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Analyzing the Effects of NPK Fertilizers on Ginger (*Zingiber officinale*) Yield and Quality

Sana Ullah[1], Abdul Malik[1]*, Amir Latif[12]*, Saqib Ali[1], Muhammad Usama Saeed[3], Muhammad Nadeem Arif[1]

[1]Department of Plant Breeding and Genetics, University of Agriculture Faisalabad, Pakistan
[2]Vegetable Research Institute, Ayub Agricultural Research Institute, Faisalabad
[3]Institute of Horticultural Sciences, University of Agriculture, Faisalabad, Pakistan
***Corresponding author e-mail**: *abdulmalikiqbalpbg@gmail.com* and *amirpbg05@gmail.com*

ABSTRACT Ginger (Zingiber officinale Rosc.) is a tropical perennial plant that is harvested for its subterranean stems and is closely linked to turmeric and cardamom. It is commonly cultivated in Asia, Africa, India, Jamaica, Mexico, and Hawaii. It has a wide range of beneficial effects, including anti-microbial, anti-nausea, anti-pyretic, analgesic, anti-inflammatory, hypoglycemic, anti-ulcer, antiemetic, and pharmaceutical uses. A field experiment was conducted at Ayub Agriculture Research Institute, Faisalabad, Pakistan in 2021 to evaluate the NPK optimization for ginger production. The data showed that all treatments showed statistically significant differences from each other in terms of rhizome thickness, yield per plant, and minimum yield per plant. Results showed that a minimum of two treatments showed statistically significant differences from each other. The maximum plant height, number of leaves per plant, leaf length, tiller thickness, rhizome length, rhizome width, rhizome thickness and yield per plant was recorded in treatment (T8) while T3 and T4 showed maximum leaf width and tillers per plant respectively.

Keywords: *NPK fertilizers; Yield; Ginger quality; Fertilizer impact; Crop management*

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INTRODUCTION *Zingiber officinale*, often known as ginger, is a tropical perennial plant that is harvested for its subterranean stems and belong to the family Zingiberaceae. It is often cultivated as an annual crop. The whole plant has a pleasant aroma, but the raw or processed subterranean rhizome is appreciated as a spice. Its medicinal usefulness is being widely acknowledged. Ginger likely originated in India in South-East Asia (Burkill, 1966; Purseglove, Brown, Green, & Robbins, 1981; Vasala, 2012).

Ginger (Zingiber officinale Rosc.) is a 2n = 2x = 22 monocotyledon belonging to the Zingiberaceae family and the Zingiberales order. The plant species Zingiberaceae belongs to the subfamily Zingiberoideae. This subfamily is characterized by plants with fragrant unbranched stems, distichous leaves, open sheaths, and hypogeal germination. These plants are mostly found in the tropical regions of the Old World, with a concentration of distribution in Indo-Malaysia (Vasala, 2012).

Ginger is closely linked to turmeric and cardamom, two additional culinary spices. Ginger is a two- to four-foot-tall perennial with grass-like leaves up to one foot long. Ginger rhizome is utilised for medicinal and culinary uses. Ginger, a plant native to warm tropical climes, is commonly cultivated in Asia, Africa, India, Jamaica, Mexico, and Hawaii (Zadeh & Kor, 2014). It develops dense clusters of flower buds in white and pink that open to reveal yellow blossoms. Rhizome describes the horizontally spreading, laterally flattened structure from which ginger develops its many stemlike offshoots. The rhizome as a whole is solid and striated. It ranges in size from 5 to 15 centimeters and may be yellow, white, or red depending on the type. Its width ranges from 1.5 to 6 centimeters and its thickness is 2 centimeters (Bhatt, Waly, Essa, & Ali, 2013).

The nutritional breakdown of fresh ginger is as follows: 80.9% water, 2.3% protein, 0.9% fat, 1.2% minerals, 2.4% fibre, and 12.3% carbs. As for minerals, ginger has iron, calcium, and phosphorus. Additionally, vitamins B1, B2, B3, and C are present. The nutritional composition varies according on the category, variety, agronomic circumstances, curing techniques, drying and storing procedures (Gugnani & Ezenwanze, 1985).

