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Evaluating the response of different synthetic and organic fertilizers on carrot vegetative and reproductive characteristics in Gothgaun, Nepal

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A B S T R A C T

This research aimed to assess the influence of various chemical and organic fertilizers on the vegetative and reproductive characteristics of the 'New Kuroda' variety of carrots (*Daucus carota*). The study included the recommended dose (RD) of NPK (80:60:60 kg ha^{-1}), individual components of N (80 kg ha^{-1}), P (60 kg ha^{-1}), and K (60 kg ha^{-1}), as well as organic sources such as goat manure (15 tons ha^{-1}), Farmyard manure (FYM) (20 tons ha^{-1}), and a control group without any fertilizer. Growth and reproductive traits were measured at 45, 55, 65, 75, and 85 days after sowing. The results indicated that the recommended NPK dose consistently outperformed other fertilizer sources, enhancing both vegetative and reproductive parameters. The highest yield of 10.94 tons ha^{-1} was achieved with NPK fertilizer, whereas organic sources such as goat manure demonstrated the second-highest growth and development traits. The control group exhibited the lowest growth and development parameters. These results show that these fertilizer sources considerably influence the vegetative and reproductive development of the 'New Kuroda' carrot variety. The outcomes indicate how various fertilizer sources may significantly improve the vegetative and reproductive growth of the 'New Kuroda' carrot; the recommended dosage of NPK in conjunction with the supply of goat manure stands out as an appropriate technique for producing carrots. This illustrates how applying a balanced dosage of these fertilizers may lead to increased carrot yield.

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1. Introduction

The carrot, formally known as *Daucus carota* L., is an Apiaceae family member with a chromosome number of 2n=18 (Yadav et al., 2021). This widely planted cool-season root vegetable is usually grown in temperate areas in the spring and summer months, wheras it is grown in tropical locations during the winter (Ahmed et al., 2014). Carrots are a worldwide popular crop, praised for their nutritionally dense roots, which are particularly high in fiber and beta-carotene a necessary precursor to vitamin A (Valšíková-Frey et al., 2021). A diversity of hues may be observed in carrot roots, including white, yellow, orange, red, purple, and dark purple. The flesh of the cultivated types was originally purple and yellow (da Silva Dias, 2014). Rich in nutrients such as carotene, thiamin, riboflavin, iron, calcium, and phosphorus, carrots may be used in a variety of culinary applications, including salads, soups, stews, and curries, as well as pickles, jams, and sweets (Afrin et al., 2019). Carrots have several therapeutic uses in addition to being used in food; they are a diuretic, intestinal cleanser, remineralizer, anti-diarrhea, tonic, and anti-anemic agent (Bahadur et al., 2015). Rich in alkaline components, carrots cleanse and revitalize the blood, providing antioxidants that promote heart health, stave against heart disease, and have anti-tumor effects (Agbede et al., 2021).

In Nepal, during 2078/79, carrot cultivation covered 3,354 hectares, yielding 37724.9 metric tons at a productivity of 11.18 metric tons per hectare (MoALD, 2022). However, the country faces lower yields compared with other carrot-producing nations, attributed to insufficient agro-technical knowledge concerning irrigation intervals and judicious fertilizer application (Kiraci et al., 2018). The overuse of inorganic fertilizers in modern agriculture has harmed the ecology and soil (Kiran et al., 2022). Lately, there has been a growing trend in utilizing organic fertilizers such as farmyard manure (FYM), vermicompost, poultry manure, neem cake, and goat manure to improve crop yield and maintain soil fertility, as noted by Yadav et al. (2023a). The quantity of soil organic carbon (C) is affected differently over the long term by the utilization of nitrogen (N), phosphorus (P), and potassium (K), which are affected by cropping patterns, soil variances, and environmental conditions (Ahmad et al., 2016). NPK, with a particular emphasis on nitrogen, is a crucial nutrient for plant growth, significantly impacting crop development and yield, as highlighted by Mandal et al. (2023). Global research efforts are focused on finding alternatives such as green manures, legumes, and organic materials to generate food that is on par with that produced using inorganic fertilizers (Zakir et al., 2012). Katel et al. (2023) found that excessive use of NPK can lead to a decrease in crop productivity. Additionally, Yadav et al. (2022a) stated that overuse of manure like poultry manure can result in contamination of crops, soil, or water. Numerous research studies have demonstrated how well farm manure and other organic nutrient supplies may increase soil fertility, crop yields, and soil water-holding capacity (Suswadi et al., 2022).

