ISSN 2518–2021 (Print) 2415–4474 (Electronic)

Fundamental and Applied Agriculture

Journal home page: https://www.f2ffoundation.org/faa/index.php/home

Vol. 8(4), pp. 717 – 729: 2023, doi: https://doi.org/10.5455/faa.169660

HORTICULTURE | ORIGINAL ARTICLE

Response of Carrot (*Daucus carota* Linn.) to Different Doses and Sources of Nitrogen in Sindhuli, Nepal

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ARTICLE INFO

Article history
Received: 16 Sep 2023
Accepted: 31 Oct 2023
Published online: 31 Dec 2023

Keywords
Carrot,
Farmyard manure,
growth,
Inorganic,
Yield

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ABSTRACT

As a root crop known for its substantial nitrogen requirements, carrot responds well to both organic and inorganic fertilizers that supply different amounts of nitrogen. This study aimed to assess the efficacy of various proportions of farmyard manure (FYM) and recommended dosages of chemical fertilizers (RDF) in carrot production to address the issues posed by their sole use. A Randomized Complete Block Design (RCBD) was used to plan the field study, which consisted of five treatments and five replications with different nitrogen rates and sources, viz., T1 (100% FYM), T2 (25% RDF+75% FYM), T3 (50% RDF+50% FYM), T4 (75% RDF+25% FYM), and T5 (100% RDF) during December 2019 to April 2020 in the tropical region of Sindhuli, Nepal. Among the treatments, T3 exhibited the earliest germination (7.60 DAS) and the most desirable plant height (42.61 cm), root length (20.41 cm), root diameter (3.01 cm), fresh root weight plant^{-1} (96.04 g), total root dry matter content (15.01%), root biomass plant^{-1} (55.44 g), and total biomass plant^{-1} (85.33 g) at harvest. However, T5 resulted in the highest leaf count plant^{-1} (8.6) and fresh foliage weight plant^{-1} (42.96 g) at harvest. Similarly, T3 was significantly higher for quality parameters, such as cortex diameter (1.36 cm), pH (6.72), TSS (12.48 ^{0}Brix), TA (0.22 g liter^{-1}), and organoleptic score (7.60). Although there were minimal root disorders in T3 (17%), T1 also had insignificant cases of cracking (8%) and postharvest weight loss (1.63%). Thus, reducing nitrogen input from the recommended dose and adding FYM improves carrot yield, quality, and shelf life. Furthermore, this guarantees higher economic returns with a B:C ratio of 1.65. Despite these positive results, the efficacy of the tested nutrient combinations needs to be analyzed on a larger scale, as well as in different ecological regions.

1. Introduction

Carrot (*Dacus carota* L.) is a cool-season crop belonging to the family Umbelliferae (Wang et al., 2015). Phylogenetically, carrots are derived from wild carrots, which are likely to have originated from Pakistan, Iran and Afghanistan (Domblides & Domblides, 2023). Carrot is supposed to be originated from the wild form of subspecies *Daucus carota* sp. *carota* (Britanica, 2023). It is primarily grown as a yearly crop in the tropics, despite the fact that it is physiologically a biennial crop (TNAU, 2013). It grows vegetatively in the first year, producing leaves and roots, and then in the second year, it produces fresh growth and flowers while using the roots as its reserve organ (Miller, 2023; Wang et al., 2015). It is particularly a cold climatic crop, but has a high degree of tolerance to relatively higher temperature ranging from 15.6ºC to 21.1ºC (Barnes, 1936). In Nepal, it is cultivated during the winter months of October/ November (AITC, 2019). It is grown worldwide as a typical vegetable crop (Mehedi et al., 2012). Globally, China is the top carrot producer followed by Uzbekistan, Russia, USA and other countries (Eric, 2011). It is also the most important winter season root crop in Nepal following radish. Carrots are grown on a total of 2,846 hectares of land, yielding a total of 31,06 Mt. The national average yield of carrot is 10.92 Mt ha^{-1} (MoALD, 2019). The varieties of carrot recommended for different agroclimatic regions of Nepal are New Kuroda (OP), Nepa Dream (F1), Sigma (F1), Nantes forte and Kuroda Mark II N (F1) (SQCC, 2022).

Regarding carrots as human nutrition, Handelman (2001) suggested that carrots are often used by people in diet primarily because of richness in vitamins and minerals. Carrots contain carotenoids, polyphenols, and vitamins, which serve as antioxidants and anticarcinogens, and boost the immune system, validating an old wives' tale that carrots are good for your eyes (Dias, 2014). In every 100 grams of ingredients, there are approximately 8285.0 mg

Cite This Article
Yadav, M., Ghimire, S., Dhital, M., Tharu, R.K. 2023. Response of Carrot (*Daucus carota* Linn.) to Different Doses and Sources of Nitrogen in Sindhuli, Nepal. *Fundamental and Applied Agriculture*, 8(4): 717–729. https://doi.org/10.5455/faa.169660

ß-carotene, 3477.0 mg α-carotene, and 1.0 µg lycopene (Handelman, 2001). Carrot has diuretic and digestive effects, is helpful for uterine stimulation and increasing the volume of urine, and simultaneously promotes skin and eye health (Sarfaraz & Farooq, 2016). Carrot extracts, which are high in antioxidants, reported to have an essential role in disease prevention (Que et al., 2019). Additionally, carrot may have antidiabetic, restorative, hepatoprotective, and retinoprotective properties, thereby proving effective against cholesterolemia and possible occurrences of cardiovascular illness (Varshney & Mishra, 2022). It is used mainly for culinary purposes such as salad and as cooked vegetable in soups, stews, curries, etc. and is also used for the preparation of pickles, jam, and sweet dishes (Varshney & Mishra, 2022; Wani & Prasad, 2015).

