RJOAS: Russian Journal of Agricultural and Socio-Economic Sciences
ISSN 2226-1184 (Online) | Issue 1(145), January 2024

UDC 633; DOI 10.18551/rjoas.2024-01.20

THE GROWTH AND YIELD TRAITS OF SWEET WAXY MAIZE UNDER NPK FERTILIZER APPLICATION WITH VARIOUS PLANT DENSITY

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ABSTRACT
One of the problems in the development of waxy maize is low production. The applications of agronomic technology such as plant density and fertilizer application are known to improve growth and increase corn yields. This study aims to observe the effect of NPK fertilizer rates applied under various plant densities on the growth and yield of sweet waxy maize GC 19099 on Cambisol soil type in Bakung Village, North Indralaya District, South Sumatera Province, Indonesia. The field experimental were arranged using Randomized Completely Block Design with plant density treatments (75 cm x 15 cm, 75 cm x 20 cm, 75 cm x 25 cm) and NPK fertilizer rate treatments (150, 300, 450 kg ha^{-1}) with three replicates. The growth and yield characters were observed include plant height, number of leaves, shoot fresh weight, root fresh weight, shoot dry weight, root dry weight, shoot root dry weight ratio, cob length and cob weight. The results showed that plant density treatment of 75 cm x 20 cm gave the best growth and yield of waxy maize. The best influence on the growth and yield of waxy maize was also obtained in NPK fertilizer rate of 300 kg ha^{-1}. The combination of planting density of 75 cm x 20 cm and NPK fertilizer rate of 300 kg ha^{-1} was the best combination in improving growth and increasing the yield of waxy corn.

KEY WORDS
Plant density, fertilizer, NPK compound, growth, yield, waxy maize.

Corn is the second food cereal crop after rice in Indonesia, therefore, it can be an alternative in meeting of food needs (Suarni and Subagio, 2013; Assidik et al., 2021). Waxy maize (*Zea mays ceratina* Kulesh) is one type of maize that can be developed for food diversification. Waxy maize is much liked by consumers, because apart from the varied color of the seeds, also because it tastes nice, savory and fluffy. Young harvest and early harvest are other advantages of waxy maize, which can anticipate food and nutritional insecurity (Suarni et al., 2019). Meanwhile, the high economic value and amylopectin content in waxy maize which almost reaches 100%, make the commodity an important source both for fresh consumption and used in various food industries (Zhang et al., 2019).

Corn has wide adaptability, because it is widely produced and consumed in marginal areas (Widowati, 2012). However, local waxy maize production is still low at around 2 tons ha^{-1}, has small cobs and is sensitive to downy mildew disease (Iriani et al., 2005).

One type of soil that can be developed for the cultivation of waxy maize is Kambisol soil. However, the problems faced in Cambisol soil include low availability of N, P and K nutrients, acid soil of pH, and low Cation Exchange Capacity (Putinella, 2014). If the growing environmental conditions are suitable, the improvement in growth and yield of maize can be achieved through the application of appropriate agronomic technology (Setyowati and Utami, 2013). The application of agronomic technology such as plant density and fertilization is an important factor in farming activities to improve the growth and increase the yield of food crops (Yan et al., 2016; Tuong et al., 2019).

Plant density determines the population, therefore, the closer of the plant density will increase the population, and vice versa. Close plant density in addition to causing competition among plants in using of nutrients and light, it can also create environmental conditions that support the development of pests and diseases (Tuong et al., 2019).

Therefore, an appropriate plant density needs to be considered in food crop cultivation activities. Besides being able to suppress weed growth, with appropriate plant density can also minimize competition among plants in utilizing nutrients, water, sunlight and growing space (Setyowati and Utami, 2013).

NPK fertilizer is a type of compound fertilizer that contains nutrients N, P, and K in balanced proportions. Apart from being used as a basic fertilizer, NPK fertilizer can also be used to supply the nutrient needs that can encourage plant growth and yield. N, P and K nutrients include essential nutrients, so these nutrients must be available in sufficient quantities for various plant metabolic processes (Mollah et al., 2020). Increasing in plant metabolic processes as a result of increasing nutrient uptake from the soil can give a positive effect in improving plant growth and development, although at the same time there will also be a decrease in soil quality (Tuong et al., 2019).

