg ha^{-1})	181,25 a	11,58 a	1084,40 a	2,48	507,81 a	176,98 a
N2 (NPK 300 kg ha^{-1})	205,56 ab	12,42 b	1128,99 ab	2,56	585,80 ab	220,14 ab
N3 (NPK 400 kg ha^{-1})	223,54 b	12,77 b	1312,83 b	2,59	607,17 b	238,98 b

HSD 5%	35,90	0,803	187,6	ns	95,7	52,72
CV (%)	12,13	4,50	10,97	8,00	11,60	23,32
Planting layout method						
P1 (Single row)	192,50	12,11	994,38 a	2,60	510,35 a	192,26 a
P2 (Jajar legowo 3:1)	206,31	13	1118,42 a	2,58	458,82 a	163,78 a
P3 (Jajar legowo 2:1)	205,14	12,33	1143,79 a	2,48	579,86 ab	188,33 a
P4 (Ring pit)	209,86	12,00	1445,04 b	2,50	718,68 b	303,77 b
HSD 5%	ns	ns	227,6	ns	157,7	57,18
CV (%)	7,20	5,92	14,54	7,37	20,89	22,94

Remarks: The numbers followed by the same letter in the same column are not significantly different in the HSD test with a confidence level of 95%. HSD: Honest Significant Difference CV: Coefficient of variation

The variables of plant height and number of leaves were only influenced by NPK fertilization and were not influenced by differences in planting layout. The variables of leaf area, fresh weight per plant and dry weight per plant were influenced by the two treatments, namely the dose of NPK fertilizer and differences in planting layout. Neither the NPK fertilizer dose nor the planting layout method had any effect on the stem diameter of sweet corn plants. Providing NPK fertilizer at doses of 300 kg ha^{-1} and 400 kg ha^{-1} showed higher growth variables than the NPK dose of 200 kg ha^{-1}.

Different planting layout methods have no effect on plant height, number of leaves and stem diameter of sweet corn plants. The planting layout method influences the variables of leaf area, fresh weight and dry weight of the plant. The planting layout method using ring pits showed higher leaf area and plant dry weight compared to other treatments. In the variable fresh weight per plant, it shows that the 2:1 row legowo planting layout method and row rings show higher yields.

3.2 Microclimate observations

In this research, we studied how the planting layout method influences the microclimate. The components observed in microclimate observations are temperature, humidity and sunlight intensity (Figure 2). Observations of air temperature show that the temperature decreases as the age of the plant increases. Air temperature decreased drastically at the age of 42 WAP and 56 WAP plants. The jajar legowo 3:1 treatment had a higher air temperature compared to the other treatments. Lined ring treatments tend to have lower temperatures. Differences in air temperature between treatments can be related to canopy density which is formed due to differences in planting distance and plant density.

Observations of relative humidity show a graph that is inversely proportional to air temperature. When the temperature is high, the relative humidity is low, and conversely, if the temperature is low, the relative humidity becomes high. Relative humidity decreased at 28 WAP, and then continued to increase at 42 WAP and peaked at 56 WAP. The lined ring layout method tends to have higher relative humidity compared to other treatments. The planting layout method that shows low relative humidity is found in the row legowo 3:1 treatment.

The value of solar radiation intensity is inversely related to the graph of relative humidity observations. The intensity of solar radiation continues to increase until the age of 42 WAP and then decreases significantly at the age of 56 WAP. The jajar legowo 3:1 treatment showed higher intensity compared to other treatments. The lined ring treatment had the lowest intensity at 14 WAP and 56 WAP, but the intensity increased drastically at 28 WAP and 42 WAP. Air temperature and solar radiation intensity have a pattern that is directly proportional, and both have values that are inversely proportional to relative humidity. When the intensity of solar radiation increases, the air temperature will increase and the relative humidity will decrease.