Carrot is mainly a heavy feeder crop that removes about 100 kg of nitrogen (N), 50 kg of phosphorous (P), and 180 kg of potassium (K) per hectare (Schollar & Robber, 1985). Therefore, the production and nutritional value of carrots are greatly influenced by soil properties and nutrient profiles, in addition to cultivars and existing climatic factors. However, the doses and timing of nitrogen is the key to the yield and quality in carrot cultivation. It encourages plant growth, including the development of leaves and stems, as well as an increase in protein synthesis (Sammauria et al., 2009). Both the organic and inorganic nutrients have potential roles on crop growth and development (Ghimire & Chhetri, 2023). Farmyard manure (FYM), poultry manure, pig manure and vermicompost are some of the most common organic fertilizers used in vegetable farming (Khanal, 2018). The application of organic fertilizers is commendable as an economic supplement to synthetic fertilizers, as well as for the long- term preservation of soil fertility status and productivity (Ghimire & Chhetri, 2023; Mnthambala et al., 2022). FYM is not necessarily a rich source of nutrients, but enhances the organic carbon content in the soil thereby boosting its physical properties (Rani & Mallareddy, 2007). These organic nutrients not only reduce the amount of chemical fertilizers but also improve soil fertility (Chumyani et al., 2010). The regular use of organic manures and fertilizers are also preferred owing to its constructive effects on soil physical and chemical properties of soil along with slow but steady release of nitrogen, phosphorous, potassium and soil organic carbon (SOC) (Zhang et al., 2009). Long-term usage of organic manure enhances soil fertility by increasing the capacity of the soil to hold onto water (Ramesh et al., 2005). However, organic manures alone may not fulfill the amount of nutrients required by the high yielding varieties due to low nutrient contents and slow release of nutrients.

In this regard, the application of organic manures, some chemical fertilizers such as di-ammonium phosphate (DAP), urea and muriate of potash (MOP), has been the main practice for maintaining soil fertility (Pilbeam et al., 2005). Organic manures, despite bulk in nature were preferred due to easy availability in the hills (Pilbeam et al., 2005). However, the majority of farmers preferred synthetic fertilizers to organics with motivation lying around the ease of application and transportation in contrast to FYM. Such an indiscriminate and/or haphazard use of inorganic fertilizers was reported to negatively alters the physical, chemical and biological properties of soil, thereby reducing the soil fertility status in the long run (Ghimire et al., 2023; Zakir et al., 2012). Moreover, Khan et al. (2008) also reported that even with the balanced use of synthetic fertilizers, high yield cannot be maintained sustainably over the years because of the continuous deterioration in soil physical and biological environments. Organic manures, despite having a lower nutrient content, contain numerous vital nutrients for plant growth and release them slowly over a longer period of time (Chapagain & Gurung, 2010). However, the inconsiderate use of synthetic fertilizers and pesticides in vegetables, that is happening at an alarming rate, are extremely deleterious for human health, environment and onto the pollinators (Dhital et al., 2015; Sharma & Singhvi, 2017).

With the growing concern for soil health, food safety and agro-chemical pollution, organic farming and thus grown food crops are getting due attention by the government, non- government organizations and farmers lately (Adhikari, 2009). The negative effects of haphazard nitrogen application can be alleviated by adding nitrogen from both organic and inorganic sources, which in turn improves soil productivity and enhances crop quality (Timsina, 2018). For this, a sustainable agriculture based on balance use of synthetics and organics is supposed to be the appropriate answer. In this regard, a field experiment was designed and conducted with an objective to evaluate yield and the yield attributes as well as the quality parameters of late sown carrots and identify the response of a carrot to different nutrient sources and their combinations. It is intended that the information demonstrated as the result of the experiment would be helpful for farmers to make appropriate choices of fertilizer combinations aiming at maximum production of characteristically superior quality carrots. On the other hand, this study is also concerned to analyze the economically viable nutrient combinations for successful carrot farming. Altogether this research shall serve as a baseline document for aspiring researchers to conduct nutrient trials using multiple cultivars as well as several more nutrient combinations in multiple ecological domains.

2. Materials and Methods

2.1. Experimental site

The experiment was conducted at the horticulture farm of the College of Natural Resources Management, Sindhuli, Nepal, located at $27^{0}15^{'}49^{''}$N latitude and $85^{0}44^{'}15^{''}$E longitude, at an elevation of 298 meters above the sea level (Figure 1), from December 2019 to April 2020. The study commenced in the normal season, *i.e.,* sowing on 1st January and harvesting on 16th April. The agro-meteorological data such as average air temperature (20-26ºC), relative humidity (54-62%) and precipitation (85-105 mm) were collected from Weather and Climate (Weather and Climate, 2020), as demonstrated in Figure 2, which was typical sub-tropical weather condition and followed a similar trend as past years.