Research reports related to the effect of planting density and NPK fertilizer on the growth and yield traits of sweet waxy maize variety GC 19099, especially on Kambisol soil, have not been found up to now. In this regard, the determination of appropriate plant density and NPK fertilizer level on Kambisol soil can be one of the references that help to ensure the availability of nutrients and sufficient sunlight to support the growth and yield of waxy maize. This study aims to observe the effect of NPK fertilizer rates applied to various plant densities on the growth and yield of sweet waxy maize GC 19099 in Kambisol soil.

MATERIALS AND METHODS OF RESEARCH

This research has been carried out in Bakung Village, North Indralaya District, South Sumatera Province, Indonesia, which lasted for four months, from March to June 2021, at an altitude of about 15 m above sea level. During the study, an average air temperature of 27.5^{o}C was recorded with an average relative air humidity of 85%, and an average rainfall of 193 mm.

The materials used in this research were sweet waxy maize seed of GC 19099 variety, NPK compound fertilizer (16:16:16) and chicken manure fertilizer. The cultivation land used was a vegetable garden owned by the farmers with a Cambisol soil type that has a pH of 6,5.

The field experimental included plant density and NPK fertilizer were arranged by using Randomized Completely Block Design with two factors. The factorial treatments tried were 1) plant density treatments, consisting of: 75 cm x 15 cm (J1), 75 cm x 20 cm (J2) and 75 cm x 25 cm (J3); and 2) NPK fertilizer rate treatments, consisting of: 150 kg ha^{-1} (P1), 300 kg ha^{-1} (P2) and 450 kg ha^{-1} (P3). There were 9 formulas based on combination of planting density and NPK fertilizer rates. Because of each treatment was replicated with three replication, therefore, 27 experimental plots were obtained. The experimental plots were made 2 m x 1.5 m and soil bulking was carried out using a hoe to improve soil aeration. Chicken manure fertilizer was added 5 tons ha^{-1} to the soil. The distance between plots was 0.5 m and the distance between blocks was 1 m which functions as a drainage channel.

Before planting, the planting holes were made with a depth of 3 cm, and each hole was filled with 2 waxy maize seeds. Maize was planted using plant density treatments. At the age of 7 days after planting (7 DAP), weed cleansing and thinning out of plants was carried out, so in each planting hole only 1 plant was left. Watering is done every day in the afternoon, except when the soil had been moistened due to exposure to rainwater. Pest and disease control uses pesticides, and was carried out if plants show symptoms of attack.

The application of NPK fertilizer according to NPK fertilizer rates treatment, was given 3 times, namely one-third rate at planting time, one-third rate at 4 weeks after planting (4 WAP) and the remain at the age of 7 WAP. Plant maintenance continues until the plants were ready to harvest. Cob harvesting was carried out when the plant was around 75 DAP, with the harvest criteria being brown cob hairs, dark green petals, and the plant begins to dry and turn to yellow.

Observations of the growth and yield traits of waxy maize were carried out on five selected sample plants from each plot. The observed variables consisted of 1) plant height (cm), measured from the base of the stem to the tip of the highest leaf, observed when the plant at 45 DAP, 2) number of leaves, was calculated on leaves that have fully opened, carried out before the plant begins flowering, 3) shoot fresh weight (g), was weight to the upper plant organs immediately after harvesting, 4) root fresh weight (g), was weighed after the roots were cleaned from soil and separated from their shoot, carried out after harvesting, 5) shoot dry weight (g), measured after the shoot was dried in the oven at 70^{o}C for 48 hours until it reached a constant weight, 6) root dry weight (g), measured after the roots were dried in the oven at 70^{o}C for 24 hours until they reach constant weight, 7) shoot root dry weight ratio (g g^{-1}), shoot dry weight divided by root dry weight, 8) cob length (cm), was measured from the base of the cob to the tip of the cob, and 9) cob weight (g), each cob from each sample plant was weighed immediately after harvesting.

