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Original Research

Response of Radish (*Raphanus sativus* L.) to NPS Fertilizer and Inter-row Spacing with Trait Correlation by PCA

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Abstract

Radish is an essential short-cycle vegetable crop for food security. However, poor agronomic *practices constrain the crop. Hence, an experiment was carried out in Horro district, Ethiopia in 2022 in a factorial randomized complete block design with three repeats, radish plants were planted at five different NPS fertilizer rates (0, 50, 100, 150, and 200 kg ha^{-1}) and three different inter row spacing (20, 30, and 40 cm) to examine the effect of NPS fertilizer and inter row spacing on growth and yield performance of radish crop. The results revealed that the main effects of NPS fertilizer rates and inter-row spacing were statistically significant (p<0.05) for all plant characteristics measured, except for fresh biomass yield, which showed significant interaction effects. The short maturity period makes the crop suitable for multiple-cropping systems. The 200 kg NPS ha^{-1} fertilizer rate and inter-row spacing of 40 cm have influenced the vegetative and root yield of the crop. The PCA plot showed a high positive correlation between traits, with the exception of days to maturity. While days to maturity, leaf number, leaf length, and plant height with high Cos2 values with long vectors were well represented on the PC plot. Generally, the results demonstrated that the maximum root yield of 41,111 kg ha^{-1} and fresh biomass of yield 124, 657 kg ha^{-1} with the combined application of 200 kg ha^{-1} NPS fertilizer and 40 cm inter-row spacing. The root and leaf yield potential of the radish crop needs to be improved by additional research for food security, particularly by exploring different fertilization strategies and crop management practices that could enhance yield outcomes.*

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INTRODUCTION

The radish is an ancient vegetable that is cultivated annually or biannually. With 2n = 2x = 18 chromosomes, it is diploid and a member of the Brassicaceae (Crucifereae) family (Gupta *et al*., 2003; Crisp, 1995). Most scholars concur that the wild radish (*Raphanus raphanistrum* L.) is most likely the ancestor of the domesticated radish (*R. sativus* L.). Radishes are a major crop from an economic perspective, and they are grown and consumed all over the world for their sweet and succulent taproot. Depending on the variety, the edible root can have a spherical, long, cylindrical, or tapering shape, and its outer skin can be white, yellow, pink, red, purple, or black (Swaamy, 2023). The young radish roots, when they have grown bigger, can be consumed fresh in salads or cooked as a side dish. They have a pungent flavor and are considered a starter. The fragile leaves can also be prepared and enjoyed as a vegetable. Radish meals can be beneficial for issues related to the liver and gallbladder (Umar *et al.,* 2019).

The taste, size, and length of the edible root of radish can differ across different regions globally. Iron, zinc, calcium, phosphorus, protein, and dietary fiber can all be found in good amounts in radish leaves and roots. Additionally, their levels of anti-nutrients such as oxalate, phytate, and tannin are low (Keyata *et al.*, 2020). Additionally, it has a multitude of beneficial compounds that improve health, including antioxidant qualities, beta-carotene, total phenolic and flavonoid levels, and L-ascorbic acid (Keyata, 2021). Radish leaves are a fantastic source of calcium, vitamin C, and antioxidants called phenols (Goyeneche *et al*., 2015). In Ethiopia, the cultivation of radish vegetables is commonly practiced in the Benishangul Gumuz region, which borders Sudan, locally named Figl, in the Berta, Amhara, and Oromo ethnic groups. Radish exhibits distinctive agronomic traits such as being highly adaptable to various climates, reaching maturity early, and thriving in poor quality soil to yield abundant produce. Additionally, both the leaves and roots of radish are commonly utilized in salads or cooked dishes (Keyata et al., 2021).