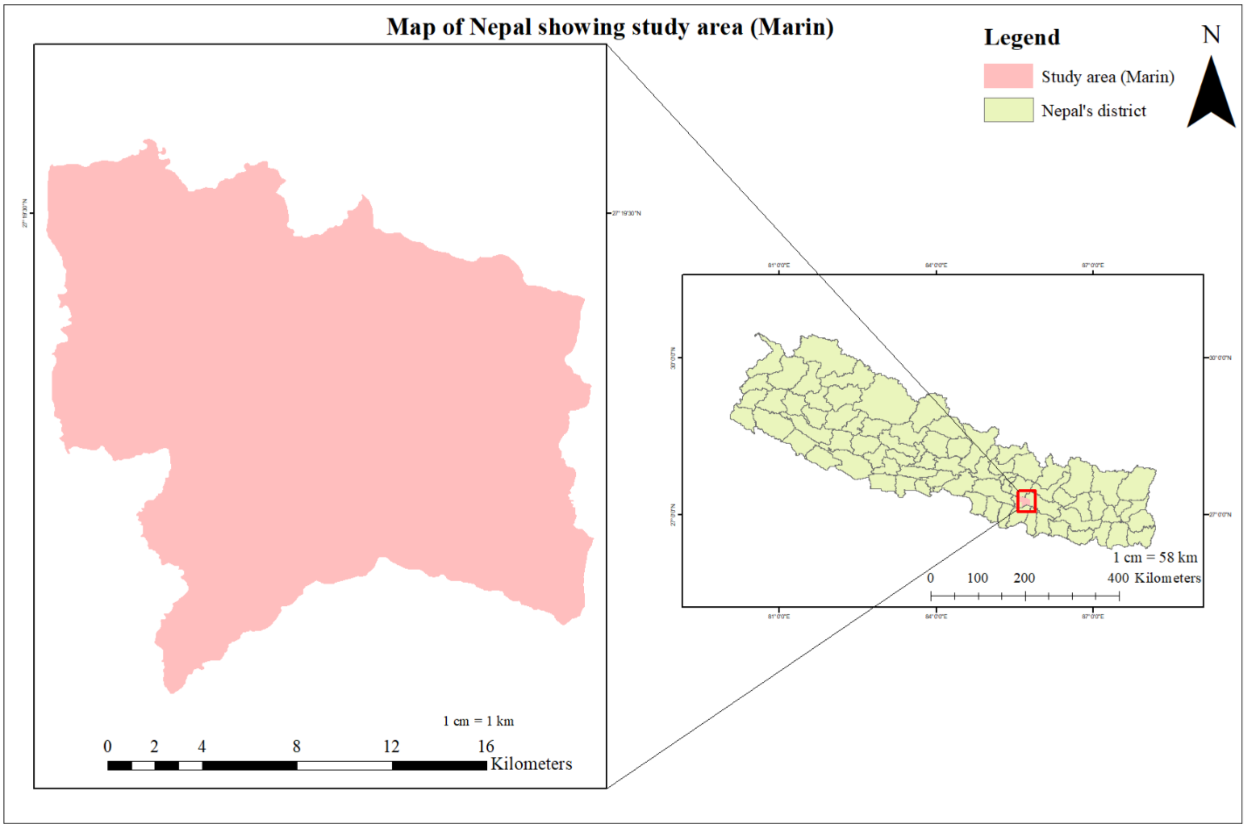

Figure 1. Map of Nepal showing Marin rural municipality, Sindhuli, Nepal.

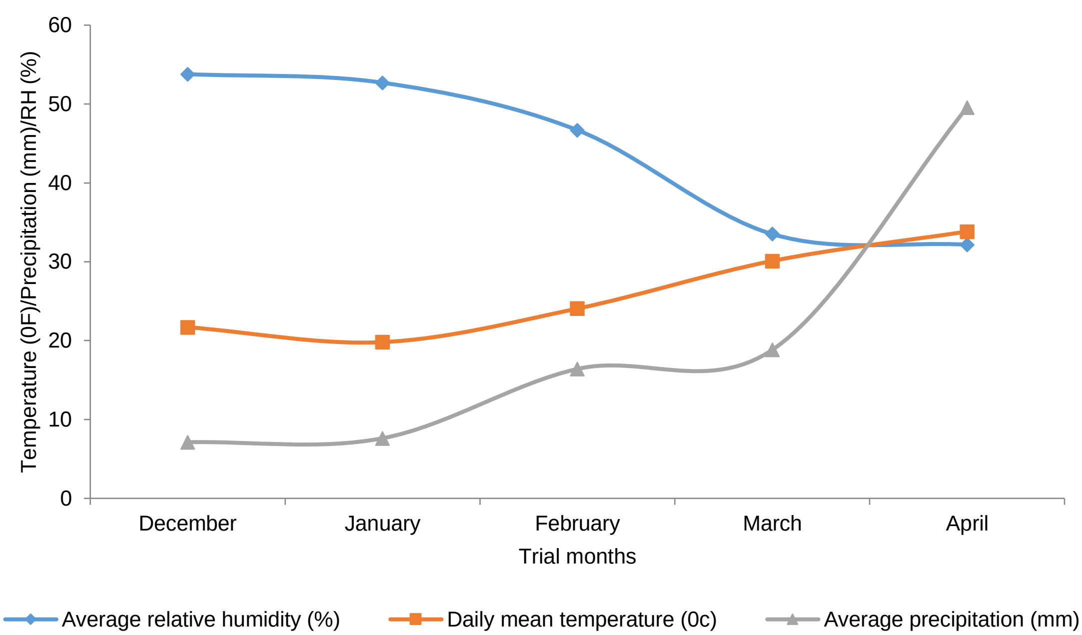

Figure 2. Graphical representation for monthly variation of temperature, relative humidity and precipitation in Sindhuli, 2020

2.2. Physico-chemical characteristics of experimental soil

For a brief study on density and qualitative nutrient values of the experimental plot soil, a composite soil sample was collected from a depth of approximately 15 cm at the experimental sites before assigning treatments. Afterwards the soil sample was subjected to laboratory analysis at the Agriculture Technological Centre, Lalitpur for the necessary physicochemical attributes by adopting appropriate methods. The analysis report is presented in Table 1.

2.3. Experimental details

A Randomized Complete Block Design (RCBD) was used to set up the field trial, with five replications containing five treatment combinations. There were five different doses of nitrogenous fertilizers and two different sources of nitrogen *viz* FYM and inorganic fertilizers, and *New Kuroda* variety was selected for the study owing to its relatively higher popularity among the farmers. The required quantity of seed was purchased from an Sahayogi Agrovet Center, Shahidchowk, Chitwan, Nepal. Similarly, the chemical fertilizers *viz* urea (46% N) and DAP (18% N, 46% P_2O_5) and MOP (60% K_2O) were procured from Manakamana Agrovet, Marin. However, FYM was the only organic source of nitrogen used in the treatments.

Table 1. Initial physico-chemical properties of the soil of the experimental site.

Soil properties	Value	Scale
Physical properties		
Sand (%)	43.10	-
Silt (%)	48.89	-
Clay (%)	8.01	-
Chemical properties		
Soil pH	5.69	Acidic
Soil organic matter (%)	3.76	Medium
Total Nitrogen (%)	0.15	Medium
Available phosphorus (kg ha^{-1})	44.68	Medium
Available potassium (kg ha^{-1})	249.86	Medium
Texture	-	Loam

The required amount of well-decomposed FYM was purchased from Marin Village. Only nitrogen was considered while maintaining the phosphorous and potassium constant. Alternatively, nutrient sources can be assumed to be nitrogen sources. The details of the treatments are presented in Table 2. The size of the individual plot was 1.8 m × 2 m (3.6 m^2). Each replication block was separated by a border/path of 1 m width and the inter-plot spacing was maintained at 1 m. Similarly, a 1-meter border was left on all sides. Altogether, there were 25 plots with a net area of 90 m^2 and gross area of 250 m^2. The crop geometry was maintained at 30 cm × 10 cm in a plot. Each plot had six rows, with 20 plants in each row for a total of 120 plants that were maintained intact in each plot. Of the six rows, the central four rows were treated as net plot rows for observation, and two rows on each side were used as border rows.