The observed data were processed statistically using ANOVA of Randomized Completely Block Design. If significant effect of the treatments were found, then the data were further tested using Least Significant Difference (LSD) test at the level of 5%. Statistical analysis was performed using Microsoft Excels.

RESULTS AND DISCUSSION

Analysis of variance of planting density and NPK fertilizer and their interaction on growth and yield traits. The results showed that plant density treatment had very significantly effect on plant height, number of leaves, shoot fresh weight, shoot dry weight, cob length and cob weight, but no significantly effect was found on root fresh weight, root dry weight, and shoot root dry weight ratio (Table 1). NPK fertilizer rates treatment had very significantly and significantly effect on all observed variables. Meanwhile, the interaction of plant density and NPK fertilizer had significantly effect on root fresh weight and root dry weight, very significantly effect on cob length and cob weight, and no significantly effect on other variables (Table 1).

Plant density and NPK fertilizer have had a significant effect on the growth and yield of waxy maize, while there was a little interaction obtained from the combination of the two treatments on growth and yield (Table 1). Tuong et al. (2019) reported that the yield and yield components of waxy maize were significantly affected by planting density and inorganic fertilizer application and the interaction of the two. The same results were also reported by Naim and Rais (2023). Fowo et al. (2022) explained planting distance can affect plant growth and yield, because it is related to the large intensity of light received by plants for the photosynthesis process and competition for growing space in providing water and nutrients for plants. Furthermore, Nurdin et al. (2020) reported that the application of NPK compound fertilizer on sloped soils was significantly able to increase the growth and yield of local corn varieties.

Table 1 – Variant analysis of the effect of planting densities and NPK fertilizer rates and their interaction to the observed variables

Variables	F count			Coefficient of variant (%)
	J	P	JP	
Plant height (cm)	9,45 **	5,72 *	0,51 ns	5,44
Number of leaf	7,92 **	4,97 *	0,88 ns	3,60
Shoot fresh weight (g)	7,37 **	7,48 **	1,93 ns	8,04
Root fresh weight (g)	1,25 ns	15,33 **	3,68 *	15,17
Shoot dry weight (g)	6,85 **	7,23 **	1,75 ns	8,03
Root dry weight (g)	1,25 ns	16,57 **	4,25 *	13,53
Shoot root dry weight ratio (g/g)	2,04 ns	3,66 *	2,52 ns	16,72
Cob length (cm)	27,62 **	99,75 **	40,48 **	1,04
Cob weight (g)	84,27 **	60,09 **	29,62 **	4,79
F table 0,05	3,63	3,63	3,01	
F table 0,01	6,22	6,22	4,77	

*Note: J = plant density, P = NPK fertilizer rate, JP = interaction of combination treatments, ns = no significantly effect, * = significantly effect, ** = very significantly effect.*

According to Mollah et al. (2020), improvements in plant growth and yield due to the application of NPK fertilizer are related to the availability of sufficient nutrients for the needs of these plants. Several research results showed that increasing of inorganic fertilizer rates applied and increasing planting density to a certain extent can have a positive influence on improving plant growth and increasing yield (Fang et al., 2018).

The effect of planting density and NPK fertilizer on plant growth and yield. The results of the LSD test on the effect of planting density on plant height showed that plant density of 75 cm x 20 cm (J2) was significantly different and showed better plant height than plant density of 75 cm x 15 cm (J1) and 75 cm x 25 cm (J3). Similarly, the highest number of leaf was achieved by J2 treatment and significantly different from J1 and J3. Meanwhile, in shoot fresh weight, the LSD test showed that between J1 and J2 treatments were not significantly different and obtained a higher shoot fresh weight compared to J3 treatment. Meanwhile, in root fresh weight variables, although there was no significant difference, the highest root fresh weight was achieved by J2 treatment (Table 2).