Despite its nutritional and agronomic advantages, little research has been done to exploit the advantages of the crop. Most of the underutilized crops consist of wild or semi-domesticated species that have been specially developed for specific local conditions and uses (Li and Siddique, 2018). The amount of plant nutrients in the soil impacts the vegetable crop development, yield, and quality directly. Plant nutrient shortages affect crop development and are crop-specific, soil-specific, and crop-stage dependent. For this reason, soil nutrient management is essential. Inorganic fertilizers' nutrients are released somewhat quickly, promoting early plant establishment and growth (Chaudhari, 2023). Conversely, maximum yield is achieved at the ideal density when plants reach maturity at their largest size yet remain closely packed and utilize every available resource (Denga *et al*., 2012). Hence, searching for an optimum NPS fertilizer and plant spacing is essential to improve radish production and diversify farming systems as alternative options in the face of climate change and increased monocropping challenges. Thus, the aim of this study was to evaluate the growth and yield performance of radish under varied NPS fertilizer rates and plant inter-row spacing.

METHODOLOGY

Description of study area

The research was conducted at Wollega University, Shambu Campus in Horro district, Horro-Guduru Wollega Zone, Ethiopia, approximately 315 km from Addis Ababa, under rain-fed conditions from September to October 2022. The site is 2,600 meters above sea level and is found at 9° 34' 0'' north latitude and 37° 6' 0'' east longitude (Figure 1). The region receives between 1700 and 2000 mm of rain on average each year, with the main wet season lasting from June to October. The average high and average low temperature at this time was 24 and 10 degrees Celsius, respectively (Tesema and Gebissa, 2022).

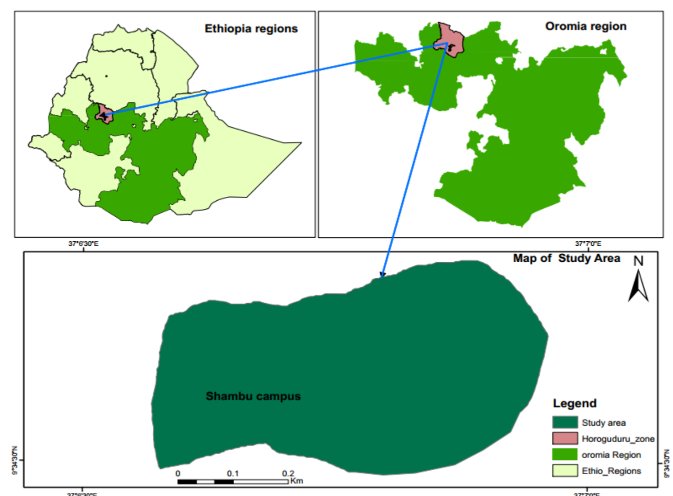


Figure 1: Map of the research site, Shambu campus.

Treatments and layout of the experiment

Three distinct inter-row spacing (20, 30, and 40 cm) and five rates of combined NPS fertilizer (0, 50, 100, 150, and 200 kg ha^{-1}) were applied using a 5x3 factorial arrangement and a randomized full block design with three replications. Each plot measured 1.8 m^2 and had width and length measures of 1.5 m and 1.2 m, respectively. The plots were spaced 0.5m apart and there was a 1m distance between blocks in the experimental area, which had a total size of 25m * 6.5m (162.5m^2).

Procedures and management for the experimental field.

Oxen-driven tillage was used to plough the experimental field, and the clods were leveled to the ground by hand. Radish seed was utilized as a test material. Finally, the plots were prepared for sowing using a spade. On September 12, 2022, hand drilling was used to sow radish seeds. The specified treatments were followed by the application of the whole amount of NPS fertilizer. Urea was sown in each plot at the suggested rate of 100 kilograms per hectare. Weeds were manually removed, and other farming practices were implemented as recommended.

Method of data recording: Data was collected from central rows, while the border rows on both sides were used as a border effect.

Days to maturity (DM): The time period in days from the appearance of plants to the day when the bottom leaves of about 90% of the plants in an area become discolored.

Leaf number (LN): to count the number of fresh leaf petioles on each plant, five plants at full maturity were chosen at random from each treatment.

Leaf length (cm): The leaf's length was determined using a ruler and reported in centimeters (cm).

Length of the root (LR): Measure the distance (in centimeters) for each treatment, starting at the base of the leaf stems and ending at the rounded tip of the five randomly chosen roots, using a ruler.

Root diameter (RD): A ruler was used to measure the diameter of five randomly chosen roots at the widest section of each plot. Cut cross-sectionally at the broadest point of the root, the diameter of the core was measured with a caliper.

Root yield: The total yield per plot or per hectare was estimated by counting the number of roots in central rows and weighing them.