A significant movement toward organic farming is underway worldwide to lessen the harmful effects of synthetic pesticides and fertilizers have on the environment and human health (Shakeel et al., 2021). When it comes to growing vegetables, the use of vermicompost or organic manure in nutrient management systems has recently gained (Ahmed et al., 2014). Organic manure is essential for improving soil health over the long term and reducing crop production costs, which makes it important in both Nepalese and global settings (Agbede et al., 2021). Additionally, according to Yadav et al. (2023b), the importance of soil biota in improving soil quality, supporting plant health, and enhancing soil resilience is significant. Furthermore, the presence of beneficial microorganisms is essential for maintaining soil fertility, enhancing plant resilience, and promoting overall crop health (Yadav et al., 2023c). While inorganic fertilizers quickly provide nutrients to fulfil crop demands, organic fertilizers gradually release minerals to promote vigorous plant development (Lamichhane et al., 2022). Carrot yields increase when inorganic fertilizers are mixed with organic manures (Chen et al., 2020). One important aspect of managing soil is applying fertilizer, which has a major impact on increasing soil fertility in agricultural activities (Afrin et al., 2019). Consumers of vegetables like organic farming because it improves the quality of their product and worries about the harmful effects of inorganic fertilizers on health are driving this trend (Dawuda et al., 2011). Consequently, many farmers have shifted to organic farming, motivated by the greater market value of organic goods in addition to health concerns (Havlin and Heiniger et al., 2020). The goal of this research is to investigate the effects of different chemical and organic fertilizer sources on carrots' vegetative and reproductive growth of carrots. In addition, identified the best source of organic fertilizer that might increase carrot productivity and associated characteristics.

2. Materials and methods

2.1. Experimental site

The field experiment, which was conducted at G.P Koirala College of Agriculture and Research Centre in Sundarharaicha, Morang, Nepal, from August to November 2023, sought to evaluate the yield of the 'New Kuroda' carrot variety. The tropical climate in the region is characterized by an average annual temperature ranging from 18.81 to 33.46 °C and an annual precipitation of 858.75 mm. The geographical coordinates are 26⁰ 40' 49.9" N latitude, 87⁰ 21' 16.7" E longitude, and an elevation of 149 m. A soil test kit was used for soil analysis; Table 1 contains more information about the product. The highest and lowest average temperatures reported during the research period were 36.74 °C and 20.44 °C, respectively, with an average precipitation of 211.09 mm (Figure 1). This study concentrated on assessing the vegetative and reproductive characteristics of the 'New Kuroda' carrot variety, which matures 85–100 days after planting and is well-known for its wonderful sweetness and ultra-fine texture.