Table 2 – Effect of planting densities and NPK fertilizer rates on plant height, number of leaf, shoot fresh weight and root fresh weight

Treatments	Plant height (cm)		Number of leaf		Shoot fresh weight (g)		Root fresh weight (g)	
				----------------------Average--------------------------				
Plant densities								
75 cm x 15 cm (J1)	179,96	a	9,98	b	328,22	b	144,44	
75 cm x 20 cm (J2)	192,89	b	10,42	c	333,84	b	160,67	
75 cm x 25 cm (J3)	177,24	a	9,76	a	291,31	a	148,00	
LSD 0,05	3,34		0,12		8,51		-	
				----------------------Average--------------------------				
NPK fertilizer rates								
150 kg ha^{-1} (P1)	178,11	a	9,84	a	304,20	a	133,56	a
300 kg ha^{-1} (P2)	190,09	c	10,36	b	344,67	b	185,56	b
450 kg ha^{-1} (P3)	181,89	b	9,96	a	304,51	a	134,00	a
LSD 0,05	3,34		0,12		8,51		7,63	

Note: The average value followed by the same letters in each column is not significantly different based on the LSD test at the level of 5%.

The LSD test on the shoot dry weight showed that there was no significant difference between the J1 and J2 treatments, but the two treatments differ markedly and obtained a higher shoot dry weight compared to the J3 treatment (Table 2). Although there were insignificant differences between the three plant density treatments to variables of root dry weight and shoot root dry weight ratios, the highest root dry weight was achieved by 75 cm x 20 cm (J2) treatment, while the highest shoot root dry weight ratio was obtained at 75 cm x 15 cm (J1) treatment (Table 3). Meanwhile, the LSD test showed that the best cob length and the heaviest cob were obtained at J2 treatment which was significantly different from J1 and J3 treatment (Table 4).

Overall, plant density of 75 cm x 20 cm (J2) had a better effect compared to other treatments, both on plant height, number of leaves, shoot fresh weight and root fresh weight (Table 2) as well as on shoot dry weight and root dry weight (Table 3). The appearance of better vegetative growth traits of waxy maize achieved by the planting density is related to the fulfillment of optimal growing environment conditions in accordance with plant needs. This condition is due to the lack of plant competition for growing factors such as sunlight, water and nutrients for plant growth and development (Fowo, 2022). Increasing the number of leaves can have a positive effect on plant growth and yield, because leaves are important organs that play a role in the photosynthesis process to produce energy and important organic compounds that are needed in improving plant growth (Mollah et al., 2020). Meanwhile, the reduced growth of waxy maize occurs at a tight planting density of 75 cm x 15 cm (J1). This is related to increase in interplant competition for light, nutrients and water (Sangoi, 2000). In addition, the decline in growth and yield of waxy maize also occurs at a tenuous planting density of 75 cm x 25 cm (J3). The decline in maize growth and yield at low population densities is associated with less plasticity in leaf area development per plant and the small capacity to form new reproductive organs which is only one cob per plant despite increased available resources (Sangoi, 2000; Laskari et al., 2011). On the other hand, low plant density opens up opportunities for weed growth that can be competitors in using the growing factors needed by plants. In addition, reduced plant populations can cause light and nutrients cannot be utilized optimally by plants, because some of the light will fall to the soil surface and nutrients will be lost due to evaporation and leaching (Kartika et al, 2018). Furthermore, there was no significantly different among planting density treatments in the variable of shoot root dry weight ratio. The shoot root dry weight ratio at planting density of 75 cm x 20 cm (J2) (2.18 g g^{-1}) is in the middle of the value between the shoot root dry weight ratio in J1 (2.31 g g^{-1}) and J3 (1.99 g g^{-1}) treatment (Table 3). Roots have a fundamental role in water and nutrient absorption, plant yield and plant tolerance to environmental stress. Measurement of the shoot root ratio can provide an idea of its influence on metabolic processes, plant growth and development and yield (Bláha, 2019). Increased in root growth and development during vegetative growth will have a positive effect on improving shoot growth and plant yield. This is due to the increasing leaf area and the effective rate of photosynthesis, so that assimilate production is also increasing which contributes to improved plant growth and yield (Rahmawati et al, 2013). The ratio of shoot root in J2 treatment had a greater positive effect on plant growth and yield. This indicates that there is a proportional distribution of assimilate for root and shoot growth, which in turn contributes greatly to the improvement of overall plant growth and development.