Fresh biomass yield per plot (FBY): the total fresh weight of all the plant parts in (kg) harvested from the central rows.

Analysis of soil

Before the crop was planted at the experimental site, soil samples were taken from 15 plots using an auger set up in a zigzag pattern, ranging in depth from 0 to 30 cm. Before planting, the samples were combined into a single sample. A one-kilogram sample of this mixture was obtained, and a mortar and pestle were used to grind the dry soil sample. The sample was initially run through a 2-mm screen to assess the soil's texture, pH, Cation Exchange Capacity (CEC), organic carbon, total nitrogen, accessible phosphorus, and sulfur, among other important physical and chemical properties at the Nekemte Soil Research Center Laboratory, Ethiopia, following the standard methods.

Statistical analysis

Using the proper protocols and Genstat software (Version 18th), the gathered data was put through an analysis of variance (ANOVA) (Payne, 2015). LSD (Least Significant Difference) was used to determine the significant differences between the treatments at the 5% significance level (Gomez and Gomez, 1984). Furthermore, R Software Version 4.2.2 (R Software, 2022) was used to create the interaction graphs that illustrate the distinct and combined effects of nitrogen levels and plant spacing. In addition to this, the correlation analysis and quality of representation of traits on the principal component plot were performed using the Rpackage.

RESULTS

Soil analysis results of the study area before planting.

The composition of the soil analysis result showed the soil is 59% sand, 16% silt, and 25% clay. Moreover, it contained 15 Meq/100g of soil CEC, 0.512 Meq/100g of available potassium, 2.03% of organic carbon (OC), a pH of 4.98, 0.095 percent of total nitrogen, 11.53 $mgkg^{-1}$ of available sulfur, and 14.05 mgkg-1 of available phosphorus (Table 1).

Table 1 Before planting, the experimental plot's soil's physical and chemical properties.

. Properties	Result
1. Physical properties (%)	
Sand (%)	59
Silt (%)	16
Clay (%)	25
Textural Class	Sandy clay loam
2. Chemical Properties	
pH (1: 2.5 H2O)	4.98
Organic Matter /OM/ (%)	1.90
Organic Carbon /OC/ (%)	2.03
CEC (Meq/100 g soil)	15
Total Nitrogen /TN/ (%)	0.095
Available Nitrogen/N/(mg/kg)	0.045
Available Phosphorus /P/ (mg/kg)	14.05
Available Potassium /K/ (meq/100g)	0.512
Available Sulfur /S/ (mg/kg)	11.53

Analysis of variance

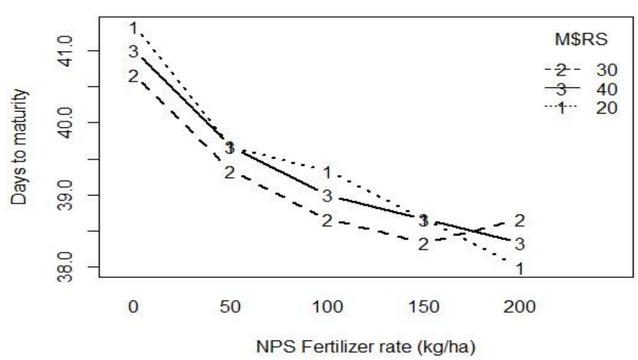
While inter-row spacing had a significant effect on leaf length, root diameter, root length, fresh biomass yield, and root yield of radish, there was a significant difference (p<0.001) in the major effects of the NPS fertilizer treatment rate on all parameters evaluated (Table 2). The fresh biomass of radish was significantly impacted by the interaction between NPS fertilizer rate and inter row spacing (p<0.001), but no significant impacts were seen for the other factors (Table 2).

Table 2: Mean square values of different agronomic characters of radish crop in response to NPS application and inter-row spacing.