It has been shown that ginger's direct anti-microbial action may be utilised to treat bacterial illnesses (Tan & Vanitha, 2004). As a powerful antioxidant, ginger extract helps reverse conditions brought on by free radical damage. Extant phenolic compounds and anthocyanins, such as gingerols and the sugevals, have been proven to have several neuro protective properties, such as analgesic effects, memory enhancement, and learning that are a result of the ageing process (Fadaki, Modaresi, & Sajjadian, 2017). Medical studies have shown that ginger has a wide range of beneficial effects, including anti-microbial, anti-nausea (Portnoi et al., 2003), anti-pyretic (SUEKAWA et al., 1984), analgesic, anti-inflammatory, hypoglycaemic (Ojewole, 2006), anti-ulcer, antiemetic (Mascolo, Jain, Jain, & Capasso, 1989). In addition to its culinary uses, Zingiber officinale has pharmaceutical uses. It has been shown to be effective in the treatment of a wide range of conditions, including indigestion, bronchitis, arthritis, high blood pressure, and migraines (Hosseini & Mirazi, 2015). In a study (Mascolo et al., 1989) validated ginger powder's efficacy in treating common migraine attacks and found it to be chemically identical to the antiepileptic medication. The annual production i.e., yield of ginger worldwide and it can be concluded that USA, China, Japan, Fiji, and Indonesia are among the top 5 countries with highest annual average yields 27554.91 kg/ha according to FAO. However, Pakistan is among the countries with least annual yield per hectare.

The major constrain for ginger production in Pakistan is the narrow genetic spectrum of ginger genotypes as well unfit soil conditions, and other environmental factors. Soil condition can be manipulated by applying optimum NPK requirements and made it fit for the ginger production. In order to optimize the NPK dosage required fir better ginger production current study was conducted.

MATERIAL AND METHODS

Experimental site description

This field experiment was conducted at Ayub Agriculture Research Institute, Faisalabad, Pakistan (AARI) in the year 2021to evaluate the NPK optimization for ginger. AARI is located approximately 73.0733° E longitudinally and is approximately 186 meters (610 feet) altitudinally above sea level.

Experimental layout

This experiment was conducted in Completely Randomized Design (CRD) with three replications to reduce the error. Pots were used to evaluate the optimization of NPK ration in ginger. Different fertilizers were used as a source of nitrogen, phosphorus and potassium including ammonium sulphate (AS), single super phosphate (SSP) and sulphate of potash (SOP) were used in different concentrations and per hectare concentrations were adjusted for pots accordingly. Poultry manure was also used as organic manure to enhance plant survival. Different levels of these fertilizers were defined and were named as T1, T2, T3 up to T8. T0 was treatment with zero level of fertilizers. Father detailed treatment plan for ginger NPK optimization is given in the Table 1.

Determination of yield and growth-related parameters of ginger

Ginger rhizomes were planted as seeds on 02/03/2021. About after four months when ginger plants were fully grown and matured different yield related descriptors were selected for data collection which including plant height, number of leaves per plant, leaf length, leaf width, tillers per plant, tiller thickness, rhizome length, rhizome width, rhizome thickness, yield per plant.

Statistical analysis

Data collected for different descriptors were subjected to analysis of variance (ANOVA) to check the statistical difference between different treatments using R 4.2.2. Correlation analysis was also carried out using R 4.2.2 to evaluate the contribution of different traits to yield.

RESULTS AND DISCUSSION

Analysis of variance

The recorded data of all the traits were subjected to CRD-ANOVA to compute their significance. In semi-controlled conditions, ANOVA for all the treatments showed a highly significant difference for all the traits except few. All mean pairwise comparisons were done by using Tukey HSD for all the treatments under semi-controlled conditions for corresponding traits.

Plant height

The data were statistically analyzed regarding the plant height and the results obtained showed in Table 2. It was represented that a minimum of two treatments showed statistically significant differences from each other. The maximum plant height (70.13 cm) was recorded in treatment (T8). It was statistically similar to treatment T4 (67.6 cm) and followed by treatments (T3, T0, T6, T7, T2, T1) with a plant height of 59.4 cm, 49.8 cm, 46.4 cm, 44.3 cm, 40.73 cm, and 40.07 respectively. While minimum plant height (18.83 cm) was recorded in treatment (T5). The bars in different lines showing that treatments are statistically significant from each other. Whereas the bars sharing the same line is showing that treatments are non-significantly different as shown in (Figure 1).