Table 3 – Effect of planting densities and NPK fertilizer rates on shoot dry weight, root dry weight, and shoot root dry weight ratio

Treatments	Shoot dry weight (g)		Root dry weight (g)		Shoot root dry weight ratio (g/g)	
	----------------------Average--------------------------					
Plant densities						
75 cm x 15 cm (J1)	82,20	b	36,11		2,31	
75 cm x 20 cm (J2)	83,36	b	39,94		2,18	
75 cm x 25 cm (J3)	73,18	a	38,22		1,99	
LSD 0,05	2,13		-		-	
	----------------------Average--------------------------					
NPK fertilizer rates						
150 kg ha^{-1} (P1)	76,24	a	33,94	a	2,30	c
300 kg ha^{-1} (P2)	86,19	b	46,17	b	1,92	a
450 kg ha^{-1} (P3)	76,31	a	34,17	a	2,26	b
LSD 0,05	2,13		1,72		0,11	

Note: The average value followed by the same letters in each column is not significantly different based on the LSD test at the level of 5%.

Increased vegetative growth of waxy maize, both lower organs of plants (roots) and upper organs of plants (leaves / shoot) at planting density of 75 cm x 20 cm (J2) has a beneficial effect on yield of waxy maize. This is clearly seen in the variables of cob length and cob weight whose results in J2 treatment are higher than J1 and J3 (Table 4). Decreased competition in the use of growth factors such as light, nutrients and water will encourage better root and leaf growth (Kartika, 2018; Fowo et al., 2022). An improvement in root and leaf growth will contribute to improved plant yields. The growth of plants that are increasingly fertile due to increased absorption of water and nutrients by the roots has a positive effect on better reception of light needed in the process of photosynthesis, so that assimilate production is increasing. Furthermore, assimilate will be contributed to all different plant organs, including to sink organs (Kareem et al., 2020).

Furthermore, the LSD test of NPK fertilizer rates treatment on plant height, number of leaves, shoot fresh weight and root fresh weight showed that NPK fertilizer of 300 kg ha^{-1} (P2) was significantly different and showed better performance than other NPK fertilizer treatments (Table 2). Similarly, the LSD test was also shown by the NPK fertilizer of 300 kg ha^{-1} on shoot dry weight and root dry weight, which showed a significantly difference and better performance than other NPK fertilizer treatments. However, at the shoot root dry weight ratio, NPK fertilizer of 300 kg ha^{-1} resulted in a smaller ratio value and was significantly different from other treatments. The highest shoot root ratio was achieved by NPK fertilizer of 150 kg ha^{-1} (P1) (Table 3). The LSD test of NPK fertilizer treatment on cob length and cob weight showed that NPK fertilizer of 300 kg ha^{-1} (P2) was significantly different and achieved better crop yields than P1 and P3 treatments (Table 4).

Table 4 – Effect of planting densities and NPK fertilizer rates on cob length and cob weight

Treatments	Cob length (cm)		Cob weight (g)	
	----------------------Average--------------------------			
Plant densities				
75 cm x 15 cm (J1)	21,36	a	190,90	a
75 cm x 20 cm (J2)	22,15	c	256,38	c
75 cm x 25 cm (J3)	21,71	b	222,55	b
LSD 0,05	0,08		3,57	
	----------------------Average--------------------------			
NPK fertilizer rates				
150 kg ha^{-1} (P1)	21,24	a	203,12	a
300 kg ha^{-1} (P2)	22,60	c	254,80	c
450 kg ha^{-1} (P3)	21,38	b	211,90	b
LSD 0,05	0,08		3,57	