Table 2. Details of treatment combinations in the nutrient trial of carrot.

Treatments	Treatment details and symbols
$FYM_{100\%}$	100% RDF (≅ 60kg N ha^{-1}) through FYM (30 Mt ha^{-1}) – T1
$RDF_{25\%}$ + $FYM_{75\%}$	75% RDF (≅ 45 kg N ha^{-1}) through FYM (22.50 Mt ha^{-1}) + 25% RDF through chemical fertilizers – T2
$RDF_{50\%}$ + $FYM_{50\%}$	50% RDF (≅ 30 kg N ha^{-1}) through FYM (15 Mt ha^{-1}) + 50% RDF through chemical fertilizers – T3
$RDF_{75\%}$ + $FYM_{25\%}$	25% RDF (≅ 15 kg N ha^{-1}) equivalent through FYM (7.5 Mt ha^{-1}) + RDF through chemical fertilizers – T4
$RDF_{100\%}$	100% RDF (≅ 60:40:40 kg NPK ha^{-1}) through chemical fertilizers – T5

2.4. Agronomic operations

2.4.1. Land preparation and sowing

The field was plowed twice followed by planking and/or leveling to ensure good tilth. Slightly raised rectangular beds (2 m x 1.8 m x 0.15 m) were prepared. The plot was maintained at 1 m apart. Seeds were sown in the first week of January, 2020 into the pulverized and well-leveled beds. Light overhead irrigation was simultaneously applied after sowing for proper seed establishment. The unsoaked seeds, mixed with fine sand were uniformly placed along the furrows approximately 1cm deep, at the spacing of 30 cm in between the rows. By the 22 days after seedling emergence, the final crop geometry of 30 cm × 10 cm was maintained via thinning out and/or gap filling as necessary.

2.4.2. Manure and fertilizer management

Based on the nutrient management strategy, FYM was applied at the recommended rate of 1500 kg ha^{-1} (AITC, 2019). It was incorporated into the plots 10 days before sowing by calculating the appropriate quantities based on the treatment thus specified (Table 2). Similarly, inorganic fertilizers were quantified separately for each treatment. The plots were applied with nitrogen, phosphorous and potassium at the recommended dose of 60:40:40 kg ha^{-1} of NPK, using urea, DAP, and MOP (AITC, 2019). The full doses of phosphorus and potassium, along with half the dose of nitrogen, were administered concurrently with sowing as the basal dose. After 36 DAS, the remaining nitrogen dose was side-dressed after weeding and earthing up.

2.4.3. Intercultural operations

The inorganic treatments had much less weed pressure, but routine intercultural techniques like wheel hoeing between the rows and hand pulling inside the rows were nevertheless carried out to maintain the soil weed-free and porous.

The first weeding was performed manually by hand pulling at 18 DAS. Additionally, hoeing, weeding, and side dressing of urea were performed at 36 DAS. Following the side dressing with urea, earthing-up was performed to cover the exposed roots. Meanwhile, light irrigation was also given once- twice a day until germination, after earthing up and manuring, and as per the soil condition, in order to maintain an adequate moisture level in the field.

2.4.4. Harvesting

The roots were harvested manually after 80-100 DAS depending upon the maturity period of the crop and also considering the pre-monsoon shower, which had started to fall. Similarly, all the required parameters were recorded from the tagged plant specimen from the net plot.

2.5. Growth measurements

A sample of five carrots was taken from each plot at three or four stages of development *viz* 40, 60, 80 days after sowing (DAS) and at harvest. A had held ruler was employed to measure the lengths of the leaves and root as well as plant canopy. A hand-held vernier caliper was used to measure the root diameter, core and cortex diameter of the samples. Root and foliage mass along with core: cortex ratio, p^H, total soluble solids (TSS), titratable acidity (TA) and organoleptic tests were estimated at harvest. Leaf length was measured from the base of the petiole to the tip of the leaf blade while plant canopy was measured as the total spread distance between the tips of the opposite leaves. Similarly, root length was measured from the shoulder to the base of the storage root and root diameter was taken the in the region of the crown, approximately 2 cm below the leaf base. For the estimation of dry matter content, roots and foliage from each of the plants thus harvested for qualitative analyses were separately subjected to oven drying at 65 ^{o}C, for 48 hours. Subsequently, DMC of roots and leaves were recorded. Moreover, the qualitative analyses of core: cortex ratio, p^H, TSS, TA as well as DMC estimation was done using 5 carrots per harvest area for all treatments. The TSS was measured using a hand refractometer (Chhetri & Ghimire, 2023). Meanwhile, results of organoleptic tase of the carrots was indexed according to the 9- point Hedonic scale (Table 3) (Wichchukit & O'Mahony, 2014; Ponomareva et al., 2021).

Table 3. Nine-point hedonic scale for evaluating organoleptic features of fresh carrot juice.

Score	Quality	Remarks
9	Like extremely	Very sweet and aromatic
8	Like very much	Sweet and aromatic
7	Like moderately	Likely sweet
6	Like slightly	Less sweet
5	Neither like nor dislike	mild flavor
4	Dislike slightly	Mostly bland
3	Dislike moderately (barely acceptable)	Watery
2	Dislike very much	Pungent flavor
1	Dislike extremely (unacceptable)	Bitter

The net returns for each treatment were also determined by adopting the formulae.

$$\text{Net return (US\$ ha}^{-1}) = \text{Gross returns} - \text{Total cost of cultivation}$$

For the shelf-life analysis, five matured carrots from each plot of al treatments were stored in normal polythene packaging in well-ventilated room for 3 weeks. At an ambient room temperature of 25 to 32.6 ^{0}C and RH of 59.68 to 65.37%, the storage weight loss of carrots was estimated. At maturity, the carrots from the central three rows in each plot were harvested. The number of carrots for this harvested area, fresh mass of the roots and shoot were noted. The yield per plot was calculated from the harvest area and extrapolated to yield per hectare. Additionally, the economics of carrot farming was also determined using the benefit cost ratio analysis. Finally, Pearson's correlation method was employed to analyze the direction and strength of the linear relationship between two yield attributing variables.