Source variation	DF	Days to maturity	leaf number	Plant height	Leaf length	Root length	root diameter	Fresh biomass	Root yield
Replication	2	0.622	0.24	5.2***	1.22***	0.97	0.013	5.558**	8297360
NPS fertilizer	4	10.2**	59.44**	546.8***	131.66**	93.69**	5.374**	2.659**	996540780**
Inter spacing (IS)	2	0.289ns	0.48ns	9.67***	4.30 ***	2.51*	0.428**	1.250**	84045709*
NPS*IS	8	0.233ns	0.13ns	0.64ns	0.08ns	0.46ns	0.019ns	1.982**	28200873
Error	28	0.384	0.17	0.41	0.09	0.36	0.004	7.715	16039870
CV (%)		1.5	4.2	2.6	1.7	3.9	2.8	10.1	18.5
SE(+)		0.51	0.24	0.52	0.24	0/45	0./05	0.71	3270.1
LSD(0.05)		1.03	0.33	1.06	0.50	1.00	0.11	1.46	6697.2

** and * were significant at 1% and 5% probability levels, respectively, whereas ns stands for non-significant. DF stands for degrees of freedom and CV for coefficient of variability.

Days to maturity: The 40 cm inter-row spacing recorded the maximum maturity (41 days), which was statistically equivalent to the 39 days for 30 cm inter-row spacing. Similarly, the maturity period under the influence of NPS fertilizer rates was approximately 40 days. (Table 3; Figure 2). Therefore, this information indicates that radishes are a type of vegetable that can be grown and harvested in a relatively short period of time, typically within 30 to 41 days.



M$RS=Inter row spacing

Figure 2. The maturity of radish to different NPS fertilizers and inter-row spacing.

Radish growth

Number of leaves plant^{-1}

The number of leaves was shown to be significantly influenced (p<0.01) by the main effects of mixed NPS fertilizer rates and inter-row spacing, but not statistically significantly by their interaction (Table 2). The greatest number of leaves per plant (10.86) was produced by the maximum fertilizer treatment of 200 kg NPS ha^{-1}, while the control group had the fewest leaves per plant (6.21). The plants that had the most leaves (9.44) were separated from one another by 40 cm, while the plants that had the fewest leaves (8.50) were separated by 20 cm (Table 3; Figure 3). Thus, wider inter-row spacing recorded 11.1% increase over the radish sown at lower interspacing.

Plant height

Plant height was highly significantly (p<0.01) affected by both the main effect of blended NPS fertilizer rates and inter spacing, while their interaction was not significant (Table 2). Application of 200 kg NPS ha^{-1} produced the highest plant height (32.04 cm), whereas the control gave the lowest plant height (12.10 cm). (Table 3). The highest rate of blended NPS application increased the plant height by 62.23% over the control. On the other hand, the 40 cm inter spacing gave the tallest radish plant height (25.66 cm), which is statistically at parity with 30 cm inter spacing, while the shortest plant height (24.07 cm) was obtained from 20 cm inter spacing (Table 3), indicating smaller variation.

Table 3. Averages of the main effects of NPS and inter-row spacing on the number of radish leaves and days until maturity.

Treatment	Days to maturity	Number of leaves	Plant height (cm)
Blended NPS			
0kg	39.89	6.21e	12.10e
50kg	39.611	7.95d	23.51d
00kg	39.611	8.89c	26.58c
150kg	39.56	10.5b	29.74b
200kg	39.72	10.86a	32.04a
LSD (5%)	0.57	0.4	1.06
Inter row spacing			
20 cm	38.67c	8.50c	24.07c
30 cm	39.23b	8.70	24.65b
40 cm	41.13a	9.44a	25.66a
(LSD 5%)	0.44	0.30	1.06
CV (%)	1.5	9.41	2.6

At the 5% significance level, there is no statistical difference between the same-letter means in the same column.

Figure 3. Photo of radish leaf and root

Leaf length

Radish leaf length was significantly (p<0.01) impacted by the amount of blended NPS fertilizer and inter row spacing, but not statistically significantly by both of them together (Table 1). The plant with the largest leaves, when treated with 200 kg NPS ha^{-1} at the maximal rate, measured 19.96 inches in length. The plant with the lowest leaf length (10.63 $plant^{-1}$) was observed when no blended NPS application was used (Table 4). In the case of spacing, the 40cmspacingtreatmentproduced a maximum leaf length of 19.96 cm, while a minimum leaf length (16.03cm) was recorded for 20cm interspacing (Table 4).

