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Optimizing Shallot Growth through Variations Fertilization NPK and Plant Density

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Variations in macronutrient fertilization and spacing are two important components in increasing shallot yield. This study aims to determine the effect of fertilization and plant spacing on shallot yield. A split-plot design with three replications was applied. The main plots were plant spacing (D1: 20 x 20 cm, D2: 20 x 15 cm, D3: 20 x 10 cm); subplots were fertilization of TSP, NPK, KNO_3, Urea, and ZA with four doses: F1 by 188, 600, 0, 180, 400 kg ha^{-1}; F2 by 75, 225, 80, 57, 300 kg ha^{-1}; F3 by 100, 300, 107, 76, 400 kg ha^{-1}; and F4 by 125, 375, 135, 95, 500 kg ha^{-1}, respectively. Data was analyzed using the Anova (Analysis of Varians) and Duncan tests. The number of leaves was positively correlated with wet bulb weight per clump (R^2 = 86.36%), and dry bulb weight per clump (R^2 = 72.40%). The optimum N, P, and K dosages to achieve the optimum relative yield were 126.85; 178.06; 95.25 kg ha^{-1}. The D3F3 interaction (plant spacing of 20x10 cm with TSP, NPK, KNO_3, Urea, and ZA fertilization by 100, 300, 107, 76, and 400 kg ha^{-1}, respectively) enhanced the dry bulbs weight per plot by 84.50%.

Keywords: *Allium ascalonicum*, bulb, fertilization, macronutrients, optimum relative yield, plant spacing.

INTRODUCTION

The shallots (*Allium ascalonicum*) is a valuable horticultural crop with high economic value in numerous countries. According to data from the BPS-Statistic of Sumatra Province (2022a), the average productivity of dry bulbs of shallots in North Sumatra is 9.5 tons per hectare, which is a little below the national productivity of 9.7 tons per hectare (BPS-Statistic Indonesia, 2022). However, the current shallots production of about 29,222 tons per year (BPS-Statistic of Sumatra Province, 2022a) doesn't meet the need to supply the local demand of North Sumatra Province. The average consumption for shallot is about 2.94 kg per month per capita (BPS-Statistic of Sumatra Province, 2022b), with the existing population of 14,8 million people (BPS-Statistic of Sumatra Province, 2022a), the shallot demand equal to 52,212.1 tons per year. Furthermore, this demand for shallots will keep growing as the population increases. It is projected that the population will increase to 17.5 million people by 2035 (BPS-Statistic of Sumatra Province, 2023). Therefore, shallot production must be increased to meet the needs of the community, increase farmers' income and welfare, and reduce dependence on shallot imports.

There are several challenges to boost shallot production in North Sumatra. Farmers do not yet understand the specific fertilizer needs for shallots, so fertilization is not carried out effectively. The habit of farmers using excessive chemical fertilizers can damage soil quality and cause environmental pollution. Undoubtedly, fertilization is one of the main keys to increasing shallot production. Some of the previous studies showed that the optimal dosage of N, P, and K fertilization resulted in the highest yield of shallot bulbs and contributed to a shared economic benefit (Tesfa *et al.*, 2015; Marrocos *et al.*,2018; Tekeste *et al.*,2018). Besides the additional production benefit, fertilization can also improve the quality of onion bulbs by increasing the amount of total phenolics and flavonoids (Simelane *et al.*, 2024). However, excess or deficiency of soil nutrients can reduce onion yield. Therefore, optimizing fertilizer combinations and balances will help to

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ensure that fertilizers are used efficiently as the right dose is achieved, reducing waste and achieving maximum yield.

Shallots require macronutrients throughout their growth cycle, with particular emphasis on nitrogen, phosphorus, potassium, and other essential elements such as calcium and magnesium. These nutrients are obtained from single and compound inorganic fertilizers, such as urea, ZA, KNO_3, TSP, and NPK, with different nutrient levels. These elements are crucial for shallots' vegetative growth, bulb formation, and yield quality. For example, the application of N fertilizer has been shown to significantly enhance plant height and bulb diameter (Khan *et al.*, 2019), as well as bulb weight and leaf number in shallot plants (Biru, 2015).

As posited by *Khan et al.* (2019), nitrogen has a marked impact on the growth of shallot leaves, bulb diameter, and overall plant productivity. Moreover, Arefi *et al.* (2013) discovered that the number of leaves, wet biomass weight, bulbs wet weight, dry biomass weight, bulbs dry weight, bulb diameter, and total productivity are significantly influenced by phosphorus and potassium.

The other challenge to increasing shallot production is a lack of understanding of farmers about planting techniques, such as optimal planting distance. Farmers have a habit of applying too wide planting distances that reduce plant population per unit area of land, consequently reducing productivity per hectare. Planting spacing must be determined carefully. Plant spacing that is too close can inhibit plant growth and reduce crop yields due to higher competition for water, nutrients, and sunlight, as well as increased pests and diseases. Therefore, the optimum planting spacing will give a higher yield.

Currently, different fertilizer combinations on the market contain different macronutrients N P K. Previous research has shown that spacing and fertilizers interact to increase shallot yield. Therefore, it is necessary to test the effect of variations in N P K fertilizer on shallots plants grown at different planting distances. This study aims to determine the effect of fertilization and plant spacing on shallot yield. So, through this research, focusing on fertilization and planting distance, it is hoped that the best practices will be found to increase shallot productivity and reduce environmental pollution. The results of this study will also provide fertilizer and spacing recommendations that shallot farmers can use to increase the productivity of their crops.