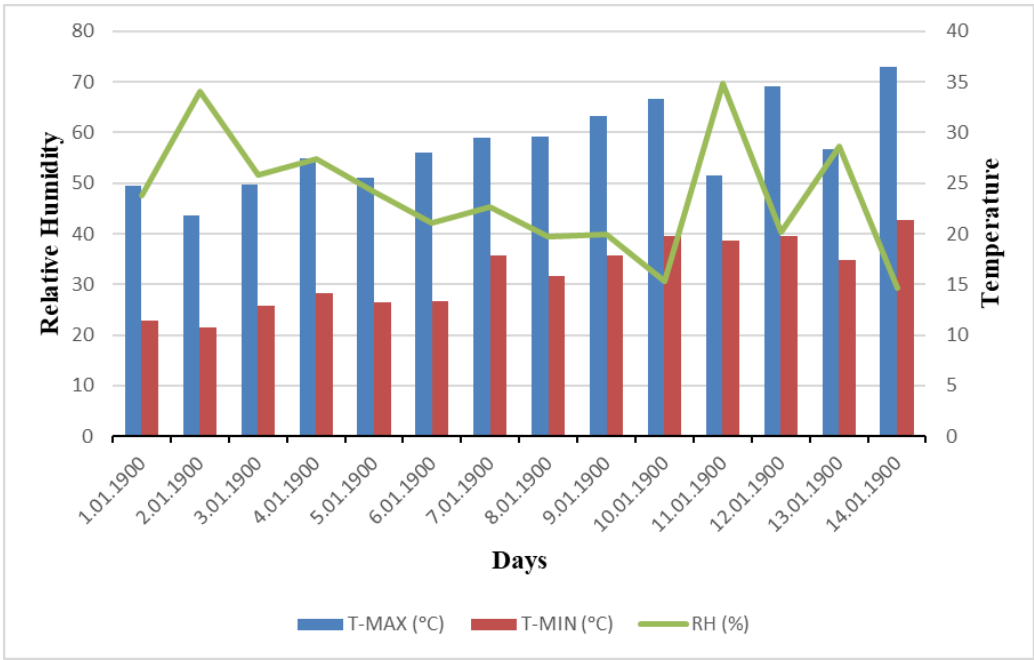

Figure 1. Meteorological data of the study site during the research period

Table 1. Soil Characteristics of Experimental site

Serial Number	Soil Characteristics	Properties
1	Nitrogen	Slightly High
2	Phosphorous	Medium
3	Potassium	Medium
4	Soil pH	6.2
5	Soil texture	Loamy soil

2.2. Research design and cultural practices

The study was designed as a Randomized Complete Block Design (RCBD), with seven treatments replicated three times for 21 plots (Yadav et al., 2022b). Each plot, measuring 3 m2 (2 m*1.5 m), contributed to a total area of 150 m2. A 1 m gap separated the two replications, but the distance between treatments remained constant at 0.5 m. Each plot comprised 100 plants with 30 cm row-to-row spacing and 10 cm plant-to-plant spacing. Organic fertilizers were administered during field preparation, whereas chemical fertilizers were added during seed sowing.

The complete phosphorus and potassium doses, along with half of the nitrogen dose, were administered during the sowing period, while the other half of the nitrogen dose was applied after the initial weeding. Manual weeding was conducted to manage weed growth, followed by irrigation. Irrigation was implemented during the early growth stage, flowering, and fruit development phases. The details of all treatments and their respective doses employed in our research are outlined in Table 2.

Table 2. List of treatments and their doses

Serial Number	Treatments	Symbol	Doses
1	RD of NPK	T1	80: 60: 60 kg ha^{-1}
2	N	T2	80 kg ha^{-1}
3	P	T3	60 kg ha^{-1}
4	K	T4	60 kg ha^{-1}
5	FYM	T5	20 t ha^{-1}
6	Goat manure	T6	15 t ha^{-1}
7	Control	T7	untreated

Note; RD; recommended dose, N; Nitrogen, P; Phosphorous, K; Potassium, FYM; farmyard manure

2.3. Data collection

Twelve plants were chosen randomly from each experimental plot to acquire the relevant data. The data were obtained at 10-day intervals. Plant height, leaf number, root length, fresh shoot weight, root diameter, dry shoot weight, and yield were all measured for both vegetative and reproductive growth.

2.4. Statistical analysis

For both replication and treatment blocks, raw data were input using MS Excel 2021 (Microsoft Corporation, Washington, USA) chronologically. Then, using statistical software (R Studio, Version 4.2.2, Boston, Massachusetts, USA), analysis of variance (ANOVA) was performed. Duncan's Multiple Range Test (DMRT) was used to compare mean values among different treatments at a significance level of 5%. Regression analysis was also performed.