2.6. Calculations and Statistical methods

Microsoft Excel 365 was used for the data entry, tabulation, and mean estimation. One-way analysis of variance (ANOVA) was used to assess the significance of changes in treatment means and to evaluate the effects of treatments on carrot yield, vegetative growth and development, and produce quality parameters. Analysis ANOVA was performed on the parameters using R Studio version 3.6.3 (Streibig, 2018). Afterwards, data were systematically processed in Microsoft Excel for further treatments, such as tabulation and diagrammatic representations. The significance of differences between treatments was compared using Duncan's Multiple Range Test (DMRT) at a 5% level of significance. And, data transformations such as log transformation and square root transformations were also carried out in case of the parameters like root and shoot biomass, and wherever necessary (Gomez & Gomez, 1984).

3. Results

3.1. Phenological and morphological parameters

The individual nutrient combinations coupled with the given cultivar showed significant effects on days to 75% germination. The average number of days recorded to attain 75% germination was 8 days, whereas the earliest germination (7.60 DAS) was reported in the treatment containing 50% RDF + 50% FYM. However, the treatment with 25% RDF + 75% FYM resulted in delayed (8.60 DAS) germination of all (Table 4).Similarly, significant variations in plant height, number of leaves, and plant canopy were observed at various nitrogen levels. Among the nutrient combinations, the treatment involving 50% RDF + 50% FYM (42.61 cm) resulted in the maximum plant height (42.61 cm) and canopy (51.4 cm) at harvest. However, 100% RDF resulted in the highest number of leaves per plant (11) at harvest. Unfortunately, the treatment containing 100% FYM produced plants with significantly lower morphological parameters at all stages of growth and development.

3.2. Growth parameters

The response of carrots to all the nutrient combinations was observed to be (highly) significant for the growth parameters such as fresh shoot and root weight as well as the respective DMC (Table 5).

3.2.1. Fresh shoot weight

Among the various nutrient combinations, treatment containing 100% RDF resulted the highest values of fresh shoot weight per plant at 80 DAS (11.69 g) as well as at harvest (42.96 g). However, the least foliage weight was reported in 100% FYM (10.12 g and 30.26 g) along the growth stages (Table 5).

3.2.2. Total DMC of shoot

A significantly highest shoot dry matter content was reported from the treatment 50% RDF and 50% FYM (12.83%), followed by 75% RDF and 25% FYM (12.22%). The lowest shoot DMC was obtained at 100% FYM alone (Table 5).

3.2.3. Fresh Root weight

Fresh root weight per plant was reportedly highest in the treatment 25% RDF and 75% FYM (20.57 g) on 80 DAS. But, the maximum root weight at harvest (96.04 g) was reported from the treatment containing 50% RDF and 50% FYM. However, the treatment constituting 100% FYM consistently reported the least values for fresh root weight per plant along the growth stages (Table 5).

3.2.4. Total DMC of root

On consideration of nutrient combinations, the combined treatment of 50% RDF and 50% FYM resulted the highest root DMC (15.01 %) whereas the least DMC of roots (9.88%) was recorded at 100% FYM (Table 5).

3.3. Yield, yield attributes and quality parameters

3.3.1. Yield and yield attributes

Yield attributing traits such as root length, root diameter, and plant biomass varied in a highly significant manner with respect to the nutrient sources, except for the top diameter of the crown (Table 6). The combined effect of 50% RDF + 50% FYM had more pronounced effects upon root diameter (3.01 cm) and root length (20.41 cm) as well as the root biomass (55.44 g plant^{-1}), top biomass (29.89 g plant^{-1}) and hence, on the total biomass per plant (85.33 g plant^{-1}). In contrary, the application of 100% FYM or 100% RDF alone resulted significantly poor yield performance.

3.3.2. Quality parameters

The nutrient combinations also had highly significant effects on all the quality parameters of carrot except the TSS, TA and p^H (Table 7). The highest cortex diameter (1.36 cm), TSS (12.48 ^{0}Brix), TA (0.30 g litre^{-1}) and organoleptic score (7.60) were recorded by the application of 50% RDF along with 50% FYM. The lowest values of these traits were obtained at the application of 100% RDF alone. The highest (0.99) and the lowest (0.81) values of core to cortex ratio were respectively reported at 100% FYM and at the combined application of 75% RDF + 25% FYM. Along with these, the carrots having corresponding highest (6.72) and lowest (6.64) p^H were obtained at the combined application of 50% RDF + 50% FYM, and at 100% FYM/ RDF alone.

The application of 50% RDF + 50% FYM was found to produce carrots of the most superior flavour and acceptability at par to the other nutrient sources.

3.4. Root disorders and post-harvest analysis

The effect of nutrient sources on root disorders such as cracking, malformation and purpling of root was found significant, with the average occurrence of 1.05 in 5 roots (Table 8). Regarding the individual parameters, greater rates of cracking (1.6/5), malformation (1.2/5) and purple top (2.0/5) were seen at 100% RDF alone, 25% RDF + 75% FYM, and 75% RDF + 25% FYM, respectively. On the other hand, the treatments comprising 100% FYM, 50% RDF + 50% FYM, and 25% RDF + 75% FYM, respectively exhibited the lowest mean proportions of cracking (0.4/5), malformation (0.2/5) and purpling (1.0/5). In general, the treatments containing 50% RDF coupled with 50% FYM was found to be least susceptible (0.87/5) to root disorders while the highest average susceptibility (1.81/5) was reported from the treatment including 100% RDF only.

The findings of the statistical analysis revealed a highly significant interaction between the nutrition sources and the storage weight loss following 3 weeks of storage. The average loss of weight in carrots was found to be 1.72%. However, the treatment including 100% FYM showed the minimal loss of weight (1.63%), indicating better shelf-life. In contrast, the highest percentage weight loss (1.81%) was evident in the treatment containing 100% RDF.