MATERIALS AND METHODS

***Study area and selection materials*:** The study was conducted in 2022 at Gurgur Aek Raja Village, Tampahan District, Toba Samosir Regency, North Sumatra, Indonesia (20° 8'12" N and 99° 5'43" E). The area is situated at an altitude of approximately 1200 meters above sea level, with temperatures ranging from 21ºC-25ºC and an annual rainfall of 2.200 millimeters.

The seeds of the Batu Ijo shallot variety in this study were obtained from the Horticultural Plant Research Centre, Lembang Vegetable Plant Research Centre, West Java, Indonesia. The seeds have a diameter of ± 3 cm. The description of the characteristics of the shallot variety Batu Ijo can be seen in Table 1.

Table 1. Description of the characteristics of the Batu Ijo variety of shallots.

Sr	Characteristic	Size
1.	Plant height (cm)	45.0-60.0
2.	Number of bulbs per clump	2.0-5.0
3.	Number of leaves per bulb	+ 12.0
4.	Weight per bulb (g)	15.0-25.0
5.	Length of bulbs (cm)	3.5-5.0
6.	Diameter of bulbs (cm)	3.0-4.5
7.	Weight of harvested wet bulbs per clump (g)	+ 92.0
8.	Dry bulbs yield per hectare (t)	18.5

Source: Ministry of Agriculture of Republic Indonesia (2004)

***Soil characteristics*:** Soil samples were taken randomly at a depth of 0-20 cm, composited, and analyzed for initial soil characteristics (Table 2). The soil at the study site is loamy sand in texture and acidic in pH. This is the common soil characteristic found in nearby villages next to the study site, including Sinar Sabungan, Sihiong, Lumban Lobu, Sionggang Selatan, Sibaruang, Jangga Toruan, and Hatinggian (Purba *et al.*, 2014; Binarta and Marpaung, 2017). The study site was characterized by high C-organic. In general, several macronutrients and micronutrients in the study site have moderate to very high abundance which is characterized by moderate total N, high exchangeable K, and high Fe contents. However, the content for the other macronutrients such as total P, available P, exchangeable-Ca, and exchangeable-Mg were low to very low. The low availability of macronutrients could become a limiting factor for shallot growth and production.

***Experimental design*:** This study used a split-plot design with three replications. The main plots were plant spacing (D1: 20 x 20 cm, D2: 20 x 15 cm, and D3: 20 x 10 cm); subplots were fertilization (F1: fertilizer of TSP, NPK, Urea, and ZA by 188, 600, 180, and 400 kg ha^{-1}, respectively; F2: fertilizer of TSP, NPK, KNO_3, Urea, and ZA by 75, 225, 80, 57, and 300 kg ha^{-1}, respectively; F3: fertilizer of TSP, NPK, KNO_3, Urea, and ZA by 100, 300, 107, 76, and 400 kg ha^{-1}, respectively; F4: fertilizer of TSP, NPK, KNO_3, Urea, and ZA by 125, 375, 135, 95, and 500 kg ha^{-1}, respectively). So, this study used a total of 36 plots. The plot size was 1.2 × 10 m with a 50 cm gap between plots and a 75 cm distance between replicates. The nutrient content for each fertilization treatment is shown in Table 3.

Table 2. Initial soil characteristics in the study site.

No.	Soil characteristics	Methods	Value	Criteria*
1	pH (H_2O)	Electrometry	4.55	Acid
2	Organic-C (%)	Spectrophotometry	3.46	High
3	Total-N (%)	Kjeldahl	0.27	Moderate
4	Available-P (ppm)	Bray-I	8.61	Very low
5	Total P_2O_5 (mg/100g	Spectrophotometry	17.72	Low
6	Exchangeable-K (me/100g)	AAS	0.84	High
7	Total-K_2 O (mg/100g)	AAS	166.75	Very high
8	Ca (me/100g)	AAS	0.95	Low
9	Mg (me/100g)	AAS	0.53	Low
10	Zn (ppm)	AAS	4	
12	Fe (ppm)	AAS	31	High
13	Exchangeable-Al (me/100g)	Titrimetry	1.47	Very low
14	Texture	Hydrometer		Loamy sand
	Sand (%)		84.26	
	Silt (%)		11.24	
	Clay (%)		4.50	

*Classification of soil characteristics refers to the Indonesian Soil Research Institute (2009)

Table 3. Total nutrient content for each treatment (kg ha^{-1}).

Nutrients	Total nutrients per treatment (kg ha^{-1})			
	F1	F2	F3	F4
N	238.80	126.62	168.87	211.25
P	66.63	25.90	34.52	43.15
K	89.64	63.49	84.78	106.45
S	143.76	89.91	119.88	149.85
Fe	9.57	3.59	4.79	5.98
Mn	1.20	0.50	0.60	0.80
Zn	0.12	0.05	0.06	0.08
B	0.12	0.05	0.06	0.08

The fertilizers used in this study were compound inorganic fertilizers such as NPK and KNO_3, as well as single inorganic fertilizers TSP, Urea, and ZA. The NPK consists of several macronutrients like N, P, K, S, and Mg with concentrations 12, 5, 15, 8, and 1.6%, respectively, and micronutrients of Fe, Mn, Zn, and B of 0.2, 0.02, 0.02, and 0.015%, respectively. The TSP fertilizer contains 17.73% P, Urea contains 46% N, KNO_3 contains 15.3% N and 12.45% K, and ZA contains 21.0% N and 24.0% S.