3. Results and discussions

3.1. Effects of different fertilizer sources on vegetative growth parameters

The variety 'New Kuroda' showed the significant variation in vegetative growth among different fertilizer sources after application, which is clearly noticeable from the results presented in Table 3. The results revealed that among the several treatments used in the study, the recommended dose of NPK exhibited the highest value for plant height, which is 20.41 cm initially at 45 days after sowing, which follows the positive growth trends and attains a maximum height of 44.53 cm at 85 days after sowing. The study conducted by Afrin et al. (2019) reported that inorganic fertilizer (NPK) in combination with organic fertilizer yielded the highest plant height of 47.58 cm at harvest. This result is found to be almost similar to our findings. This can be due to the recommended dose of NPK supplying the optimal amount of essential nutrients such as nitrogen, phosphorus, and potassium, thus fostering robust growth and maximizing carrot plant height. Similar results were also concluded in the study by Kiran et al. (2022). Katel et al. (2021) found that super combined fertilizer releases its active ingredients gradually, a characteristic that proves beneficial in the agricultural sector.

Likewise, goat manure and the recommended dose of Nitrogen and phosphorous recorded the second highest plant height and number of leaves after their application, which is 42.25 cm, 38.80 cm, 38.72 cm, and 10.90, 11.20, and 10.93, respectively. This result is very close to the findings given by the previous study carried out by Kiran et al. (2022) and Smoleń et al. (2014). After applying goat manure and the required amounts of nitrogen and phosphorus, carrot plants develop more vigorously because of increased soil fertility and nutrient availability, which results in increased plant height and leaf count. Farmyard manures exhibited the average plant height and leaf number as compared to other chemical fertilizers and goat manures. Initially, FYM records 15.01 cm plant height and 5.43 leaf numbers which increases and gives a final plant height of 38.53 cm and 10.56 leaves number as given in Table 4.

Table 3. Effects of various sources of fertilizers on plant heights of carrots

Treatments	Plant height (cm)					
	45DAS	55DAS	65DAS	75DAS	85DAS	Pooled
NPK	20.41^{a}	31.88^{a}	40.78^{a}	42.16^{a}	44.53^{a}	35.95^{a}
Goat manure	17.31^{bc}	29.57^{ab}	40.16^{a}	41.69^{a}	42.25^{ab}	34.19^{ab}
N	18.92^{ab}	29.73^{ab}	35.87^{ab}	38.26^{ab}	38.80^{bc}	32.32^{abc}
P	16.80^{bc}	26.68^{bc}	34.81^{b}	38.20^{ab}	38.72^{bc}	31.04^{bc}
K	14.33^{c}	22.72^{c}	31.34^{bc}	37.63^{ab}	37.89^{bc}	28.78^{c}
FYM	15.01^{c}	25.43^{c}	33.15^{bc}	38.05^{ab}	38.53^{bc}	30.02^{c}
Control	9.17^{d}	18.29^{d}	28.27^{c}	32.29^{b}	34.64^{c}	24.53^{d}
Grand mean	15.996	26.319	34.914	38.328	39.34	30.979
CV %	9.933	8.608	7.587	8.512	6.604	6.388
SEM (±)	0.823	1.110	1.078	0.946	0.846	0.894
F-test	***	***	***	*	*	***

* Significant at 5% level of significance. ** Significant at 1% level of significance. *** Significant at 0.1% level of significance. NS: Non-significant. SEM: Standard error of the mean. CV: Coefficient of difference. PH: Plant height.

According to Ahmed et al. (2014), they concluded that the average plant height was given by FYM which supports our findings. The slow release of nutrients from farmyard manure promotes consistent carrot development, as shown by the plants' increased height and leaf counts. The lowest results were recorded in the control in which no fertilizers were applied. The lowest plant height was 9.17 cm at 45 DAS which grew slowly and reached at maximum height of 34.64 cm. Similarly, the overall mean plant height and leaf number at harvest time were recorded as 39.34 cm and 10.64 respectively. Overall, the results showed that vegetative growth followed a positive growth trend in terms of both plant height and leaf number among the several treatments used in the study. The results were highly significant at 0.1% level of significance. These findings were also supported by the previous study by Kiran et al. (2022) and Kiraci et al. (2018). The lowest plant height and leaf number in the control may be due to insufficient nutrient supply, hindering overall growth.