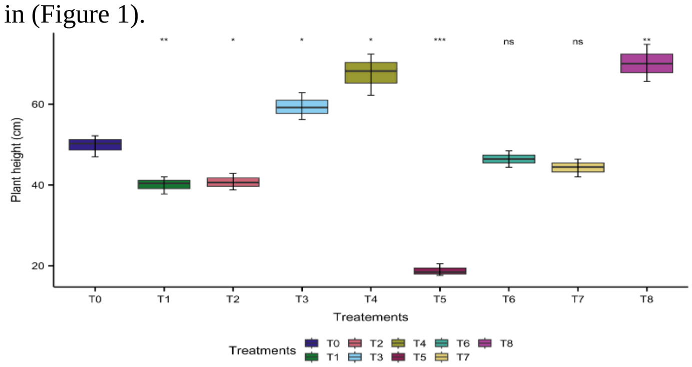

Figure 1: *Mean comparison of treatments for plant height*

Number of leaves

The data were statistically analyzed regarding the number of leaves and the results obtained showed in Table 2. It was represented that a minimum of two treatments showed statistically significant differences from each other. The maximum number of leaves (37) was recorded in treatment (T8). It was statistically at par with treatment T3 (26) and followed by treatments (T4, T0, T6, T7, T2, T1) with the number of leaves 24, 22, 21, 19, 15, and 14 respectively. While minimum number of leaves (6) was recorded in treatment (T5). The bars in different lines showing that treatments are statistically significant from each other. Whereas the bars sharing the same line is showing that treatments are non-significantly different as shown in (Figure 2).

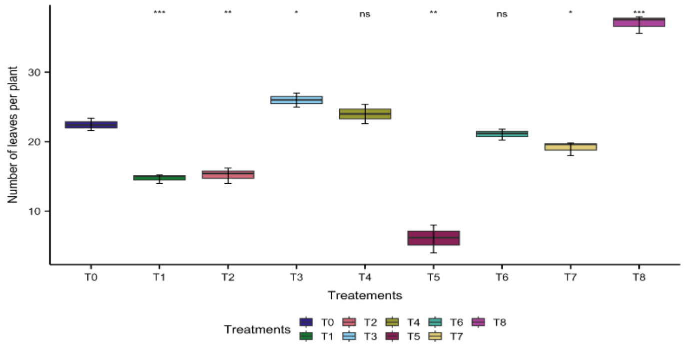

Figure 2: *Mean comparison of treatments for number of leaves*

Leaf length

The data were statistically analyzed regarding the leaf length and the results obtained showed in Table 2. It was represented that a minimum of two treatments showed statistically significant differences from each other. The maximum leaf length (24.4 cm) was recorded in treatment (T8). It was statistically similar to treatment T3 (22.1 cm) and followed by treatments (T4, T0, T6, T7, T2, T1) with a leaf length of 18.9 cm, 18.2 cm, 17.7 cm, 17.3 cm, 15 cm, and 14.6 respectively. While minimum leaf length (5.8 cm) was recorded in treatment (T5). The bars in different lines showing that treatments are statistically significant from each other. Whereas the bars sharing the same line is showing that treatments are non-significantly different as shown in (Figure 3).