***Cultivation practices*:** Treatment plots were covered with 1.2 x 10 x 0.2 m of silver-coloured plastic mulch, and an 8 cm planting hole was made according to the spacing treatment. Prior to covering the plastic mulch, fertilizer was applied evenly to the soil surface at a rate of 10 t ha^{-1} or 12 kg plot^{-1} one week before planting. ¾ of the seeds were planted in the soil with the shallots budding upwards. Fertilizer was applied three times during the study: at planting, 15 days after planting (DAP), and at 25 DAP. The dose of fertilizer varied according to the treatment (Table 3). Weed control was carried out manually according to field conditions, while insecticides and fungicides were sprayed to control pests and diseases. The plants were harvested at 70 DAP.

***Parameters and data analysis*:** The study parameters include plant height and number of leaves observed at 50 DAP, while the number of onions, wet bulb weight per clump and wet bulb weight per plot, dry bulb weight per clump, dry bulb weight per plot with an average moisture content of 80-84%, onion length and onion diameter observed after harvest at 70 DAP. Analysis of variance (ANOVA) was used to analyze the data when the treatment was statistically significant ($p<0.05$) and DMRT was used to test for differences between treatments (Steel and Torrie, 1980). Observational data were analyzed using IBM SPSS software version 25. Regression and correlation were used to determine the relationship between growth and production. Regression analysis was also performed between N, P, and K dosage and dry bulb weight per plot (DBWP) according to Sopha *et al.* (2015); Adi *et al.* (2019) to determine the optimal recommendations for N, P, and K fertilizer. In detail, the analysis steps were as follows:

a) Calculate relative results by comparing each variable value to the maximum value obtained from each dosage using the following formula:

$$RY = \frac{Yi}{Ymax}$$

Where: Yi = the values of the treatment variables N, P, and K to i; Ymax = maximum values of the treatment variables N, P, and K

b) The relative yield value (y) is regressed to the dosage of N, P, or K (x) with regression models quadratic, logistic, linear, or exponential. Based on the quadratic regression model $y = ax^2 + bx + c$, the optimum fertilizer dosage was calculated by using the derivative formula of the regression equation: $dy/dx = 2ax + b = -b/2a$ with y =

plant relative value, x = fertilizer dosage, while a, b, c are constant values.

c) Determining the status of N, P, and K fertilizers to obtain optimum relative yields which are divided into 5 categories, namely: 1) extra low (<50%); 2) low (50-75%); 3) sufficient (75-100%); 4) high (100%); and 5) very high (>100%).

RESULTS

Plant spacing treatment (D) significantly affected the number of leaves, number of bulbs, wet weight of bulbs per clump, dry bulbs weight per clump, wet weight of bulbs per plot, dry weight of bulbs per plot, bulbs diameter, and bulbs length, according to the analysis results. In contrast, only the bulb diameter was significantly affected by the fertilization treatment (F). The wet weight of bulbs per clump, dry weight of bulbs per clump, and wet weight of bulbs per plot increased significantly with the interaction between spacing and fertilizer (D×F), as presented in Table 4.

***Effects of planting distance and fertilization*:** The result showed that the wider planting spacing of 20 x 20 cm (D1) has a higher number of leaves, number of bulbs, wet bulb weight per clump, dry tuber weight per clump, bulb length, and bulb diameter compared to the narrower planting spacing of 20 x 15 cm (D2) and 20 x 10 cm (D3) (Table 5). In contrast, the narrowest spacing (20 x 10 cm) showed lower growth on all parameters that were observed individually including the number of leaves, number of bulbs, and wet bulb weight per clump. The planting spacing treatment of 20 x 20 cm was able to increase the number of leaves by 11.09% and 19.74%, the number of bulbs by 15.54% and 17.35%, and the wet bulbs weight per clump by 21.0% and 37.0%, dry tuber weight per clump by 14.24% and 24.62%, bulb length by 6.83% and 5.64%, and bulb diameter by 11.75% and 12.18% compared to the narrower spacing of 20 x 15 cm and 20 x 10 cm, respectively. However, the narrowest spacing gave the highest production per plot, which 20 x 10 cm increased wet bulb weight by 34.33% and 28.64% and dry bulb weight by 57.67% and 47.78% when compared to the wider spacing of 20 x 20 cm and 20 x 15 cm, respectively.

Contrary to planting spacing, the highest bulb yield was not produced by the treatment with the highest or lowest fertilizer dose, but by the F3 treatment, which has a total NPK of 25% lower than F4, 5-48% lower than F1, but 25% higher than F2.

***Effects of the interaction of spacing and fertilization*:** The interaction between planting distance and fertilization is presented in Table 6. The D1F4 treatment produced the highest dry weight bulbs per clump but did not show significant differences with treatments D1F1, D1F2, D1F3, D2F1, and D2F3. The treatment D1F4 increased the dry weight bulb per clump by 35.09% and 40.63% compared to

Table 4. F test results of the effect of planting distance and fertilization on shallots growth and yield.

Source	F-value								
	PH	NL	NB	WWBC	DWBC	WWBP	DWBP	BL	BD
Replicate	1.83^{ns}	1.71^{ns}	1.04^{ns}	0.66^{ns}	14.43*	2.23^{ns}	2.84*	3.38*	0.39^{ns}
D	2.65^{ns}	9.14*	4.68*	8.07*	17.11*	12.86*	91.72*	3.70*	9.29*
F	0.07^{ns}	0.46^{ns}	0.10^{ns}	0.18^{ns}	0.73^{ns}	0.28^{ns}	1.03^{ns}	1.56^{ns}	2.37*
D×F	0.49^{ns}	0.34^{ns}	0.09^{ns}	4.28*	4.55*	1.86^{ns}	3.12*	0.25^{ns}	1.41^{ns}

*Significantly different based on DMRT at p<0.05, ns: Not significant, D (planting distance), F (fertilization), PH: plant height, NL: number of leaves, NB: number of bulbs, WWBC: wet weight of bulbs per clump, DWBC: dry weight of bulbs per clump, WWBP: wet weight of bulbs per plot, DWBP: dry weight of bulbs per plot, BL: bulb length and BD: bulb diameter

Table 5. Effect of planting distance and fertilization on shallots growth and Yield.