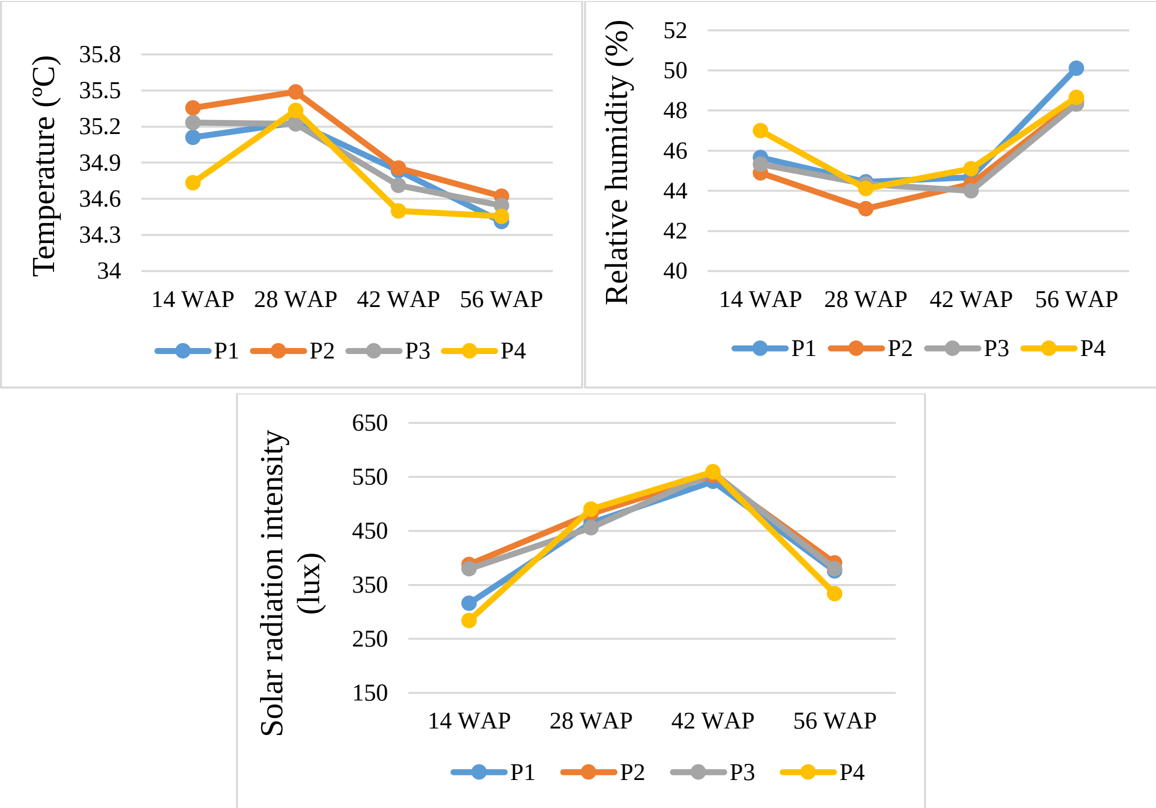

Fig.2: The effect of planting layout methods on air temperature, relative humidity and solar radiation intensity at each observation age

3.3 Yield Observations

The effect of administering NPK fertilizer doses and planting layout methods on sweet corn plants is presented in Table 2. There is no interaction between the two treatments, but each factor has its own influence.

Table 2. Effect of NPK dosage and planting layout method on sweet corn yield observations

Treatment	Number of cobs per plot	Length of cob contains (cm)	Cob diameter (cm)	Cob weight with husk (g)	Cob weight without husk (g)	Harvest index
NPK fertilizer dosage						
N1(NPK 200 kg ha^{-1})	48,92	17,86 a	4,76	257,34 a	177,33 a	0,51
N2 (NPK 300 kg ha^{-1})	50,50	19,38 ab	4,85	298,75 b	196,74 ab	0,50
N3 (NPK 400 kg ha^{-1})	50,08	22,73 b	5,13	295,18 b	203,93 b	0,52
HSD 5%	ns	3,668	ns	34,34	23,60	ns
CV (%)	15,96	12,61	8,05	8,32	8,42	20,83
Planting layout method						
P1 (Single row)	43,78 ab	18,39 a	5,05	245,635 a	176,111 a	0,44 a
P2 (Jajar legowo 3:1)	34,67 a	20,31 b	4,94	295,536 b	200,536 b	0,58 b
P3 (Jajar legowo 2:1)	53,22 b	20,46 b	4,76	278,492 ab	188,948 ab	0,49 ab
P4 (Ring pit)	67,67 c	20,81 b	4,90	315,357 b	205,071 b	0,53 ab
HSD 5%	10,56	1,384	ns	43,75	19,93	9,93
CV (%)	15,91	5,20	6,45	11,57	7,77	14,30

Remarks: The numbers followed by the same letter in the same column are not significantly different in the HSD test with a confidence level of 95%. HSD: Honest Significant Difference CV: Coefficient of variation

The dose of NPK fertilizer affects the yield variables of sweet corn plants which include the length of the filled cob, the weight of the cob with the husk and the weight of the cob without the husk. Differences in NPK fertilizer doses did not affect on the number of cobs per plot, ear diameter and harvest index. Giving NPK at a dose of 300 kg ha^{-1} and 400 kg ha^{-1} showed higher results compared to the NPK dose of 200 kg ha^{-1}.