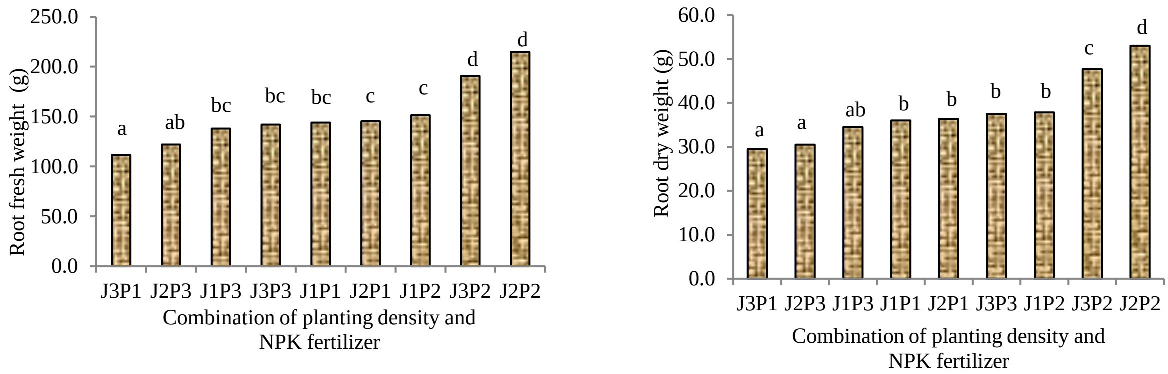
Note: The average value followed by the same letters in each column is not significantly different based on the LSD test at the level of 5%.

The results showed that NPK fertilizer rate of 300 kg ha^{-1} (P2) had a positive and better effect than NPK fertilizer of 150 kg ha^{-1} (P1) and 450 kg ha^{-1} (P3) on plant height, number of leaves, shoot fresh weight and root fresh weight (Table 2), as well as on shoot dry weight and root dry weight (Table 3). These results are in line with the research report of Pusparini et al. (2018) on hybrid corn plants. This indicated that the NPK fertilizer of 300 kg ha^{-1} is the best dose of fertilizer that can be used to encourage optimal waxy maize growth and yield. The application of NPK fertilizer provides advantages, because in one application it can provide several essential nutrients for plants to improve cell activity, cell division and elongation and other plant physiological activities, consequently making plants grow more fertile (Kareem et al., 2020; Mollah et al., 2020). Efficiently absorption of water and nutrients supported by optimal capture of light and CO_2, will encourage higher photosynthetic activity for the formation of assimilate which will be translocated to all sink organs including in the improvement of plant vegetative growth (Kareem et al., 2020).

Meanwhile, in the variable of shoot root dry weight ratio, it showed that the lowest value was found in NPK fertilizer of 300 kg ha^{-1} (P2) which was significantly different from the treatment of P1 and P3 (Table 3). A low of shoot root ratio indicates increased root growth and development, which promotes an increase in water and nutrient absorption to support the growth of the upper part of the plant organs. Such conditions will stimulate a better rate of cell division and elongation, increased leaf area, so that the rate of photosynthesis becomes more effective which results in increasing dry matter production, plant growth and yield (Rahmawati et al., 2013). A decrease in the shoot root ratio indicates an increase in root growth and development, as it is associated with an increase in root dry weight.