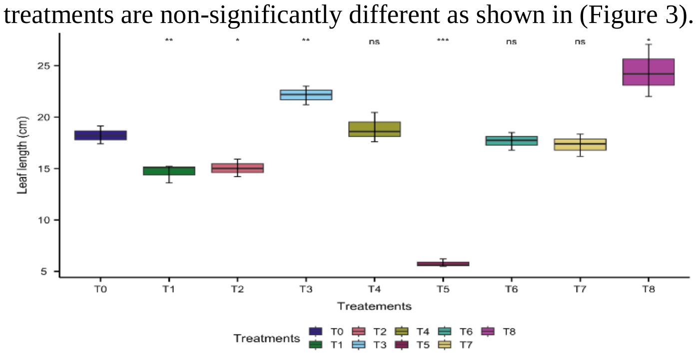

Figure 3: *Mean comparison of treatments for leaf length.*

Leaf width

The data were statistically analyzed regarding the leaf width and the results obtained showed in Table 2. It was represented that all the treatments showed statistically non-significant differences from each other. The maximum leaf width (2.1 cm) was recorded in treatment (T3). It was statistically similar to treatment T8 (2.07 cm) and followed by treatments (T4, T2, T6, T5) with a leaf width of 2.03 cm, 2.02 cm, 1.99 cm, and 1.95 cm respectively. While minimum leaf width (1.94 cm) was recorded in treatment (T0, T1, and T7). The bars sharing the same line is showing that treatments are non-significantly different as shown in (Figure 4).

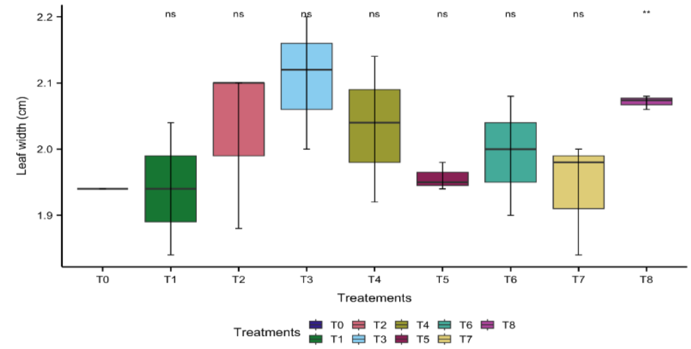

Figure 4*: Mean comparison of treatments for leaf width.*

Tiller thickness

The data were statistically analyzed regarding the tiller thickness and the results obtained showed in Table 2. It was represented that all the treatments showed statistically non-significant differences from each other. The maximum tiller thickness (10.96 mm) was recorded in treatment (T8). It was statistically similar to treatment T1 (10.39 mm) and followed by treatments (T7, T5, T3, T6, T0, T4) with a leaf width of 10.32 mm, 10.24 mm, 9.99 mm, 9.89 mm, 9.80 mm, and 9.43 mm respectively. While minimum leaf width (8.81 mm) was recorded in treatment (T2). The bars sharing the same line is showing that treatments are non-significantly different as shown in (Figure 5).

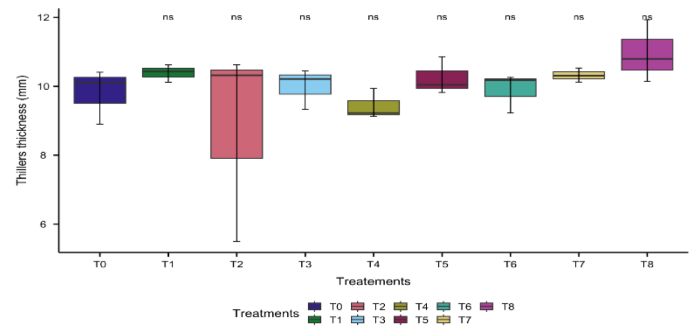

Figure 5*: Mean comparison of treatments for tiller thickness.*

Tillers per plant

The data were statistically analyzed regarding the tillers per plant and the results obtained showed in Table 2. It was represented that all the treatments showed statistically non-significant differences from each other. The maximum tiller per plant (13) was recorded in treatment (T4). It was statistically similar to treatment T8 (12) and followed by treatments (T0, T3, T6, T7, T1, T2) with a tillers per plant of 10, 9, 8, 6, 5, and 5 cm respectively. While minimum tillers per plant (3 cm) was recorded in treatment (T5). The bars sharing the same line is showing that treatments are non-significantly different as shown in (Figure 6).