The planting layout method does not affect the diameter of the cobs, but it does affect the number of cobs per plot, the length of the filled cobs, the weight of the cobs with husks, the weight of the cobs without husks and the harvest index. The planting layout with a lined ring pattern shows a higher number of cobs per plot compared to other planting patterns. Observing the length of the filled cobs, the weight of the cobs with husks, the weight of the cobs without husks and the harvest index showed that the planting patterns of jajar legowo 3:1, jajar legowo 2:1 and lined rings had values that were not significantly different. The pattern of planting row legowo 2:1 and single row had values that were not significantly different when observing the weight of cobs with husks and the weight of cobs without husks. When observing the harvest index of pattern of planting, single row planting, row legowo 2:1 and row rows have results that are not significantly different.

IV. DISCUSSION

Based on the data obtained, there was no interaction between the two treatments, however the use of NPK fertilizer and planting patterns had an effect on the growth and yield of sweet corn plants. In the treatments carried out in the research, the largest population was found in the ring pit planting layout (lined circles) with 280 plants per plot. That way, the yields produced in this layout show the highest. Research conducted on white corn shows that grain yield increases with plant density, double-row planting produces 12-18.22% higher yields compared to single-row (Akbar *et al*., 2016). Plant population greatly influences crop yields in unit area. Research conducted on peanut plants shows that planting patterns and plant density influence crop growth rate and harvest index (Rasekh *et al*., 2010).

Plant layout and plant density influence canopy architecture which then influences radiation interception and absorption of CO_2 which will be converted into carbohydrates. The higher the carbohydrates produced, the higher the harvest will be. The canopy formed due to differences in planting layout will affect the interception and utilization of solar radiation in corn plants, this will result in photosynthesis running less well and reducing grain yield (Valadabadi and Farahani, 2010; Duncan *et al*., 2018). A larger plant population, with appropriate layout arrangements and paying attention to canopy architecture will increase corn grain yield. Corn grain yield is influenced by the number of plants per unit area, the number of cobs per plant, the number of seeds per cob and the weight of seeds per ear (Gozubenli *et al*., 2004).

In a row planting layout, it is still possible for the corn plant canopy to grow freely and receive maximum sunlight. In a single row plant layout, the population produced per unit area is smaller than in other treatments. Apart from population differences, in a single row planting layout the empty space between corn plants is wider, this can result in a greater evapotranspiration rate and more water and nutrient loss. A high population will produce higher yields, but competition between plants for resources such as light, nutrients and water must be considered (Onat *et al*., 2017; Zhang *et al*., 2020).

The dose of NPK fertilizer greatly influences the growth and yield of corn plants. Giving NPK 200 kg ha^{-1} showed the lowest results in all variables. Giving NPK at a dose of 300 kg ha^{-1} and 400 kg ha^{-1} showed results that were not significantly different, therefore giving 300 kg ha^{-1} was more economically profitable to reduce input (cost). One of the nutrients contained in NPK fertilizer is nitrogen. Nitrogen has an important role in plant growth, is a protein constituent and has an important role in the photosynthesis process. Previous research examined the role of nitrogen in corn plants, giving the highest dose of urea, namely 520 kg ha^{-1}, showed higher results in the parameters of total fresh weight, relative growth rate, leaf area index and crop growth rate (Valadabadi and Farahani, 2010). Plant density and nitrogen fertilizer dosage influence the growth and yield of corn plants. Increasing the corn plant population of 88888 ha^{-1} with a fertilizer dose of 161 kg N ha^{-1} can increase grain yield by 65.16% compared to a population of 44444 ha^{-1} with 92 kg N ha^{-1} (Zeleke *et al*., 2018).

Apart from nitrogen, fulfilling the nutrient element phosphorus in corn plants significantly increases the leaf area index, crop growth rate, dry weight and yield of corn plants (Amanullah *et al*., 2010). An increase in the leaf are index value is related to an increase in leaf area, where a wider leaf area will maximize the absorption of PAR (Photosynthetically Active Radiation). Potassium also has an important role in the process of photosynthesis and absorption of CO_2. In conditions of potassium deficiency, photosynthetic activity decreases due to leaf chlorosis due to the accumulation of reactive oxygen species (ROS) (Du *et al*., 2019). Not only growth, potassium plays a role in improving the quality of sweet corn through sugar transportation. Potassium is needed by plants in the process of photosynthesis, ATP production, sugar translocation, starch production in grains, nitrogen fixation and protein synthesis (Wolde, 2016).