T	PH (cm)	NL	NB	WWBC (g)	DWBC (g)	WWBP (kg)	DWBP (kg)	BL (mm)	BD (mm)
D (planting distance)									
D1	48.50	21.63a	10.49a	227.51a	94.50a	68.24b	32.44b	27.81a	33.08a
D2	47.74	19.23b	8.86b	179.73b	81.04b	71.26b	34.61b	25.91b	29.19b
D3	44.80	17.36b	8.67b	142.92c	71.23c	91.67a	51.15a	26.24ab	29.50b
F (fertilization)									
F1	47.12	21.63	9.44	180.06	83.30	74.08	38.04	25.71	28.85c
F2	46.47	19.12	9.53	182.24	78.99	77.51	38.66	26.99	31.86a
F3	47.17	19.54	9.18	187.50	85.50	79.32	40.21	27.10	30.84b
F4	47.32	20.11	9.21	184.00	81.23	77.31	40.68	26.81	30.83b

Numbers followed by different letters in the same column were significantly different at p<0.05, T (treatment), D1 (20x20 cm), D2 (20x15 cm), D3 (20x10 cm); F1: TSP, NPK, Urea, ZA (188, 600, 180, 400 kg ha^{-1}); F2: TSP, NPK, KNO_3, Urea, ZA (75, 225, 80, 57, 300 kg ha^{-1}); F3: TSP, NPK, KNO_3, Urea, ZA (100, 300, 107, 76, 400 kg ha^{-1}); F4: TSP, NPK, KNO_3, Urea, ZA (125, 375, 135, 95, 500 kg ha^{-1}); PH: plant height, NL: number of leaves, NB: number of bulbs, WWBC: wet weight of bulbs per clump, DWBC: dry weight of bulbs per clump, WWBP: wet weight of bulbs per plot, DWBP: dry weight of bulbs per plot, BL: bulb length and BD: bulb diameter

Table 6. The effect of planting distance and fertilization (DxF) interaction on shallots growth and yield.

D	F	PH	NL	NB	WWBC	DWBC	WWBP	DWBP	BL	BD
D1	F1	48.55	21.20	10.70	213.77abc	96.92a	64.13	31.24cde	27.37	31.95
	F2	48.36	21.73	11.00	243.60a	97.01a	73.07	32.84cde	27.91	33.13
	F3	49.30	21.17	10.00	199.70bcd	84.61ab	59.90	28.97e	27.97	33.42
	F4	47.91	22.40	10.27	252.97a	99.45a	75.87	36.71cd	28.00	33.84
D2	F1	45.88	18.83	8.82	185.00bcd	81.70ab	73.23	36.57cd	25.21	28.23
	F2	47.03	17.83	8.76	159.03cde	73.41b	63.00	30.64de	25.87	29.41
	F3	49.48	20.50	9.06	217.37ab	95.41a	86.10	38.23c	26.22	28.50
	F4	48.58	19.73	8.82	158.30cde	73.62b	62.70	32.99cde	26.33	30.62
D3	F1	46.94	16.47	8.82	141.40e	71.29b	84.87	46.30b	24.54	26.35
	F2	44.03	17.80	8.82	144.10de	66.54b	96.47	52.51ab	27.20	33.05
	F3	42.76	16.97	8.48	145.43de	76.48b	91.97	53.45a	27.10	30.59
	F4	45.48	18.20	8.55	140.73e	70.62b	93.37	52.35ab	26.10	28.02

Note: Numbers followed by different letters in the same column were significantly different at $p<0.05$, D (planting distance), F (fertilization), D1 (20x20 cm), D2 (20x15 cm), D3 (20x10 cm); F1: TSP, NPK, Urea, ZA (188, 600, 180, 400 kg ha^{-1}); F2: TSP, NPK, KNO_3, Urea, ZA (75, 225, 80, 57, 300 kg ha^{-1}); F3: TSP, NPK, KNO_3, Urea, ZA (100, 300, 107, 76, 400 kg ha^{-1}); F4: TSP, NPK, KNO_3, Urea, ZA (125, 375, 135, 95, 500 kg ha^{-1}); PH: plant height, NL: number of leaves, NB: number of bulbs, WWBC: wet weight of bulbs per clump, DWBC: dry weight of bulbs per clump, WWBP: wet weight of bulbs per plot, DWBP: dry weight of bulbs per plot, BL: bulb length and BD: bulb diameter

Table 7. Soil analysis results of each experimental plot.