Yield and yield components of radish

Root length

The main influence of inter-row spacing and NPS fertilizer rates was found to have a highly significant (p<0.01) effect on root length, but not on their interaction (Table 2). The longest radish root measured 19.02 cm in length and was grown with 200 kg ha^{-1} of blended NPS fertilizer. Using 150 kg of NPS ha^{-1} resulted in a slightly shorter radish root length of 17.80 cm. Conversely, the shortest radish root length of 11.22 cm was observed when no blended NPS fertilizer was applied (Table 4; Figure 3). The greatest root length of 15.71 cm was observed with 40 cm inter-row spacing, while a root length of 15.17 cm was recorded with 30 cm spacing (Table 4).

Table 4. The primary impact of blended NPS and inter row spacing on radish root length, root diameter, and leaf length.

Treatment	**Root length (cm)**	**leaf length**	**Root diameter**
Blended NPS			
0kg	11.22^{e}	10.63^{e}	1.513^{e}
50kg	13.08^{d}	14.92^{d}	2.39^{d}
100kg	15.21^{c}	17.61^{c}	2.66^{c}
150kg	17.80^{b}	19.39^{b}	3.24^{b}
200kg	19.02^{a}	19.96^{a}	3.48^{a}
LSD (5%)	0.59	0.28	0.07
Inter row spacing			
20 cm	14.91^{b}	16.01^{c}	2.49^{c}
30 cm	15.17^{b}	16.41^{b}	2.65^{b}
40 cm	15.71^{a}	19.96^{a}	2.83^{a}
(LSD 5%)	0.45	0.22	0.05ns
CV (%)	3.9	1.8	2.5

Means with the same letter are not significantly different at 5% probability levels.

Root diameter

Even though their interaction was not significant, the main impacts of combined NPS fertilizer rates and inter-row spacing were found to have a highly significant (P<0.01) influence on root diameter (Table 2). The maximum root diameter of 2.83 cm was recorded from 40 cm inter-row spacing, while the lowest root diameter of 2.49 cm was obtained from 20 cm inter-row spacing. The largest root diameter, 3.48 cm, was achieved by applying 200 kg NPS ha^{-1}; the smallest root diameter, 1.53 cm, was achieved by not applying NPS, indicating a 127.5% increase in root diameter (Table 4).

Root yield

The combined NPS rates and inter-row spacing had a substantial ($p<0.01$) effect on the total volume of roots produced. Moreover, there was a significant ($p<0.001$) impact of the interaction between these two characteristics on the total root production (Table 2). The maximum overall yield of 41,111 kg ha^{-1}was achieved by applying a combination of 200 kg ha^{-1} blended NPS and 40 cm inter-row spacing. Conversely, the lowest total yield of 10,979 kg ha^{-1} was obtained when there was no application of nitrogen, phosphorus, and sulfur (NPS) and plant spacing of 20 centimeters (Table 5).

Fresh biomass yield

The main effects and interaction effects of the mixed NPS fertilizer application and inter-row spacing on total biomass were found to have a significant impact, as per the analysis of variance (Table 2). The combination of 200 kg NPS ha^{-1} and 40 cm inter-row spacing produced the highest mean biomass production values, reaching 124,657 kg ha^{-1}. The lowest biomass output of 28,844 kg ha^{-1} produced with no NPS fertilizer and 20 cm inter-row spacing was surpassed by a treatment combination of 200 kg NPS ha^{-1} and 30 cm inter-row spacing, resulting in a total fresh biomass production of 122,259 kg ha^{-1} (Table 5).

Table 5. The combined effect of blended NPS and inter row spacing on fresh biomass (FBM) and root weight (RWPP) of radish in the Horro district, Western Ethiopia.