To maximize yield potential and land use efficiency, planting patterns can be carried out using an intercropping system. For further research, it is necessary to study in more depth the sweet corn intercropping system combined with undercrops such as legumes. Setting the planting pattern of corn plants intercropped with soybeans affects the uptake and distribution of nutrients such as nitrogen (N), phosphorus (P) and potassium (K) (Raza *et al*., 2019). Nitrogen fertilization and intercropping of corn with alfalfa showed an increase in photosynthetic characteristics, photosynthetic nitrogen utilization efficiency (PNUE) and yield up to 25% (Nasar *et al*., 2021).

V. CONCLUSION

This research shows that the ring pit planting layout method produces higher growth and yields in sweet corn. In addition, the ring pit planting layout produces the largest population. To meet nutrient needs due to population changes, an NPK fertilizer dose of 300-400 kg ha^{-1} is required.

REFERENCES

[1] Akbar, M.A., M.A. Siddique, M.S. Marma, M.M. Rahman, M.R.I. Molla, *et al*. 2016. Planting arrangement, population density and fertilizer application rate for white maize (*Zea mays* L.) production in Bandarban Valley. Agric. For. Fish. 5(6): 215–224. doi: 10.11648/j.aff.20160506.12.

[2] Amanullah, M. Asif, K. Nawab, Z. Shah, M. Hassan, *et al*. 2010. Impact of planting density and P-fertilizer source on the growth analysis of maize. Pakistan J. Bot. 42(4): 2349–2357.

[3] Baranowska, A. 2023. The nutritional value and health benefits of sweet corn kernels (*Zea mays* ssp. *saccharata*). Heal. Probl. Civiliz. 17(4): 408–416. doi: 10.5114/hpc.2023.133364.

[4] Bellasio, C., and H. Griffiths. 2014. Acclimation to low light by C4 maize: Implications for bundle sheath leakiness. Plant, Cell Environ. 37(5): 1046–1058. doi: 10.1111/pce.12194.

[5] Bernhard, B.J., and F.E. Below. 2020. Plant population and row spacing effects on corn: Plant growth, phenology, and grain yield. Agron. J. 112(4): 2456–2465. doi: 10.1002/agj2.20245.

[6] Bhatt, P.S. 2012. Response of sweet corn hybrid to varying plant densities and nitrogen levels. African J. Agric. Res. 7(46): 6158–6166. doi: 10.5897/AJAR12.557.

[7] Bilska, A., and P. Sowiński. 2010. Closure of plasmodesmata in maize (*Zea mays*) at low temperature: A new mechanism for inhibition of photosynthesis. Ann. Bot. 106(5): 675–686. doi: 10.1093/aob/mcq169.

[8] Du, Q., X. hua Zhao, L. Xia, C. ji Jiang, X. guang Wang, *et al*. 2019. Effects of potassium deficiency on photosynthesis, chloroplast ultrastructure, ROS, and antioxidant activities in maize (*Zea mays* L.). J. Integr. Agric. 18(2): 395–406. doi: 10.1016/S2095-3119(18)61953-7.

[9] Duncan, E.G., C.A. O'Sullivan, M.M. Roper, J.S. Biggs, and M.B. Peoples. 2018. Influence of co-application of nitrogen with phosphorus, potassium and sulphur on the apparent efficiency of nitrogen fertilizer use, grain yield and protein content of wheat: Review. F. Crop. Res. 226: 56–65. doi: 10.1016/j.fcr.2018.07.010.

[10] Gozubenli, H., M. Kilinc, O. Sener, and O. Konuskan. 2004. Effects of single and twin row planting on yield and yield components in maize. Asian J. Plant Sci. 3(2): 203–206. doi: 10.3923/ajps.2004.203.206.

[11] Gul, S., M.H. Khan, B.A. Khanday, and S. Nabi. 2015. Effect of sowing methods and NPK levels on growth and yield of rainfed maize (*Zea mays* L.). Scientifica (Cairo). 2015: 1–6. doi: 10.1155/2015/198575.

[12] Hayat, R., S. Ali, U. Amara, R. Khalid, and I. Ahmed. 2010. Soil beneficial bacteria and their role in plant growth promotion: A review. Ann. Microbiol. 60(4): 579–598. doi: 10.1007/s13213-010-0117-1.

[13] Magezi, E.F., Y. Nakano, and T. Sakurai. 2023. Mechanization in Tanzania: impact of tractorization on intensification and extensification of rice farming. JICA Ogata Research Institute Discussion Paper No.7. Springer Nature Singapore Pte Ltd., Tokyo. p. 177–194

[14] Nasar, J., W. Khan, M.Z. Khan, H.I. Gitari, J.F. Gbolayori, *et al*. 2021. Photosynthetic activities and photosynthetic nitrogen use efficiency of maize crop under different planting patterns and nitrogen fertilization. J. Soil Sci. Plant Nutr. 21(3): 2274–2284. doi: 10.1007/s42729-021-00520-1.