Treatment	Soil characteristics					
	Total N (%)	P-Bray I (ppm)	Exchangable K	Ca (me/100 g)	Mg	Fe (ppm)
D1F1	0.21 (M)	37.11 (VH)	1.33 (VH)	4.46 (L)	0.67 (L)	34 (H)
D1F2	0.29 (M)	35.48 (VH)	2.12 (VH)	5.10 (L)	1.16 (M)	32 (H)
D1F3	0.30 (M)	53.93 (VH)	2.10 (VH)	8.59 (M)	1.81 (M)	33 (H)
D1F4	0.32 (M)	40.84 (VH)	1.87 (VH)	6.55 (M)	1.49 (M)	37 (H)
D2F1	0.31 (M)	56.01 (VH)	2.11 (VH)	9.40 (M)	1.75 (M)	30 (H)
D2F2	0.35 (M)	53.75 (VH)	2.26 (VH)	8.62 (M)	1.99 (M)	38 (H)
D2F3	0.33 (M)	41.26 (VH)	2.11 (VH)	11.07 (H)	2.58 (H)	33 (H)
D2F4	0.35 (M)	53.90 (VH)	2.35 (VH)	9.02 (M)	1.82 (M)	37 (H)
D3F1	0.31 (M)	46.83 (VH)	2.17 (VH)	7.51 (M)	1.65 (M)	30 (H)
D3F2	0.30 (M)	48.30 (VH)	2.19 (VH)	6.08 (M)	1.38 (M)	33 (H)
D3F3	0.35 (M)	44.33 (VH)	0.37 (L)	6.56 (M)	1.87 (M)	37 (H)
D3F4	0.35 (M)	65.86 (VH)	0.31 (L)	8.18 (M)	1.78 (M)	39 (H)

VH (very high); H (high); M (moderate); L (low); D1 (20x20 cm), D2 (20x15 cm), D3 (20x10 cm); F1: TSP, NPK, Urea, ZA (188, 600, 180, 400 kg ha^{-1}); F2: TSP, NPK, KNO_3, Urea, ZA (75, 225, 80, 57, 300 kg ha^{-1}); F3: TSP, NPK, KNO_3, Urea, ZA (100, 300, 107, 76, 400 kg ha^{-1}); F4: TSP, NPK, KNO_3, Urea, ZA (125, 375, 135, 95, 500 kg ha^{-1})

20 x 15 cm and 20 x 10 cm with the same fertilizer treatments. However, on plot observation, the treatments with the highest dry weight bulb were recorded in D3F3 but showed no difference with D3F2 and D3F4. The D3F3 increased dry weight bulb per plot by 84.50% and 39.81% compared to 20 x 20 cm and 20 x 15 cm with the same rate of fertilizer.

***Soil nutrient status of each treatment*:** The results of the soil analysis taken at harvest for each treatment are shown in Table 7. The macronutrient and micronutrient levels for most of the treatment varied from moderate to very high. All treatments show a moderate total N, very high available P, and high Fe. Most of the treatments show very high K and moderate Ca and Mg.

***Regression and correlation analysis*:** Regression and correlation analyses show that an increase in the number of leaves has an influence of about 86.36% on the weight of wet bulbs per clump, with a Pearson correlation coefficient value of r = 0.922, which shows a very strong positive correlation between the number of leaves and the weight of dry bulbs per clump. Furthermore, the number of leaves also has an influence of about 72.37% on the weight of dry bulbs per clump, with a Pearson correlation coefficient value of r = 0.851, showing a strong positive correlation between the two growth variables (Fig.1).

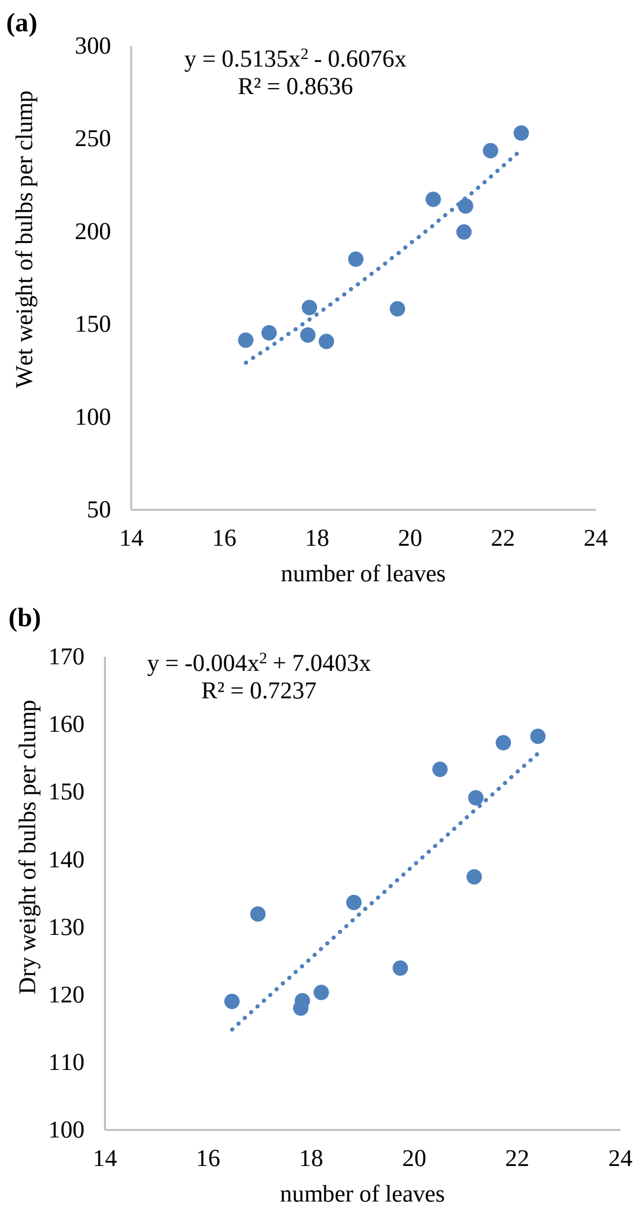

Figure 1. Regression and correlation number of the leaf with the weight of wet bulbs per clump (a), and weight of dry bulbs per clump (b).