Treatment		Root weight (kg/ha)	FBM (kg/ha)
NPS rate (kg ha^{-1})	inter row spacing (cm)		
0	20	10979i	28844i
0	30	13674h	32941j
0	40	14370h	40326i
50	20	15500gh	42922i
50	30	16759gh	48654h
50	40	16900g	50430gh
100	20	20039f	53426g
100	30	21356f	61015f
100	40	24661e	66454e
150	20	25202e	74722d
150	30	26915d	76109d
150	40	33759c	83769c
200	20	37463b	95763b
200	30	41111ab	122259ab
200	40	41556a	124657a
LSD0.05		2125.9	6349.8
CV (%)		18.45	10.1

FBY=Fresh biomass yield, RWPP= root weight,

PCA-based association and representation quality of radish characteristics on PCA

The eigenvalues, percent cumulative, and variance percent of the data set are presented in Table 6. The highest eigenvalues represent the maximum variance in the data set. Thus, in this study, the first PC1 had the significantly highest eigenvalue variance (6.45) followed by PC2 (0.82), which accounts together for more than 90% of the total variation. Furthermore, the association among different variables can be visualized from the variable correlation plot. All grouped variables projected on the right side of the x-axis of the graph had high and strong positive correlation, while the fresh biomass yield (FBM) with less than 90 degrees of angle with these grouped traits on the right side of the PC plot also had positive association (Figure 4). Whereas, days to maturity showed a strong negative association with all traits displayed in the opposite direction on the right side of the x-axis.

Table 6. Eigen value variance, percent cumulative, variance percent

Dimension	Eigen value	percent cumulative	variance percent
Dim.1	6.45	80.59	80.59
Dim.2	0.82	10.30	90.89
Dim.3	0.41	5.10	95.99
Dim.4	0.17	2.13	98.13
Dim.5	0.09	1.11	99.23
Dim.6	0.04	0.46	99.69
Dim.7	0.01	0.17	99.86
Dim.8	0.01	0.14	100.00

Estimating the quality of representation of traits on factor map

The quality of representation of traits on the PC map is shown in Figure 5. Cos2 is a measure of how well the variables are represented on a factor map, and this can be visualized using the corrplot package in R. Thus, the quality of representation of traits can be estimated from Cos2 values and gradient color of traits (Figure 5). Thus, fresh biomass yield, leaf number, root diameter, leaf length, and plant height traits with an increasing intensity of red color imply high cos2 values and good representation. While blue colored traits root weight and days to maturity) had low Cos2 values and were not effectively represented on the factor map.

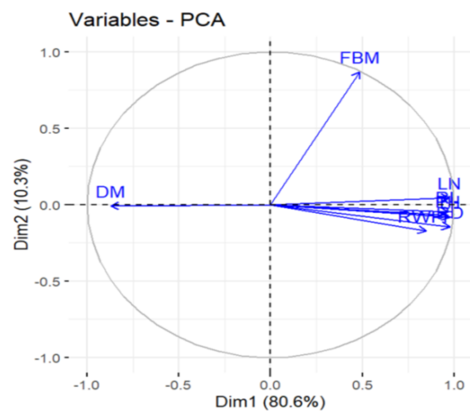


Figure 4. Variables correlation plot of radish yield and yield components.

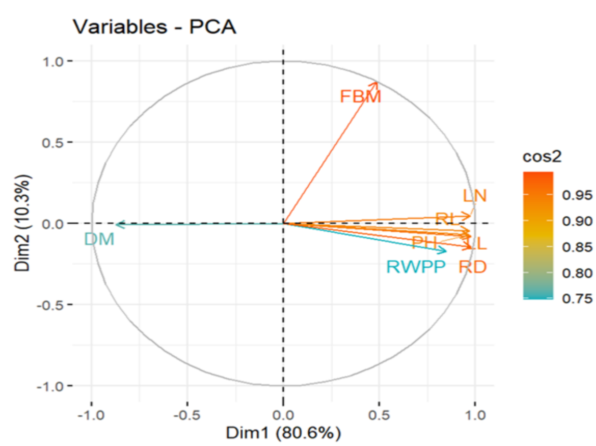


Figure 5. Quality of representation of traits colored by their Cos2 values in yield and yield components of radish.