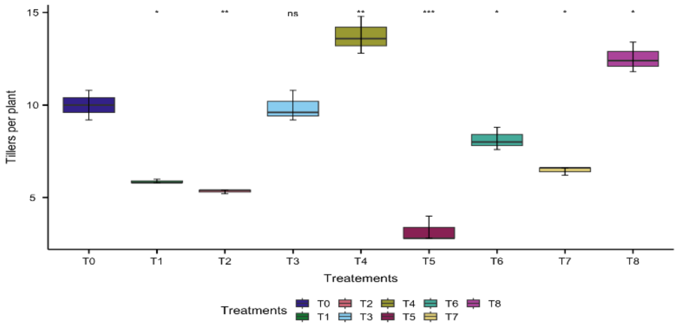

***Figure 6**: Mean comparison of treatments for tillers per plant.*

Rhizome length

The data were statistically analyzed regarding the rhizome length and the results obtained showed in Table 2. It was represented that all the treatments showed statistically significant differences from each other. The maximum rhizome length (10.4 cm) was recorded in treatment (T8). It was statistically similar to treatment T3 (9.4 cm) and followed by treatments (T4, T0, T6, T7, T1, T2) with a rhizome length of 8 cm, 7.8 cm, 6.1 cm, 5.4 cm, 4.4 cm, and 4.2 cm respectively. While minimum rhizome length (1.8 cm) was recorded in treatment (T5). The bars sharing the same line is showing that treatments are non-significantly different as shown in (Figure 7).

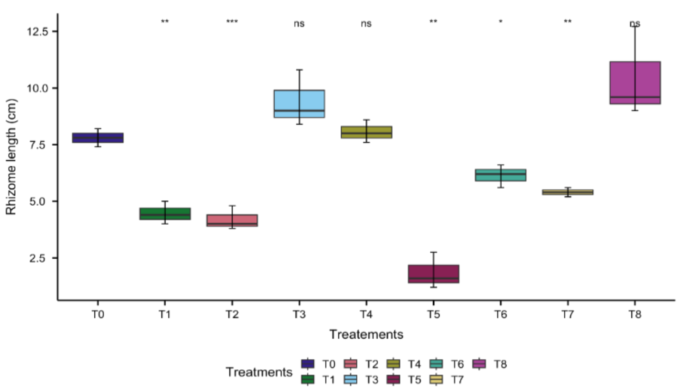

***Figure 7**: Mean comparison of treatments for rhizome length.*

Rhizome width

The data were statistically analyzed regarding the rhizome width and the results obtained showed in Table 2. It was represented that all the treatments showed statistically significant differences from each other. The maximum rhizome width (4.4 cm) was recorded in treatment (T8). It was statistically similar to treatment T3 (3.8 cm) and followed by treatments (T4, T0, T6, T7, T1, T2) with a rhizome width of 3.3 cm, 3 cm, 2.8 cm, 2.7 cm, 2.6 cm, and 2.4 cm respectively. While minimum rhizome width (1.3 cm) was recorded in treatment (T5). The bars sharing the same line is showing that treatments are non-significantly different as shown in (Figure 8).

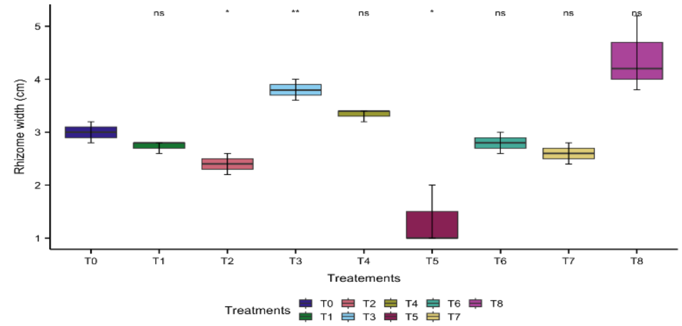

***Figure 8**: Mean comparison of treatments for rhizome width.*

Rhizome thickness

The data were statistically analyzed regarding the rhizome thickness and the results obtained showed in Table 2. It was represented that a minimum of two treatments showed statistically significant differences from each other. The maximum rhizome thickness (33.06 mm) was recorded in treatment (T8). It was statistically at par with treatment T3 (27.87 mm) and followed by treatments (T4, T0, T6, T7, T2, T1) with the rhizome thickness 26.82 mm, 25.87 mm, 22.45 mm, 20.87 mm, 19.45 mm, and 19.32 mm respectively. While minimum rhizome thickness (13.28 mm) was recorded in treatment (T5). The bars in different lines showing that treatments are statistically significant from each other. Whereas the bars sharing the same line is showing that treatments are non-significantly different as shown in (Figure 9).