Table 4. Effect of various sources of fertilizer on the number of leaves in carrot

Treatments	Leaf numbers (LN)					
	45DAS	55DAS	65DAS	75DAS	85DAS	Pooled
NPK	6.00^{a}	8.13^{a}	10.16^{a}	11.10^{a}	11.83^{a}	9.44^{a}
Goat manure	5.96^{a}	7.60^{ab}	9.23^{b}	9.73^{bc}	10.90^{ab}	8.68^{a}
N	5.86^{a}	7.13^{abc}	8.80^{bc}	9.33^{bc}	11.20^{ab}	8.46^{bc}
P	5.90^{a}	7.56^{ab}	8.73^{bc}	9.80^{b}	10.93^{ab}	8.58^{b}
K	5.33^{a}	6.93^{bc}	8.63^{bc}	9.26^{bc}	10.20^{b}	8.07^{d}
FYM	5.43^{a}	6.96^{bc}	8.36^{c}	9.23^{c}	10.56^{b}	8.11^{cd}
Control	4.03^{b}	6.10^{c}	7.33^{d}	8.20^{d}	8.86^{c}	6.90^{e}
Grand mean	5.504	7.204	8.752	9.523	10.642	8.325
CV %	6.772	8.047	4.687	2.979	5.277	2.400
SEM (±)	0.167	0.177	0.197	0.200	0.219	0.172
F-test	***	*	***	***	***	***

* Significant at 5% level of significance. ** Significant at 1% level of significance. *** Significant at 0.1% level of significance. NS: Non-significant. SEM: Standard error of the mean. CV: Coefficient of difference. LN: Leaf number

3.2. Effect of different fertilizer sources on reproductive growth parameters

Tables 5 and 6 illustrate the response of several reproductive parameters to the different fertilizer sources used in the study, such as fresh shoot weight, fresh dry weight, dry shoot weight, dry root weight, root length, root diameter, shoot diameter, and ultimate yield. The results recorded significant variation among these metrics, except for dry root weight and shoot diameter. The 'New Kuroda' variety of carrot treated with the recommended dose of synthetic fertilizer, NPK records the highest reproductive growth among all above mentioned parameters. The highest fresh and dry shoot weights were observed in the NPK treatment at 61.06 g and 9.03 g, respectively. Following closely were the weights from goat manure at 41.23 g and 8.40 g, and then the recommended nitrogen quantity at 44.26 g and 8.00 g.

Contrary to our findings, Kiran et al. (2022) reported the highest fresh plant weight (128.00 g) with the combined application of chemical (NPK) and organic fertilizers. Discrepancies between their results and ours could be attributed to variations in soil composition, climate conditions, and microbial activity, influencing nutrient availability. Additionally, differences in fertilizer application rates, timing, and sources may also contribute to variations in plant growth, underscoring the influence of environmental and fertilizer management practices. The second highest fresh shoot weight was recorded by the recommended dose of Nitrogen that is (44.26 g). This result is in parallel with the findings reported by Smoleń et al. (2014). This is due to the optimal nitrogen dose that boosts plant growth, enhancing proper development and biomass accumulation. The lowest value for fresh shoot weight was recorded in the control treatment by Kumar et al. (2023), and this result is similar to our findings with treatments without any fertilizer application. It may be because the absence of fertilizer leads to nutrient deficiency, hindering plant growth and reducing fresh shoot weight. Similarly, the highest Fresh & dry root weights were noticed in the recommended dose of NPK followed by the recommended dose of nitrogen and goat manures. This result is well supported by the previous study carried out by Kiran et al. (2022) and Colombari et al. (2018). This is because of the optimum application of NPK and goat manures which contain essential nutrients, promoting robust root development, and ensuring increased fresh and dry weight of roots. When subjected to farmyard manure application, this particular variety exhibits favorable responses, demonstrating significant improvements across various reproductive characteristics. The fresh and dry weights provided by farmyard manure closely resemble those from goat manure. This similarity arises from the fact that farmyard manure enhances soil with organic material, replicating the nutrient effects of goat manure and resulting in comparable fresh and dry weights in plant development. Findings from researchers Hussain and Kerketta et al. (2023) and Kiraci et al. (2018) align closely with our observations using farmyard manure.