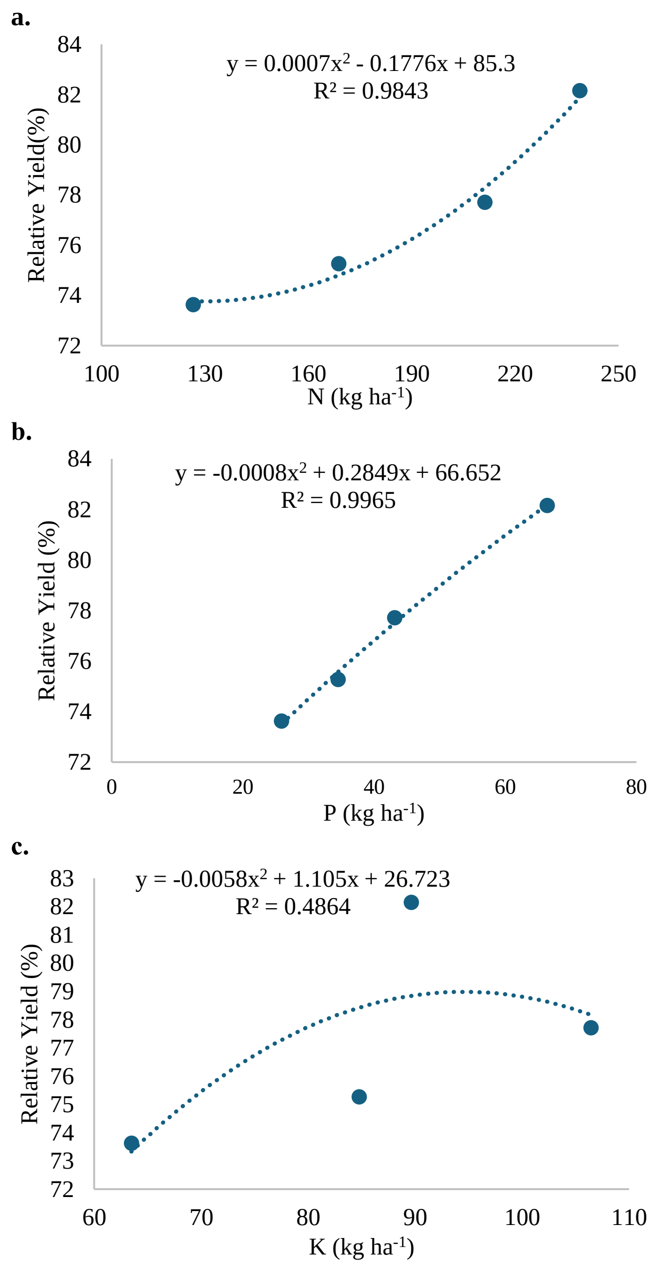

Figure 2. Correlation of nutrient dosage N (a), P (b), and K (c) on relative production.

The relationship between N, P, and K dose on relative yield was quadratic (Fig. 2) with R^2 values of 0.98, 0.99, and 0.48 respectively. Based on the quadratic equation for relative yield, the optimum dose of N was 126.85 kg ha^{-1} to obtain a relative yield of 74.03%. Meanwhile, the P and K requirements were 178.06 and 95.25 kg ha^{-1}, respectively, to obtain optimum relative yields of 92.01 and 79.35%. Based on the relative yield percentage, it is known that the status of N, P, and K to achieve optimum yield are low, sufficient, and sufficient respectively.

DISCUSSION

Effects of planting distance showed that the wider spacing was able to increase all parameters observed per plant including the number of leaves, the number of tubers, the wet weight of bulbs per clump, the dry weight of bulbs per clump, the length of bulbs, and the diameter of bulbs compared to the narrower spacing. In line with dos Santos *et al.* (2018), research showed that the average weight of tubers per plant of

IPA 11, Rio das Antas, and Serena at narrower planting spacing was less than that at wider planting spacing. Panataria *et al.* (2023) reported that shallots in the wider spacing (25 x 15 cm) had 12.86% longer roots than those in the narrower spacing (15 x 15 cm). In addition, Das *et al.* (2020) explained that there is less competition between plants for space, nutrients, light, and water in wider spacing than in narrower spacing. Moravčević *et al.* (2011) also reported that shallots with wider spacing (300,000 plants ha^{-1}) had more leaves than those with narrower spacing (900,000 plants ha^{-1}) at 40-110 DAP.

In contrast, the highest production of wet bulb weight and dry bulb weight per plot was achieved at the narrowest spacing. The results of this study prove that closer spacing is beneficial in increasing the onion production per plot. This is associated with an increase in the number of plants per unit area. This finding is consistent with other previous studies using different shallots varieties, such as Gujarat Junagadh White Onion 3 (Ginoya *et al.*, 2018), Candy and Texas Grano 1015 Y (Russo, 2008), where bulbs production per hectare was higher with tighter plant spacing compared to wider spacing.

In general, the fertilization factor exerts a notable influence on the diameter of the shallot's bulbs, as evidenced by the maximum bulb diameter observed in the F2 treatment. As illustrated in Table 5, the data indicates that treatment F3 yielded the highest production, including the wet weight of bulbs per clump, the dry weight of bulbs per clump, the wet weight of bulbs per plot, and bulb length. In contrast, treatment F1 typically yielded diminished growth and production outcomes. Despite a notable increase in tuber diameter, the F2 treatment was unable to significantly enhance the number and length of tubers, which are crucial supporting components for production. The impact of fertilization on total onion yield can be observed in the simultaneous increase of yield components, including length, diameter, fresh weight, and dry matter percentage (Fekry, 2017). The insignificant results of fertilization treatment on shallot bulb production, as reported in this study, are in accordance with findings by Sopha *et al.* (2015); Farid *et al.* (2022).