Discussion

Soil analysis result

Radish is a short-maturing crop, specifically its roots and leaves, which are consumed by small-scale farmers; however, it is neglected by research, limiting its production and utilization. Therefore, improving the crop is useful to exploit the diverse benefits of the crop. This research was meant to observe the response of radish to the change in fertility, and plant population. Thus, the soil texture of the study area was a sandy clay loam soil (Table 1), and a modest CEC (15 Meq/100g soil) was found in the experimental soil (USDA' 1987). According to the FAO (2006) rating, there is very little potassium available (0.512 Meq/100g) (Table 1). According to EthioSIS (2014). The soil at the experimental site also has a pH of 4.98, is strongly acidic in response, and has a medium amount of total N (0.095%) and very little accessible S (11.53 mg kg^{-1}). The organic carbon (OC) level (2.03%) might be categorized as medium (Tadese, 1991). While the soil's available phosphorus concentration was medium (14.05 mg kg^{-1}) (Cottenie, 1980). The low potassium content may be due to the kaolinite clay's weak capacity to retain potassium ions and, consequently, high sensitivity to cation leaching as a result of the excessive rainfall in the research location (Mengel and Kirkby, 2001). In low-pH soils, phosphorus is attached to the surfaces of hydrous oxide, Fe oxide, and Al oxide, reducing plant accessibility (Johan *et al*., 2021). Radish grows in a variety of soil conditions, from neutral to alkaline (Fageria and Zimmermannet, 1998). The ideal soil pH for growing radishes typically falls within the range of 5.0 to 6.5 (Hazelton and Murphy, 2007). This revealed the soil's pH is suitable for radish growth; however, the major soil nutrients are deficient, requiring fertilizer application.

Phenology of radish

The maturity period of radish was generally short (about 40 days) in response to the applied NPS fertilizer and inter-row spacing, demonstrating that plants with dense populations may mature earlier due to competition for resources. Splittstoesser (1990) explained that having wider inter-row spaces reduces the competition for sunlight, water, and nutrients encouraging higher photosynthesis resulting higher amount of dry matter assimilation caused by a higher number of leaves leads to prolonged vegetative growth and delayed maturity, The short maturity period of radishes makes it suitable crop for achieving multiple cycles of production per year ultimately leading to increased land productivity per unit area and adaptable to climate change effects. Additionally, this helps to diversify income and the potential to contribute to food security, especially where malnutrition is a chronic problem (Li *et al*. 2020). Neglected crop species can play a vital role in enhancing a variety of diets and production diversity due to their rich nutrient content, profitability, resilience to climate change, and adaptability at the local.

Growth and development of radish

Moreover, in this study, an increased application of NPS fertilizer improved radish growth, as enhancing the NPS fertilizer concentration increases the availability of nitrogen influence several biochemical and physiological processes in plants, which in turn promotes plant growth by stimulating cell division and enlargement. It boosts the synthesis of protein that results in the build-up of carbohydrates and an improvement in plant growth indices (Zaman *etal*, 2011) and is involved in the content of co-enzymes, phospholipids, nucleic acids, and phosphorus, which are also necessary for metabolic activities and the synthesis of energy (Taheri *et al*., 2011). High levels of P2O5 and S contribute to the metabolic processes such as the formation of nucleic acids, phospholipids, co-enzymes, and chlorophyll, which in turn enhance the growth and development of plants (El-Shafie and El-Gamaily, 2002). From 18 cm apart radish spacing, In contrast to the current findings, Khan *et al*. (2016) reported a maximum number of leaves (41.66), root weight $plant^{-1}$ (1625 gm), root length (43.36 cm), root width (mid) (7.34 cm), and biomass (1726 g). This result coincides with Norman's (2012) report of maximum leaf length in wider interspacing, followed by narrow interspacing, and the minimum leaf length is in the minimum interspacing. Furthermore, according to Gorakh *et al*. (2021), radishes grown with 30 cm x 15 cm spacing and 120 kg ha^{-1} of nitrogen demonstrated higher growth characteristics. In the current study, plants under lower density produced a more upright growth habit than plants under wider population densities, indicating that they modify and adjust their leaf orientation depending on spacing and competition for light.