[15] Onat, B., H. Bakal, L. Gulluoglu, and H. Arioglu. 2017. The effects of row spacing and plant density on yield and yield components of peanut grown as a double crop in mediterranean environment in Turkey. Turkish J. F. Crop. 22(1): 71–80. doi: 10.17557/TJFC.303885.

[16] Pettigrew, W.T. 2008. Potassium influences on yield and quality production for maize, wheat, soybean and cotton. Physiol. Plant. 133(4): 670–681. doi: 10.1111/j.1399-3054.2008.01073.x.

[17] Pratama, H., T. Islami, and A. Rifianto. 2022. Uji hasil dan kualitas dua varietas jagung manis (*Zea mays* L. var. Saccharata) pada pemberian pupuk tunggal dan majemuk. Produksi Tanam. 10(5): 297–306. doi: 10.21776/ub.protan.2022.010.05.03.

[18] Rasekh, H., J. Asghari, M.N.S. Wishkai, S.L. Massoumi, and R. Zakerineja. 2010. Effect of planting pattern and plant density on physiological characteristics and yield of peanut (*Arachis hypogaea* L.) in Iran. Res. J. Biol. Sci. 5(8): 542–547. doi: 10.3923/rjbsci.2010.542.547.

[19] Raza, M.A., M.H. Bin Khalid, X. Zhang, L.Y. Feng, I. Khan, *et al*. 2019. Effect of planting patterns on yield, nutrient accumulation and distribution in maize and soybean under relay intercropping systems. Sci. Rep. 9(1): 1–14. doi: 10.1038/s41598-019-41364-1.

[20] Sheng, S., T. Li, and R. Liu. 2018. Corn phytochemicals and their health benefits. Food Sci. Hum. Wellness 7(3): 185–

195. doi: 10.1016/j.fshw.2018.09.003.

[21] Ugur, A., and H.A. Maden. 2015. Sowing and planting period on yield and ear quality of sweet corn (*Zea mays* L. var. saccharata). Ciência e Agrotecnologia 39(1): 48–57. doi: 10.1590/s1413-70542015000100006.

[22] Valadabadi, S.A., and H.A. Farahani. 2010. Effects of planting density and pattern on physiological growth indices in maize (*Zea mays* L.) under nitrogenous fertilizer application. J. Agric. Ext. Rural Dev. 2(3): 040–047.

[23] Widaryanto, E., M. Roviq, and A. Saitama. 2019. An effective method of leaf area measurement of sweet potatoes. Biosci. Res. 16(2): 1423–1431. https://www.isisn.org/BR16(2)2019/1423-1431-16(2)2019BR19-214.pdf.

[24] Wolde, Z. 2016. A Review on evaluation of soil potassium status and crop response to potassium fertilization. J. Environ. Earth Sci. 6(8): 38–44. www.iiste.org.

[25] Xue, J., Y. Zhao, L. Gou, Z. Shi, M. Yao, *et al*. 2016. How high plant density of maize affects basal internode development and strength formation. Crop Sci. 56(6): 3295–3306. doi: 10.2135/cropsci2016.04.0243.

[26] Yang, L., Y.X. Chi, Y.F. Wang, M. Zeeshan, and X.B. Zhou. 2021. Gradual application of potassium fertilizer elevated the sugar conversion mechanism and yield of waxy and sweet fresh-eaten maize in the semiarid cold region. J. Food Qual. 2021. doi: 10.1155/2021/6611124.

[27] Yulisma. 2011. Pertumbuhan dan hasil beberapa varietas jagung pada berbagai jarak tanam. Jurnal Penelitian Pertanian Tanaman Pangan. p. 196–203

[28] Zeleke, A., G. Alemayehu, and G. Yihenew. 2018. Effects of planting density and nitrogen fertilizer rate on yield and yield related traits of maize (*Zea mays* L.) in Northwestern, Ethiopia. Adv. Crop Sci. Technol. 06(02): 1–6. doi: 10.4172/2329-8863.1000352.

[29] Zhang, D., Z. Sun, L. Feng, W. Bai, N. Yang, *et al*. 2020. Maize plant density affects yield, growth and source-sink relationship of crops in maize/peanut intercropping. F. Crop. Res. 257: 107926. doi: 10.1016/j.fcr.2020.107926.