Contrary to planting spacing, the fertilizer treatment did not show a certain pattern in increasing or decreasing yield by lower or highest fertilizer. This situation is in line with the concept of nutrient adequacy as a key factor in increasing the growth and yield of shallots, the value of which can vary depending on the variety and the type and condition of the land/planting medium (Sopha *et al.*, 2021). Nutrient competition under conditions of deficiency or excess or imbalance in the ratio of N, P, and K fertilizer applications will affect the disturbance of nutrient uptake and utilization, which will then reduce crop yield and quality (Li *et al.*, 2019). Specifically, yield and quality reductions in Allium species due to excess N occur due to excessive vegetative growth, which inhibits the allocation of dry matter to tubers, delays maturity, increases susceptibility to pests (Tekalign *et al.*, 2012) or the formation of physical characteristics such as thick-necked tubers (Etana *et al.*, 2019). Similarly, for K nutrients, over-application, and inappropriate sources can disrupt the balance of base cations, inhibit the uptake of other macro-nutrients, and induce salt intoxication in plants, resulting in reduced yield, quality, and appearance (Wang *et al.*, 2022).

In this study, there were several combinations of fertilizers containing macronutrients such as nitrogen, phosphorus, potassium, sulfur, and magnesium, each of which plays a role in promoting the growth and production of shallots. In line with the research of Assefa *et al.* (2016), namely for nitrogen and phosphorus fertilization in shallots, the researchers recommended application rates of 42 kg ha^{-1} N combined with 76 kg ha^{-1} P for optimal shallots production in the study areas. Purba (2014) reported that there was an interaction effect between NPK and KCl fertilizers on the growth and yield of shallot plants, which included plant height, number of leaves, number of bulbs per bunch, wet bulb weight, and dry bulb weight. The same research was also carried out by Yusuf *et al.* (2023) and the results showed that the treatment with seaweed extract and NPK resulted in a higher number of leaves, plant height, fresh plant and bulb weight, dry plant weight and number of bulbs per cluster. Similarly, for fertilizer doses, the results showed that a dose of 92 kg ha^{-1} N and 242 kg ha^{-1} NPS for the Bombay Red variety (Shura *et al.*, 2022) and a dose of 150 kg ha^{-1} NPS fertilizer for Nafis (Kitila *et al.*, 2022) resulted in optimum production.

The application of KNO_3 in treatments F2, F3, and F4 has been shown to have a better effect on shallot growth and production. Potassium nitrate is considered to be one of the best sources of potassium and nitrogen due to its superiority as an easily soluble compound fertilizer. This makes its content immediately available and can be directly absorbed by plant roots in the form of K^+ and NO_3^-. Research on the application of KNO_3 fertilizer in shallots has been reported by Ernita *et al.* (2022) that KNO_3 has a positive effect on seed germination, seedling growth, and mitotic activity in onions. Asri *et al.* (2021) also reported that the production of botanical seeds in quantity and quality (TSS: true shallots seeds) treated with KNO_3 accelerated shoot formation and vegetative growth of three shallots varieties: Sanren, Superpilip, and Tajuk. KNO_3 fertilizer applied to shallots under salt stress conditions reduced the detrimental effects of salt stress on seed germination, seedling growth, mitotic activity, and chromosomal abnormalities (Çavuşoğlu *et al.*, 2017). Furthermore, in the context of purple spot disease control in onions, KNO_3 is effective in reducing disease severity and increasing yield components, providing a safe alternative to chemical fungicides (Dong *et al.*, 2014).

This study showed that the interaction of planting spacing, and fertilizer treatments increased shallot yield. The highest dry bulb weight per plot was recorded on D3F3. In accordance with the findings of Hordofa *et al.*, (2020), which indicate that the interaction between nitrogen and plant spacing results in a notable enhancement in growth and production, as well as economic advantages.

Several studies have been conducted and reported on the interaction between nitrogen and spacing on shallot growth and production. For example, a study by Gebretsadik and Dechassa (2018)reported that the interaction of 10.5 cm inter-row spacing and 82 kg ha^{-1} N fertilization produced the highest quality marketable bulbs and provided significant economic benefits. Gebretsadik and Dechassa (2018) also reported that the combination of 100 kg ha^{-1} N and 6 cm row spacing in shallots provided maximum yield and economic benefits. This is further supported by Hordofa *et al.* (2020), who studied planting distance and nitrogen fertilization, where the researchers concluded that closer row spacing (7.5 cm) combined with 125 kg ha^{-1} N could be recommended for optimal yield of the superior red onion variety 'Huruta' in the study area. Mazumder *et al.* (2019) also studied the effect of different NPK fertilizer rates and spacing on the growth of shallots variety BARI Piaz-1 and reported that 20 x 10 cm spacing and NPK fertilizer dose (160:70:100 kg ha^{-1}) resulted in better vegetative growth of shallots in terms of plant height and number of leaves per plant.

Furthermore, Sitepu *et al.* (2013) reported the interaction between potassium and spacing on shallots growth and production and found that potassium fertilizer of 20 g m^{-2} KCl and a closer spacing (10 x 10 cm) had the heaviest weight of wet and dry bulbs per plot. The interaction between phosphorus fertilizer and plant spacing has a significant effect on shallots production, in line with the study by Saud *et al.* (2013), who recommended the application of potassium fertilizer (120 kg ha^{-1} K_2O) at a spacing of 20 cm for the best growth and maximum yield of shallots in the agroclimatic conditions of the study area. This has also been demonstrated by Sharangi and Sahu (2009) who found that placement of phosphate fertilizer at 5 cm distance from the plant row at a dose of 60 kg ha^{-1} P_2O_5 proved to be optimal for achieving higher shallots yield under experimental conditions.