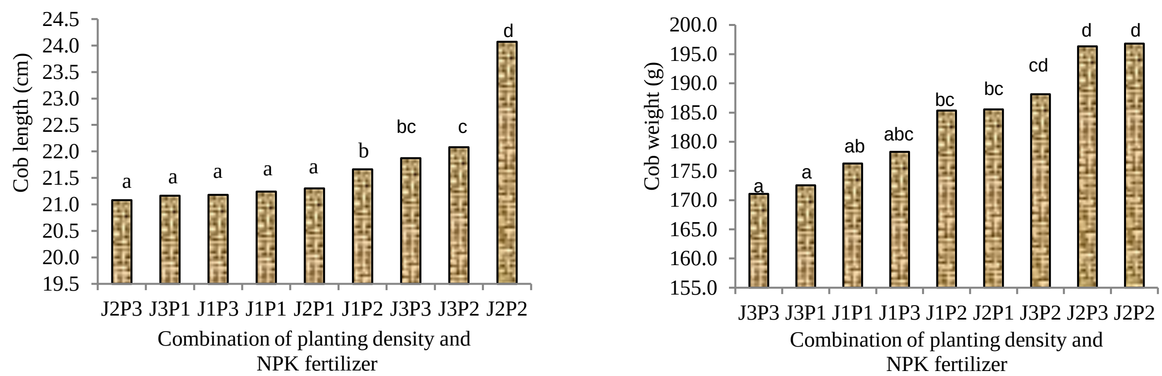
Improvement of vegetative growth of waxy maize at NPK fertilizer of 300 kg ha^{-1} (P2) further contributes positively to the yield components, namely cob length and cob weight. The length of the cob and the weight of the cob in the P2 treatment were higher than in the P1 and P3 treatments (Table 4). Higher plants and a greater number of leaves allowed waxy maize to capture light and CO_2 optimally. This condition will support plants to carry out the photosynthesis process more efficiently, so that the assimilate produced increases. Furthermore, assimilate will be used by plants to produce energy for improved plant growth and increased plant yield (Molah et al., 2020). N, P and K elements contained in NPK fertilizer play a very important role in supporting plant growth and yield. N is needed for vegetative growth of plants. N nutrients absorbed by plants play an important role in the formation of chlorophyll, which will further affect the increase in the rate of photosynthesis for the formation of assimilate (Molah et al., 2020). Meanwhile, P and K elements are needed by plants, especially to support generative growth related to improving the quantity and quality of plant yields (Fowo et al., 2022).

Effect of interaction between planting density and NPK fertilizer on plant growth and yield. The LSD test on the interaction of the combination of plant density and NPK fertilizer on root fresh weight and root dry weight disclosed that the highest results were obtained at a combination of planting density of 75 cm x 20 cm and NPK fertilizer of 300 kg ha^{-1} (J2P2) (Figure 1a and Figure 1b). These results indicate that in the combination of J2P2 treatment, the growing space produced at the planting density of 75 cm x 20 cm avoids competition between plants in nutrient utilization, so that the application of NPK fertilizer of 300 kg ha^{-1} at those planting density can be utilized by plants optimally. Such conditions will support better root growth and development in the absorption and utilization of nutrients and water. As explained by Kareem et al. (2020), the N nutrient contained in NPK fertilizer if its availability can be utilized efficiently by plants because it is not hindered by growing space, it can encourage better root growth, thus encouraging plant growth to be more fertile and will further affect the dry weight of plants.



(a) (b)

Figure 1 – Effect of interaction between planting densities and NPK fertilizer rates on (a) root fresh weight and (b) root dry weight



(a) (b)

Figure 2 – Effect of interaction between planting densities and NPK fertilizer rates on (a) cob length and (b) cob weight

Furthermore, better root growth in the combination of J2P2 treatment turned out to have a positive effect on cob length and cob weight, as the results of the LSD test showed that the highest cob length and cob weight were also obtained in the combination of J2P2 treatment (Figure 2a and Figure 2b). The increasing of yield achieved in the combination of J2P2 treatments is related to the ability of plants to utilize nutrient from fertilizers applied efficiently. Zeleke et al. (2018) explained that, reduced competition on the use of nutrients, soil and light as well as increased nutrients available to plants can lead to improved corn yields. Furthermore, stated by Fang et al (2018), usually plant yields will show a decreasing response to planting density and inorganic fertilizer rates, with the highest yield will be achieved under conditions of optimal planting density and fertilizer rates.

CONCLUSION

The single treatment of planting densities and NPK fertilizer rates affected the growth and yield of waxy maize. The best growth and the highest yield of waxy maize were founded in 75 cm x 20 cm planting density, and the same was founded in NPK fertilizer rate of 300 kg ha^{-1}. Meanwhile, the best growth of root and the highest yield were achieved from the combination of the middle planting densities and NPK fertilizer rates, i.e. 75 cm x 20 cm planting density and NPK fertilizer rate of 300 kg ha^{-1}. Therefore, it could be concluded that the combination of 75 cm x 20 cm planting density and 300 kg ha^{-1} NPK fertilizer rate be used for better growth and high yield of waxy maize under Cambisol soil condition.

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