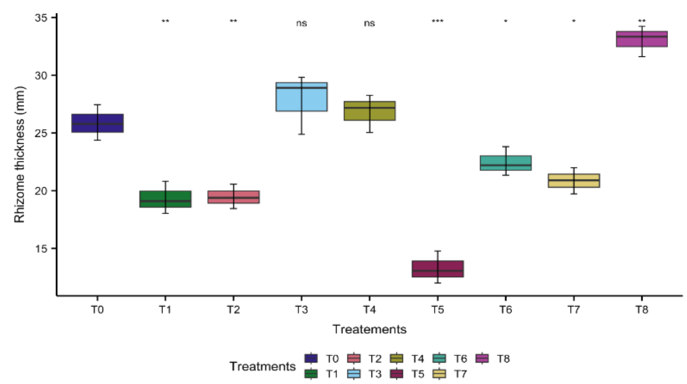

***Figure 9:** Mean comparison of treatments for rhizome thickness.*

Yield per plant

The data were statistically analyzed regarding the yield per plant and the results obtained showed in Table 2. It was represented that all the treatments showed statistically significant differences from each other. The maximum yield per plant (152 g) was recorded in treatment (T8). It was statistically similar to treatment T3 (145 g) and followed by treatments (T4, T0, T6, T7, T1, T2) with a yield per plant of 136 g, 131 g, 110 g, 102 g, 96 g, and 95 g respectively. While minimum yield per plant (29 g) was recorded in treatment (T5). The bars sharing the same line is showing that treatments are non-significantly different as shown in (Figure 10).

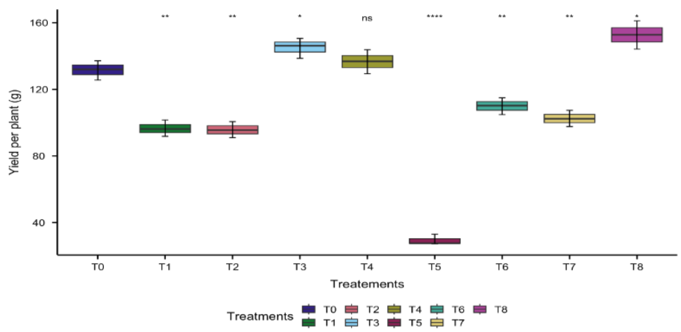

***Figure 10**: Mean comparison of treatments for yield per plant*

Correlation

Correlation analysis measures the association between their quality and yield-related traits. Plant breeder may create a criterion and could improve the yield according to this analysis. Correlation shows the traits are genetically linked with each other. The strong correlation between two traits helps us to select a plant for one trait by selecting the other linked trait. The reasons behind the correlation are the pleiotropic gene effect and linkage effect. It is the degree of association between the two or more independent variables. The various characters are associated with economic production. In crop plants, the relative position of various plant parameters in plant breeding for the improvements of related traits like, growth and yield could be shown through association analysis (Figure 11). It is the method to give value to the relationship. The value of a correlation coefficient ranges between -1 and +1.

Phenotypic correlation between PH and other traits

Plant height showed a highly significant and positive correlation with the number of leaves per plant, leaf length, leaf width, tillers per plant, rhizome length, rhizome width, rhizome thickness, and yield per plant. While tiller thickness showed a non-significant correlation for the plant height. (Ahmed, Naeem, et al., 2024; Anargha, Sreekala, Nair, & Abraham, 2021) showed a highly significant and positive correlation between plant height with the number of tillers, leaf length, leaf area, and rhizome thickness. (Ahmed, Zeng, et al., 2024; Das, Behera, Sahoo, Barik, & Subudhi, 2022) showed a positive correlation of plant height with rhizome yield due to tillers number.

Phenotypic correlation between NLPP and other traits

The number of leaves per plant showed a highly significant and positive correlation with leaf length, leaf width, rhizome length, rhizome width, rhizome thickness, and yield per plant. The number of leaves showed a significant and positive correlation with tillers per plant. While tiller thickness showed a non-significant correlation for the number of leaves. (Ali et al., 2024; Nandkangre et al., 2016) showed a significant and positive correlation of the number of leaves per plant with leaf length, leaf width, tiller thickness, plant height, tillers per plant, rhizome length, rhizome width, rhizome thickness, and rhizome weight per plant. (Das et al., 2022) showed a significant and positive correlation between the number of leaves per plant with rhizome yield.