Table 5. Effect of various sources of fertilizers on the reproductive growth of carrot

Treatments	FSW (g)	FRW (g)	DSW (g)	DRW (g)
NPK	61.06^{a}	89.06^{a}	9.03^{a}	11.56^{a}
Goat manure	41.23^{b}	68.98^{ab}	8.40^{a}	10.20^{ab}
N	44.26^{b}	69.06^{ab}	8.00^{a}	8.75^{abc}
P	35.50^{b}	60.33^{ab}	7.25^{ab}	8.93^{abc}
K	35.30^{b}	49.95^{bc}	6.68^{ab}	7.20^{bc}
FYM	35.73^{b}	66.66^{ab}	5.52^{bc}	7.51^{bc}
Control	31.13^{b}	28.79^{c}	3.82^{c}	5.48^{c}
Grand mean	40.604	61.836	6.958	8.520
CV %	20.736	27.283	18.240	24.404
SEM (±)	2.545	5.017	0.441	0.597
F-test	*	*	**	NS

* Significant at 5% level of significance. ** Significant at 1% level of significance. *** Significant at 0.1% level of significance. NS: Non-significant. SEM: Standard error of the mean. CV: Coefficient of difference. FSW: Fresh shoot weight. FRW: Fresh root weight. DSW: Dry shoot weight. DRW: Dry root weight.

Synthetic fertilizers provide precise nutrient control, boosting initial growth, while organic sources such as compost enhance soil structure, microbial activity, and nutrient retention, collectively promoting robust reproductive parameters in carrots Havlin and Heiniger et al. (2020), and Ahmad et al. (2016). Application of these fertilizers has a major impact on carrot yields in terms of root length, root diameter, shoot diameter, and overall yield. In terms of reproductive measures such as root length at a significance level of 5%, root diameter at a significance level of 1%, and yield at a significance level of 0.1%, the findings were highly significant across several fertilizers. This is consistent with the outcomes suggested by the previous study by Ige et al. (2019) and Kiran et al. (2022). The highest root length (21.52 cm), root diameter (2.63 cm), shoot diameter (0.41 cm), and yield (10.94 tons ha^{-1}) were observed on the recommended dose of fertilizers, followed by the recommended dose of nitrogen, goat manure which is clearly presented in table 6. The reasons behind this are because of timely available of essential nutrients as released by NPK and goat manure is highly rich in organic matter as well as essential nutrients, which further boosts initial growth ensuring rapid developments of reproductive traits in carrots resulting in highest root length, diameter, shoot diameter, and yields.

According to the Kiran et al. (2022), they concluded that the recommended dose of synthetic fertilizers along with organic amendments plays a significant role in the proper development of reproductive traits, which is also superior as compared to other fertilizer sources. This shows that their results agree with our findings suggesting that synthetic fertilizers along with organic amendments may be the suitable fertilizers sources for effective growth and developments of carrot crops. The yields recorded by farmyard manures and phosphorous were similar to the average yield of carrot among all treatments showing that using these fertilizers in combination might give better results. The lowest yield was recorded in the control group, in which no fertilizer was applied. This lowest yield is because of the lack of essential nutrients that plants require during growth and development, hindering plant overall growth and thus reducing the final yield in carrot. These results are also supported by several studies carried out by Hussain & Kerketta et al (2023), Afrin et al. (2019) & Kiran et al. (2022). Additionally, Adhikari et al. (2023) and Sangam et al. (2023) both noted that organic fertilizers have the potential to significantly enhance crop productivity. Therefore, Goat manure governed better yield production after NPK combined, which reflects partial agreement with the aforesaid findings.