3.5. Economics of the carrot production

The economic parameters of carrot varied significantly with respect to the nutrient combinations (Table 9). The highest cost of cultivation (US$ 3954.21 ha^{-1}) was recorded in 100% RDF. However, the lowest cost of cultivation (US$ 3202.46 ha^{-1}) was found in 100% FYM treatment. Similarly, the treatment 50% RDF + 50% FYM resulted the maximum yield (14.63 Mt ha^{-1}), while the lowest yield (11.14 Mt ha^{-1}) was reported in 100% FYM. At the farm gate price of US$ 380.10 Mt^{-1}, the produce was sold in the rural market of Marin (Sindhuli). The maximum gross return (US$ 5560.86 ha^{-1}), net return (US$ 2180.79 ha^{-1}) and benefit: cost (B:C) ratio of 1.65 was observed in 50% RDF + 50% FYM, while the minimum gross return (US$ 4234.31 ha^{-1}) was observed in the control treatment of 100% FYM. However, the minimum net return (US$ 1011.53 ha^{-1}) and B:C ratio (1.30) was obtained in 75% RDF + 25% FYM during the course of investigation.

Table 4. Morphological parameters of carrot as per the nutrient sources and their combinations at different growth stages.

Treatments	75% germination	Plant height (cm)			Number of leaves plant^{-1}			Plant canopy		
		40 DAS	60 DAS	At harvest	40 DAS	60 DAS	At harvest	40 DAS	60 DAS	At harvest
T1	7.8^{bc}	6.8^{b}	18.9^{a}	36.1^{bc}	6.4^{a}	7.6^{b}	9.0^{b}	11.6^{b}	26.9^{a}	40.9^{b}
T2	8.6^{a}	7.3^{a}	21.1^{a}	33.1^{c}	6.6^{a}	8.2^{ab}	10.4^{a}	11.8^{b}	29.7^{a}	43.9^{b}
T3	7.6^{c}	7.3^{a}	22.1^{a}	42.6^{a}	6.4^{a}	8.4^{ab}	10.0^{ab}	13.8^{a}	32.0^{a}	51.4^{a}
T4	7.8^{bc}	6.8^{b}	18.6^{a}	37.3^{b}	6.8^{a}	8.6^{a}	10.6^{a}	12.7^{ab}	27.4^{a}	41.1^{b}
T5	8.4^{ab}	6.5^{a}	20.5^{a}	38.9^{b}	6.6^{a}	8.2^{ab}	10.8^{a}	12.2^{ab}	29.6^{a}	44.9^{b}
SEm (±)	0.24	0.11	1.36	1.13	0.33	0.33	0.44	0.61	1.68	1.56
LSD (α = 0.05)	0.72	0.32	4.08	3.39	0.99	0.99	1.32	1.81	5.03	4.68
CV%	6.7	3.49	15.1	6.71	11.2	9.04	9.67	10.9	12.89	7.86
F test (α = 0.05)	*	**	NS	***	NS	NS	*	NS	NS	**
Grand mean	8.04	6.93	20.3	37.62	6.56	8.2	10.16	12.4	29.1	44.41

Means followed by the same letter(s) within a column are non-significant at 5% level of significance as designed by DMRT. SEm (Standard error of mean); LSD (Least significance difference); CV (Coefficient of variation). Level of significance: *** (P<0.001); ** (P<0.01); ; *(P<0.05) and NS (non-significant).

Table 5. Growth parameters of carrot as influenced by nutrient sources and their combinations at different growth stages.

Treatments	Fresh weight of shoot plant^{-1} (g)		Total DMC of shoot (%)	Fresh weight of roots plant^{-1} (g)		Total DMC of roots (%)
	80 DAS	At harvest		80 DAS	At harvest	
T1	10.12^{c}	30.26^{b}	9.6^{a}	14.89^{b}	84.61^{ab}	9.88^{c}
T2	12.49^{a}	38.52^{ab}	10.71^{c}	20.57^{a}	86.40^{ab}	13.28^{b}
T3	10.85^{bc}	33.43^{b}	12.83^{a}	18.08^{ab}	96.04^{a}	15.01^{a}
T4	11.57^{abc}	38.48^{ab}	12.22^{b}	15.43^{b}	92.27^{ab}	13.66^{ab}
T5	11.69^{ab}	42.96^{a}	10.42^{e}	17.39^{ab}	82.24^{b}	12.35^{b}
SEm (±)	0.51	2.8	0.06	1.05	4.42	0.5
LSD (α = 0.05)	1.53	8.4	0.18	3.15	13.24	1.49
CV%	10.03	17.05	1.18	13.61	11.19	8.67
F-test (α = 0.05)	*	*	***	*	NS	***
Grand mean	11.35	36.73	11.16	17.27	88.31	12.83

Means followed by the same letter(s) within a column are non-significant at 5% level of significance as designed by DMRT. SEm (Standard error of mean); LSD (Least significance difference); CV (Coefficient of variation). Level of significance: *** (P<0.001); *(P<0.05) and NS (non-significant).

Table 6. Yield and yield parameters of carrot as influenced by nutrient sources and their combinations.

Treatments	Root diameter (cm)	Top diameter (cm)	Root length (cm)	Root biomass plant^{-1}(g)	Top biomass plant^{-1} (g)	Total biomass plant^{-1} (g)
T1	2.26^{d}	1.29^{a}	15.24^{c}	40.12^{e}	25.13^{d}	65.26^{d}
T2	2.41^{bc}	1.32^{a}	16.58^{b}	45.02^{c}	26.55^{c}	71.57^{c}
T3	3.01^{a}	1.32^{a}	20.41^{a}	55.44^{a}	29.89^{a}	85.33^{a}
T4	2.63^{b}	1.30^{a}	19.91^{a}	50.69^{b}	27.32^{b}	78.01^{b}
T5	2.51^{bc}	1.23^{a}	15.38^{c}	41.97^{d}	24.08^{e}	66.06^{d}
SEm (±)	0.12	0.07	0.31	0.23	0.18	0.29
LSD (α = 0.05)	0.35	0.25	0.94	0.68	0.54	0.88
CV%	10.33	14.08	4.02	1.1	1.52	0.89
F test (α = 0.05)	***	NS	***	***	***	***
Grand mean	2.56	1.29	17.5	46.65	26.6	73.24

Means followed by the same letter(s) within a column are non-significant at 5% level of significance as designed by DMRT. SEm (Standard error of mean); LSD (Least significance difference); CV (Coefficient of variation). Level of significance: *** (P<0.001) and NS (non-significant).