Yield and yield components

When compared to the control group, radish root length rose by 71% with a high blended NPS treatment rate (200 kg ha^{-1}). The rapid growth of roots can be credited to the abundant nutrients found in NPS fertilizer, and the nutrients were effectively used to produce more food substances, which were then sent to the growing roots, resulting in longer and wider roots (Shanu *etal,* 2019). Similarly, Mehedi *et al*. (2012) and Moniruzzaman *et al.* (2013) discovered that using higher nitrogen levels resulted in the longest roots. In this study, maximum NPS rate and wider spacing resulted in a highest root diameter and root length than the control which may be attributed to providing more nutrients may have assisted in producing a larger quantity of food substances, which were then transferred to the growing root Shanu *et al. (*2019) and El-Desuki *et al*., 2005) indicated increased nitrogen and widening spacing resulted larger radish root width and plant height. Likewise, Cole (1985) also reasoned that an enlarged radish root's diameter was due to an increased amount of phosphorus in the soil. Fertilizers containing sulfur and phosphorus encourage metabolic activities (Arif *et al*., 2016). Additionally, according to Cole (1985), an adequate supply of phosphorus resulted in good radish establishment and yield. Another study on radishes revealed that 120 kg NPK of fertilizer per hectare was ideal to achieve significant yield and yield components improvement Umar *et al*., 2017). Another finding showed that when N was supplied at a rate of 200 kg ha^{-1}, the maximum number of leaves (18.70), leaf length (33.33 cm), root length (23.77 cm), root diameter (4.43 cm), root weight (139.28 g), and yield (99.88 t ha^{-1}) were observed (Jilani *et al*., 2010).

Principal component analysis (PCA) is a powerful statistical technique for streamlining data and facilitating the interpretation of patterns and connections. PCA can be used to display the relationships between variables, identify the most significant aspects of a data set, and make data-driven decisions (Saccenti, 2024). In this study, the first two PCA with the highest eigenvalues accounted for more than 90% total variation. For standardized data, the eigenvalue is commonly applied in data analysis, like PCs, as a cutoff point for maximum variance in datasets. The relationship between variables was mirrored in the character vectors' angle, and a small angle between vectors on the plot signifies a positive correlation. There was a positive correlation as the angle between two trait vectors was less than 90 degrees (Ajaykumar *et al*., 2023). Accordingly, all grouped traits such as leaf number, leaf length, plant height, root length, root yield, and root diameter on the right side of the x-axis had high and strong positive correlation, followed by FBM (Figure 4). While there is a negative association between the two characters if their angle is more than 90 degrees, which is known as an obtuse angle (Ajaykumar et al., 2023). Hence, the days to maturity trait situated on the opposite side of the plot had a strong negative association with all traits displayed on the right side of the x-axis (Figure 4). This may be because of the short life cycle of the radish plant. A measure of how effectively the variables is represented on a factor map is called Cos2, and the corrplot tool in R was used to visualize the Cos2 of qualities in each dimension: Thus, the degree of representation on plot can also be estimated using the gradient colors of traits based on their cos2 values indicating traits with increasing intensity in red color had high Cos2 values and well representation on PC map than blue colored traits.

CONCLUSION

The findings indicated that significance (P<0.01) response of radish for maturity, quantity of leaves, thickness of roots, overall biomass production, and root yield to the applied NPS fertilizer levels and inter-row spacing, with the major effect of NPS fertilizer being significantly higher than the effect of inter-row spacing in all categories except days to maturity. Radish matures within about 40 days, of time which makes it a crop of choice for a multiple cropping system. Generally, maximum root yield (41,111 kg ha^{-1}) and fresh biomass yield (124,657 kg ha^{-1}) of radish were achieved by the combined application of 200 kg ha^{-1} NPS fertilizer and 40 cm inter row spacing. Principal component analysis showed that the first two PCA with eigenvalues of (6.45) followed by PC2 (0.82) accounted for more than 90% total variation of the dataset. Except for days to maturity, there was a positive correlation among all the traits studied, as indicated by the variables' correlation plot. The leaf number, leaf length, root diameter, fresh biomass yield, and plant height red colored Cos2 values traits had high Cos2 values and were better represented on the factor map than days to maturity and root yield traits. Thus, the results demonstrate that radish was responsive to changes in fertility and plant population, and additional agronomic studies would improve the distinct root and leaf yield potential to food security in the face of climate change.

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Conflict of interest
The authors claim that there is no conflict of interest.

Authors' contribution statement
Mohammed Ali: Conceptualization, methodology, data collection, investigation, funding acquisition, and writing the first manuscript draft Zerihun Jalata**:** Formal analysis, software, validation, supervision, revision, and final submission of the paper. Ebisa Olika Keyata: Conceptualization, supervision, validation, and reviewing.

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