At Table 7, the results of the initial soil analysis in this study also showed that nitrogen nutrient status was moderate, potassium very high, and Fe high. A comparison of the soil nutrient status before planting and during harvest showed that nitrogen, potassium, and iron were stable. While phosphorus availability increased from very low to very high after the addition of phosphorus fertilizer in each fertilizer combination applied in each treatment. The addition of manure at 10 t ha^{-1} or 12 kg $plot^{-1}$ in all treatments also had a positive effect on nutrient availability. Manure increases the activity of soil micro-organisms that help decompose organic matter, thereby increasing the availability of phosphorus for plant uptake. Manure application can reduce the use of chemical fertilizers while increasing crop yields. Atman *et al.* (2023) have reported that applying of manure 15 t ha^{-1} can reduce the need for NPK fertilizer by 25% and has a significant effect on increasing the yield of dry bulbs of shallots. In contrast, the low phosphorus availability in treatments for D3F3 and D3F4 was related to the phenomena where plants take up most nutrients from the soil. In this case, plants grown in these treatments tended to take more phosphorus from the soil, resulting in low P levels.

There is a positive correlation between the increase in the number of leaves with the wet weight of bulbs per clump and the dry weight of bulbs per clump. Other factors influencing bulb weight are the significant effect of the planting distance treatment on all observations, which are growth components that support bulb production, and the significant effect of the interaction treatment of planting distance and fertilizer on the wet weight of bulbs per clump and dry weight of bulbs per clump. According to another study, the application of a combination of N, P, and K fertilization also resulted in a significant positive correlation between shallot generative traits (number of bulbs, bulbs weight) and vegetative traits (plant height, number of leaves, number of tillers) (Susilawati *et al.*, 2018). The results of Marpaung and Rosliani (2019) showed a direct correlation between bulb yield and the number of leaves or tillers produced after the adaptation test treatment of five shallot varieties in the humid highlands. Higher yields and more bulbs are often correlated with more leaves.

This study found that the increase in yield of shallots per plot was influenced by a mixture of plant spacing treatments related to plant density or plant population per unit area, as well as macronutrient fertilization with N, P, and K. Plant spacing of 20 x 10 cm with fertilization of TSP, NPK, KNO_3, urea and ZA of 100, 300, 107, 76 and 400 kg ha^{-1} respectively can increase shallots yield by 84.50% compared to 20 x 20 cm spacing with the same fertilizer dose. Nitrogen supply stimulates vegetative growth to the maximum, while potassium and phosphorus are very important for the development of the bulbs, thus influencing the size and quality of the shallot's bulbs. This proves that in addition to fertilization factors, plant density or plant population contributes proportionally to a significant increase in yield. This research proves the importance of plant population management and fertilization in increasing the agricultural productivity of shallots.

Based on the result of the study, in practice, our recommendation for shallot production is the combination of Batu Ijo shallot variety with 20 x 10 cm planting spacing and fertilized by TSP, NPK, KNO_3, urea, and ZA of 100, 300, 107, 76, and 400 kg ha^{-1} respectively. Based on the result, the best treatment in this study produced 53.45 kg $plot^{-1}$ equal to 26.1 t ha^{-1}. Theoretically, this recommendation is expected to boost the farmer yield higher than the current yield recorded on the BPS-Statistic of Sumatra Province (2022a).

However, this study has several limitations. It should be noted that the study was done in the upland area of Toba Samosir.

Upland areas have very specific soil and climatic conditions that differ from other types of land. So, the effectivity of the same treatment in another type of land like the lowlands might give a different result. Furthermore, this study only uses Batu Ijo as a test variety. The practical application of this study only works best with the same variety. This indicated that in the future, there is a need to test the treatments with more variety. Several studies have shown that different variety has a different optimum plant spacing and nutrient requirements. Several studies on spacing have also reported a variety of optimal spacing for optimal yield production such as 12 x 20 cm, 6 x 20 cm, and 10x20 cm for Nafis, Robat, and Nasik varieties (Wassie *et al.*, 2022), 6 x 20 cm for Red Bombay variety (Gebretsadik and Dechassa, 2018), and 10 x 40 cm for Red Adama variety (Alemu *et al.*, 2022) to produced optimum onion bulbs. Likewise, for fertilizer doses, several studies also showed that optimal doses vary greatly among the different shallot varieties (Shura *et al.*, 2022; Kitila *et al.*, 2022).

Conclusion**:** The combination of treatment fertilization and planting distance has an influence on increasing the productivity of shallots. A planting distance of 20 x 10 cm combined with TSP, NPK, KNO_3, Urea, and ZA fertilizers at 100, 300, 107, 76, and 400 kg ha^{-1} respectively, can increase the dry weight of bulbs per plot by 84.50% compared to the wider planting spacing of 20 x 20 cm with the same fertilizer treatments. Thus, based on the results, this study suggests that the 20 x 10 cm planting spacing should be fertilized with TSP, NPK, KNO_3, Urea, and ZA at doses 100, 300, 107, 76, and 400 kg ha^{-1} respectively to obtain better shallot production. Based on regression analysis, the optimum rates of N, P, and K for optimum relative yield of Batu Ijo shallot variety were 126.85, 178.06, and 95.25 kg ha^{-1}.

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