Table 7. Quality parameters of carrots as affected by different nutrient sources and their combinations.

Treatments	Quality Parameters						
	Core diameter (cm)	Cortex diameter (cm)	Core: Cortex ratio	TSS (ºBrix)	p^{H}	TA (g litre^{-1})	Organoleptic score
FYM$_{100\%}$	1.22^{a}	1.24^{cd}	0.99^{a}	12.07^{ab}	6.64^{a}	0.24^{a}	4.80^{b}
FYM$_{75\%}$+RDF$_{25\%}$	1.07^{c}	1.29^{bc}	0.83^{cd}	11.98^{b}	6.70^{a}	0.26^{a}	5.20^{b}
FYM$_{50\%}$+RDF$_{50\%}$	1.14^{b}	1.36^{a}	0.84^{c}	12.48^{a}	6.72^{a}	0.30^{a}	7.60^{a}
FYM$_{25\%}$+RDF$_{75\%}$	1.05^{c}	1.30^{b}	0.81^{d}	11.96^{b}	6.68^{a}	0.26^{a}	4.80^{b}
RDF$_{100\%}$	1.15^{b}	1.20^{d}	0.96^{a}	11.88^{b}	6.64^{a}	0.22^{a}	4.40^{b}
SEm (±)	0.01	0.02	0.01	0.15	0.04	0.03	0.68
LSD (α = 0.05)	0.04	0.06	0.03	0.45	0.10	0.08	2.05
CV%	2.45	3.39	2.06	2.8	1.13	24.4	28.54
F test (α = 0.05)	***	***	***	NS	NS	NS	*
Grand mean	1.13	1.27	0.89	12.07	6.68	0.26	5.36

Means followed by the same letter (s) within a column are non-significant at 5% level of significance as designed by DMRT. SEm (Standard error of mean); LSD (Least significance difference); CV (Coefficient of variation). Level of significance: *** (P<0.001); ** (P<0.01); * (P<0.05) and NS (non-significant).

Table 8. Status of root disorders and shelf-life of carrots in relation to various nutrient sources and their combinations.

Treatments	Roots affected (n=5)			Average root disorder (n=5)	Storage weight loss (%)
	Cracking	Malformation	Purpling		
T1	0.40^{c}	1.00^{a}	1.40^{a}	0.93^{ab}	1.63^{e}
T2	0.60^{a}	1.20^{a}	1.00^{a}	0.93^{ab}	1.68^{d}
T3	1.20^{abc}	0.20^{b}	1.20^{a}	0.87^{b}	1.72^{c}
T4	1.40^{ab}	0.20^{b}	2.00^{a}	1.20^{ab}	1.77^{b}
T5	1.60^{a}	0.80^{ab}	1.80^{a}	1.40^{a}	1.81^{a}
SEm (±)	0.27	0.24	0.37	0.18	0.01
LSD (α = 0.05)	0.81	0.71	1.11	0.55	0.02
CV%	58.09	78.51	55.92	39.01	0.74
F test (α = 0.05)	*	**	NS	NS	***
Grand mean	1.04	0.8	1.48	1.05	1.72

Means followed by the same letter(s) within a column are non-significant at 5% level of significance as designed by DMRT. SEm (Standard error of mean); LSD (Least significance difference); CV (Coefficient of variation). Level of significance: *** (P<0.001); ** (P<0.01); * (P<0.05) and NS (non-significant).

Table 9. Effect of different nutrient combinations on the economics of carrot production

Treatments	Yield (Mt ha^{-1})	Gross return (US$ ha^{-1}) @ 380.10 Mt^{-1}	Treatment cost (US$)	Total cost of cultivation (US$ ha^{-1})	Net Return (US$ ha^{-1})	B:C Ratio
T1	11.14^{e}	4234.31^{e}	1.15^{d}	3202.46^{e}	1031.86^{d}	1.32^{d}
T2	12.51^{b}	4755.05^{c}	1.16^{d}	3234.13^{d}	1520.91^{b}	1.47^{b}
T3	14.63^{a}	5560.86^{a}	1.22^{c}	3380.07^{c}	2180.79^{a}	1.65^{a}
T4	11.66^{d}	4433.64^{d}	1.23^{b}	3420.43^{b}	1011.53^{d}	1.30^{e}
T5	14.08^{b}	5350.14^{b}	1.42^{a}	3954.21^{a}	1395.93^{b}	1.35^{c}
SEm (±)	0.02	6.46	0.0004	0.004	6.46	0.002
LSD (α = 0.05)	0.5	19.38	0.02	0.0001	19.38	0.005
CV%	0.29	0.3	0.81	0.0003	1.01	0.28
F test (α = 0.05)	***	***	**	***	***	***
Grand mean	12.80	4866.80	1.24	3438.26	1428.4	1.42

Means followed by the same letter(s) within a column are non-significant at 5% level of significance as designed by DMRT. SEm (Standard error of mean); LSD (Least significance difference); CV (Coefficient of variation). Level of significance: *** (P<0.001).

4. Discussion

In general, the seedling establishment and development of carrot during the early stages of growth progressed more or less indifferently, as expected in all five fertilizer level treatments. During the field trial, the effect of various fertilizer levels was visually noticeable at the early stages of growth, such as the high fertilizer rate, clearly contributing to carrots with distinctly larger and lush foliage. Interestingly, it seemed that vegetative growth was not hindered significantly by nutrient deficiency during the early growth stages, but analyses of the growth parameter data showed an increase in size, weight, or length of the morphological features as the fertilizer levels increased and as the growing season progressed (Sekoli, 2009).