Phenotypic correlation between LL and other traits

Leaf length showed a highly significant and positive correlation with leaf width, rhizome length, rhizome width, rhizome thickness, and yield per plant. The leaf length showed a significant and positive correlation with tillers per plant. While tiller thickness showed a non-significant correlation for the leaf length. (Nandkangre et al., 2016) showed a significant and positive correlation of leaf length with leaf width, tiller thickness, plant height, tillers per plant, rhizome length, rhizome width, rhizome thickness, and rhizome weight per plant. (Kumar et al., 2016; Li et al., 2024) showed a significant and positive correlation between leaf length with plant height.

Phenotypic correlation between LW and other traits

Leaf width showed a highly significant and positive correlation with tillers per plant, rhizome length, rhizome width, rhizome thickness, and yield per plant. While tiller thickness showed a non-significant correlation for the leaf width. (Zambrano Blanco & Baldin Pinheiro, 2017) showed a highly significant and positive correlation of leaf width with yield per plant and rhizome thickness. (Kumar et al., 2016) showed a significant and positive correlation between leaf width plant height and leaf length.

Phenotypic correlation between TPP and other traits

Tillers per plant showed a highly significant and positive correlation with rhizome length, rhizome width, and rhizome thickness. The tillers per plant showed a significant and positive correlation with yield per plant. While tiller thickness showed a non-significant correlation for the tillers per plant. (Nandkangre et al., 2016) showed a significant and positive correlation of tillers per plant with rhizome length and rhizome weight per plant.

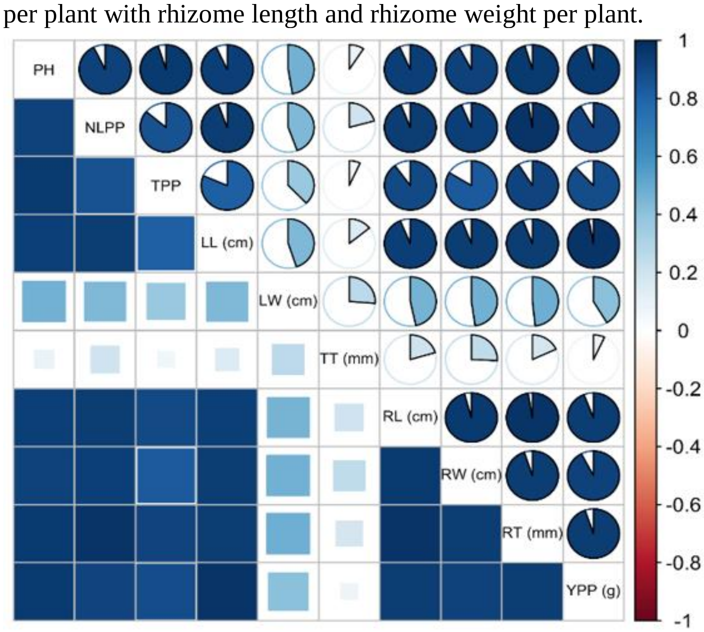

***Figure 11:** Graphical representation of phenotypic correlation for the yield and morphological traits*

Phenotypic correlation between TT and other traits

Tiller thickness showed a non-significant correlation with rhizome length, rhizome width, rhizome thickness, and yield per plant. (Nandkangre et al., 2016) showed a negative correlation between tiller thickness with rhizome weight per plant.

Phenotypic correlation between RL and other traits

Rhizome length showed a highly significant and positive correlation with rhizome width, rhizome thickness, and yield per plant. (Nandkangre et al., 2016) showed a positive correlation of rhizome length with rhizome width, rhizome thickness, and rhizome weight per plant. (Kumar et al., 2016) showed a significant and positive correlation of rhizome length with plant height, leaf length, leaf width, and the number of leaves.

Phenotypic correlation between RW and other traits

Rhizome width showed a highly significant and positive correlation with rhizome thickness, and yield per plant. (Nandkangre et al., 2016) showed a positive correlation of rhizome width with rhizome thickness and rhizome weight per plant. (Kumar et al., 2016) showed a significant and positive correlation between rhizome width with leaf length and leaf width.