Table 6. Effect of different sources of fertilizer on the reproductive parameters of carrot

Treatments	RL (cm)	RD (cm)	SD (cm)	Yields (ton^{-1}ha)
NPK	21.52^{a}	2.63^{a}	0.41^{a}	10.94^{a}
Goat manure	19.10^{abc}	2.46^{ab}	0.34^{ab}	9.53^{ab}
N	19.77^{ab}	2.40^{ab}	0.33^{ab}	9.37^{ab}
P	18.27^{bc}	2.35^{ab}	0.30^{ab}	7.95^{bc}
K	17.97^{bc}	2.11^{b}	0.25^{b}	4.93^{de}
FYM	18.84^{bc}	2.31^{ab}	0.26^{b}	6.13^{cd}
Control	17.00^{c}	1.74^{c}	0.23^{b}	3.80^{e}
Grand mean	18.926	2.288	0.302	7.523
CV %	6.916	9.148	22.744	14.327
SEM (±)	0.378	0.071	0.018	0.578
F-test	*	**	NS	***

* Significant at 5% level of significance. ** Significant at 1% level of significance. *** Significant at 0.1% level of significance. NS: Non-significant. SEM: Standard error of the mean. CV: Coefficient of difference. RL: Root length. RD: Root diameter. SD: Shoot diameter.

3.3. Regression analysis

The scatter diagram and linear regression equation are shown in Figure 2, along with the coefficient of determination (R2) and the fitted simple regression line of Y (Yield) on independent variables X (plant heights, root length, root diameter, leaf number, fresh root weight, fresh shoot weight). Carrot yields and all independent variables show substantial linear connections, as the findings demonstrate. The degree of correlation between the variables and the yield variance that can be accounted for by each variable is shown by the R2 values. Plant height (73%) followed by root length (49%), root diameter (57%), leaf number (63%), fresh root weight (53%), and fresh shoot weight (26%) were the parameters that contributed most to the overall carrot fruit output among those examined. The significance of length and fresh weight of root is emphasized as they are identified as the most important quality parameters for carrots, as indicated by the highest R2 values in this study. However, it is noted that despite these parameters being identified as significant contributors to carrot yield, the applications (presumably referring to the use of different fertilizers) did not show a significant impact compared to the control, as indicated by the lowest R2 values for these parameters. Other factors that may have contributed to the remaining amount include the study's fertilizer dosages, irrigation schedules, planting dates, and weed management strategies. A higher R2 value denotes a more accurate depiction of the link between the independent variables and carrot yields, showing a better fit of the regression line to the data. Overall, as Figure 2 makes evident, the most significant factors for increased carrot fruit output of the 'New Kuroda' variety were plant height, leaf count, and root diameter.