Phenotypic correlation between RT and YPP.

Rhizome thickness showed a highly significant and positive correlation with yield per plant. (Nandkangre et al., 2016; Zeng et al., 2024) showed a positive correlation between rhizome thickness with rhizome weight per plant.

Table 1: Treatment plan for experiment

Dose per hectare (Kg)						Dose per pot per 2 Plants (gm)							
Trt.	N	P	K	S	PM	AS (N1)	AS (N2)	AS (N3)	AS (N4)	SSP	SOP	S in All	PM
T0	0	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
T1	0	0	0	0	741	0.0	0.0	0.0	0.0	0.0	0.0	0.0	18.7
T2	100	25	100	167		3.0	3.0	3.0	3.0	3.5	5.1	4.2	
T3	200	50	200	334		6.0	6.0	6.0	6.0	7.0	10.1	8.4	
T4	400	100	400	668		12.0	12.0	12.0	12.0	14.0	20.2	16.9	
T5	400	100	400	668		12.0	12.0	12.0	12.0	14.0	20.2	16.9	
T6	600	150	600	1002		18.1	18.1	18.1	18.1	21.1	30.3	25.3	
T7	800	200	800	1336		24.1	24.1	24.1	24.1	28.1	40.4	33.8	
T8	400	400	400	0		12.6 (will be applied in four doses)							
Note: AS (N1) at the time of sowing, AS (N2) after 2 months, AS (N3) after 4 months and As (N4) after 6 months, and same for NPK doses													

Table 2: Analysis of variance results for all the treatments

	DF	PH	NLPP	LL	LW	TPP	TT	RL	RW	RT	YPP
Genotype	8	745.18**	222.19**	83.50**	0.011^{NS}	36.33**	1.13^{NS}	22.65**	2.28**	102.23**	4194.85**
Error	18	9.43	1.41	1.53	0.007	0.44	1.22	0.83	0.12	2.41	33.60
CV%		6.32	5.76	7.21	4.24	7.92	11.08	14.16	11.81	6.69	5.22

*Note: **= Significant at 1% level of significance (P<0.01), *=significant at 5% level of significance (P<0.05), (PH) Plant height, (NLPP) Number of leaves per plant, (LL) Leaf length, (LW) Leaf width, (TPP) Tillers per plant, (TT) Tiller thickness, (RL) Rhizome length, (RW) Rhizome width, (RT) Rhizome thickness, (YPP) Yield per plant.*

Table 3: Correlation for the yield and morphological traits

	PH	NLPP	LL	LW	TPP	TT	RL	RW	RT
NLPP	0.9280**								
LL	0.9504**	0.8610**							
LW	0.9309**	0.9446**	0.8146**						
TPP	0.4740**	0.4439*	0.3775*	0.4487**					
TT	0.0923NS	0.2073NS	0.0690NS	0.1419NS	0.2621NS				
RL	0.9326**	0.9400**	0.8987**	0.9368**	0.4655**	0.2048NS			
RW	0.9223**	0.9372**	0.8369**	0.9409**	0.4763**	0.2569NS	0.9573**		
RT	0.9528**	0.9733**	0.9108**	0.9408**	0.4824**	0.1815NS	0.9735**	0.9491**	
YPP	0.9534**	0.9169**	0.8812**	0.9707**	0.4139*	0.0701NS	0.9402**	0.9227**	0.9476**

*Note: **= Significant at 1% level of significance (P<0.01), *=Significant at 5% level of significance (P<0.05) and NS = Non-significant, (PH) Plant height, (NLPP) Number of leaves per plant, (LL) Leaf length, (LW) Leaf width, (TPP) Tillers per plant, (TT) Tiller thickness, (RL) Rhizome length, (RW) Rhizome width, (RT) Rhizome thickness, (YPP) Yield per plant*

CONCLUSION

The results of this experiment revealed that the recommended dose if NPK for ginger is 400 kg/hectare. Providing this dose of NPK will show maximum plant height, number of leaves per plant, leaf length, tiller thickness, rhizome length, rhizome width, rhizome thickness and yield per plant. However maximum leaf width and tillers per plant can be obtained providing NPK in 20:50:200 and 400:100:400 ratios respectively.

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