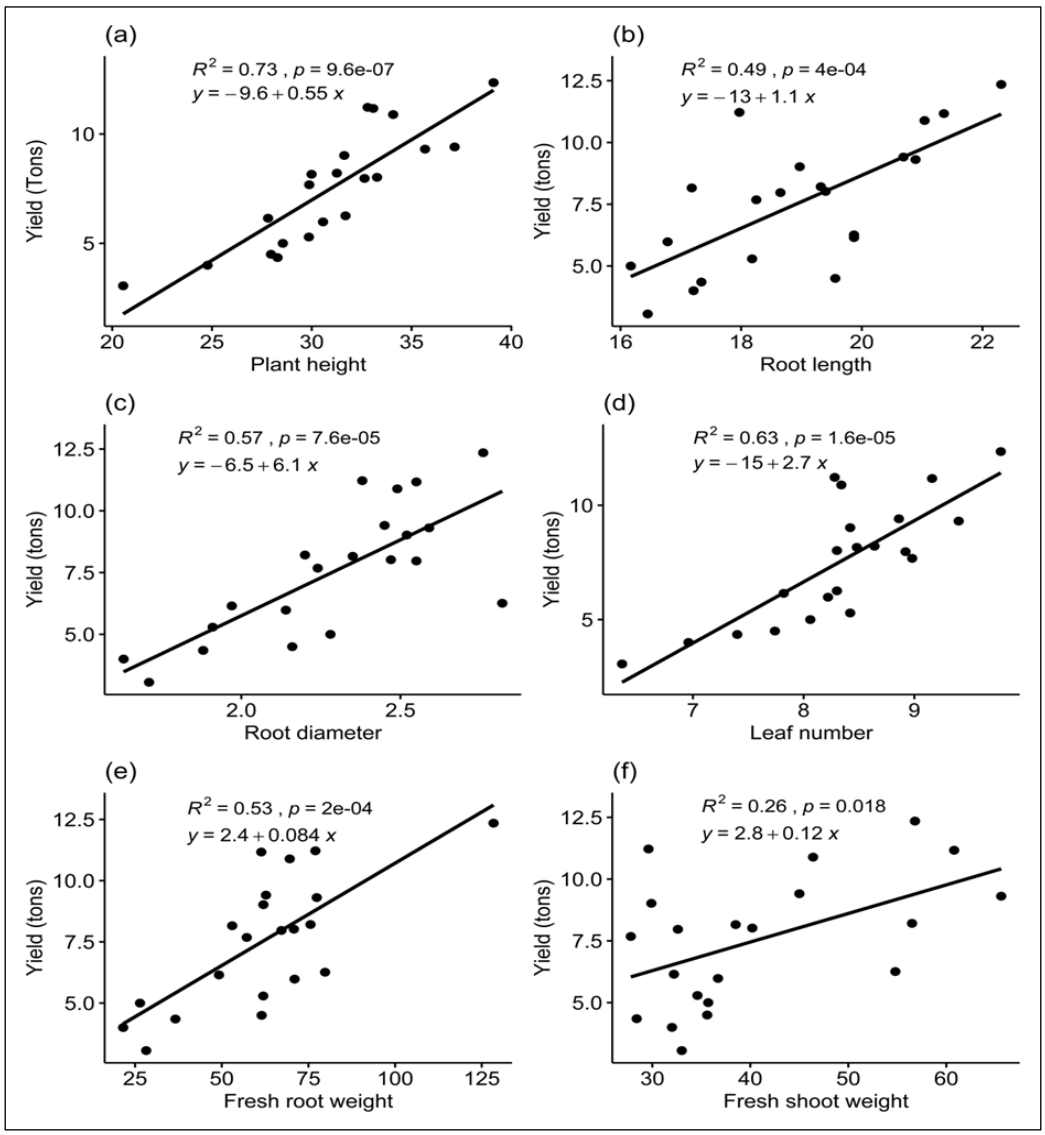

Figure 2. A scatter diagram, the linear regression equation, the coefficient of determination (R2), and the fitted simple regression line of Y (Yield) on X [(a)Plant heights (cm), (b)Root length (cm), (c)Root diameter (cm), (d)Leaf number, (e)Fresh root weight (g), (f)Fresh shoot weight (g)].

5. Conclusion

In conclusion, this study reveals a clear superiority of the recommended NPK dose in optimizing both vegetative and reproductive parameters, resulting in the highest yield of 10.94 tons ha^{-1} for the 'New Kuroda' carrot variety. Organic sources, particularly goat manure, demonstrated commendable growth and development traits, securing the second-highest performance. Notably, the control group exhibited the least favorable outcomes. These findings emphasize the substantial positive impact of NPK and organic fertilizers on the growth of 'New Kuroda' carrots. The study suggests using balanced synthetic fertilizer and organic additions, such as goat dung, in modern agricultural practices as an environmentally responsible way to boost carrot crop yields. This research emphasizes the effectiveness of using NPK in conjunction with goat dung, emphasizing these methods as essential strategies for obtaining strong carrot yields. This study highlights how a balanced fertilizer programme may greatly increase carrot output and offers important new information for sustainable farming methods.

Compliance with Ethical Standards

Conflict of Interest

The authors declare that they have no conflict of interest.

Authors' Contributions

Dipesh Kumar MEHATA: Conceptualization, Funding acquisition, Validation, Visualization, Supervision, Investigation, Methodology, Resources, Software, Writing – review & editing: **Reema ISHWAR, Bina Kumari SAH, Sushma NEUPANE, Anish SUBEDİ, Sangita Puwar MAGAR**: Data curation. **Ravi ACHARYA**: Investigation, Supervision, Writing – review & editing. **Rupesh Raj YADAV, Jyoti KHATI, Abhishek Kumar SAH, Arzu CHAUDHARY**: Writing – original draft. All authors have read and agreed to the published version of the manuscript.

Ethical approval

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Data availability

Not applicable.

Consent for publication

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