4.1. Effect of nitrogen sources on phonological and morphological parameters

The combination of RDF and cattle manure in varying proportions influences seed germination, plant height, and leaf development. The combined application of FYM and RDF enables synergistic effects of organic matter and supplemented nutrients on carrot germination and growth. The addition of fertilizer complements the organic matter provided by FYM, ensuring the availability of essential nutrients in the soil (Awomi et al., 2018; Chapagain & Gurung, 2010). The higher germination rate observed in 25% RDF+ 75% FYM treatment suggests that the combined effect of organic matter and supplemented nutrients enhanced seed germination. Despite the slow rate of germination of carrot seeds, the presence of both organic matter and fertilizers creates an optimal growth environment for the carrot seeds, promoting their successful germination and early development. Plant height is one of the indicators of carrot growth and development (Rubatzky et al., 1999). Therefore, the maintenance of functional leaves on the plaints is of prime importance, as this morphological structure is associated with photo assimilation and hence, yield (Wazziki et al., 2015). A consistent maximum plant height was reported in the treatment 50% RDF and 50% FYM throughout the growth stages, which was closely followed by $RDF_{100\%}$. The similar findings are also reported by Awomi et al. (2018) and Pandey and Sharma (2017). This might be the result of higher nutrient availability from the inorganic sources via RDF and increased nutrient use efficiency due to the organic manure in combination rather than nutrients. At all growth stages, the maximum number of leaves was recorded for RDF100%, followed by RDF75%+ FYM25%, and the minimum leaf number was consistently obtained for FYM100%. Similarly, the plant canopy of the plants escalated in correspondence to the plant height; the greater the plant height, the greater the leaf length and hence the canopy, and vice versa. The results are in conformity with the findings of Awomi et al. (2018). The absence of farmyard manure hindered leaf production, despite the concentrated nutrients from the inorganic fertilizers adequately supporting the foliar growth of plants. Nitrogen, in particular, plays a vital role in promoting leaf development and foliage growth (Yousaf et al., 2021). It is a crucial component of amino acids, proteins, and chlorophyll, which are essential for photosynthesis and overall plant health. The chemical fertilizers as applied via RDF are in readily available forms, which can be quickly absorbed by the plant roots. This immediate availability of nutrients allows for efficient uptake and utilization by the plants, leading to enhanced growth and leaf development (Ouda & Mahadeen, 2008).

4.2. Effect of nitrogen sources on growth, and yield parameters

The FYM treatment alone has low nutrient concentration and slow nutrient release capacity, affecting growth and yield-attributing parameters like root weight, TDM, root diameter, and plant biomass (Herencia & Maqueda, 2016). Insufficient organic nutrient supply can reduce overall nutrient use efficiency due to rapid volatilization, immobilization, and leaching losses owing to poor soil properties (Ahmed et al., 2014). However, FYM in the synergistic mixture enhances soil fertility, moisture retention, and nutrient availability thereby creating suitable environment for root penetration and growth (Zhang et al., 2014).

The field trial demonstrated that a combined application of FYM and inorganic fertilizers, as per the recommended dose, performed best across growth stages, enhancing nutrient availability and supporting sustained growth of carrot plants. This approach, combined with organic matter, facilitated microbial activity and improved nutrient availability. Organic matter improves soil structure, water-holding capacity, root penetration and nutrient retention (Yadav et al., 2018). FYM can provide all 13 types of soil micronutrients in substantial quantity which no inorganic fertilizer can provide (Das et al., 2013). The recommended dose of RDF fertilizer, consisting of 50% organic matter, ensures a balanced supply of essential nutrients like nitrogen (N), phosphorus (P), and potassium (K). These nutrients are crucial for plant growth, supporting root development, metabolism, stress tolerance, water regulation, and nutrient transport. The combination of organic matter and supplemented nutrients creates an ideal growth environment for roots proliferation. The organic matter improves soil structure, allowing roots to penetrate easily and access water and nutrients (Yadav et al., 2018). The balanced nutrient supply from the RDF further supports root growth, leading to increased root length, root diameter, and fresh weight of roots. The balanced nutrient supply from the RDF, along with the organic matter from FYM, contributes to vigorous foliage growth (Ghimire et al., 2023). The critical role of supplied nutrients in chlorophyll synthesis is crucial for efficient photosynthesis and nutrient uptake, thereby enhancing leaf biomass and total dry matter. The organic matter from FYM fosters microbial activity in the soil (Ghimire & Chhetri, 2023). Microorganisms play a synergistic role in converting complex organic compounds into simpler forms for plant uptake, ensuring the sustained availability of nutrients for plant growth and biomass accumulation. The combination of organic matter and supplemented nutrients supports various physiological processes essential for plant growth (Ghimire et al., 2023). FYM enhances nutrient assimilation and protein synthesis through balanced nutrient supply and organic matter content, promoting optimal plant growth, biomass accumulation, and improved soil structure. It increases the soil's ability to retain moisture and nutrients, making them more available for plant uptake (Ahmed et al., 2014). The enhanced water and nutrient uptake efficiency contribute to better growth and biomass accumulation in the carrot plant. Thus, the integrated nutrient supply enhances the growth and yield-attributing parameters through optimizing the organic matter content of the soil, nutrient availability, balance nutrient supply to the plants enhancing the root growth and development, optimizing microbial activities, nutrient recycling, and improving water and nutrient uptake efficiency.

4.3. Effect of nitrogen sources on quality parameters

The core and cortex diameter as well as their ratio recorded a significant response to the nutrient combinations. This finding was in conflict to the joint speculation of Hailu et al. (2008), where the core diameter varied non-significantly with nutrient sources. Several factors could contribute to this discrepancy, including variations in experimental conditions, nutrient availability and uptake, synergistic or antagonistic effects between nutrients, genetic variation among carrot cultivars, and potential methodological differences. Similar findings are also reported by Pandey et al. (2017) where the application of 100% FYM alone resulted a significantly higher core to cortex ratio, whereas the lowest value was obtained on application of 50% RDF + 50% FYM each.

Moreover, Northolt et al. (2004) also asserted that thicker carrot roots had a relatively smaller cortex and larger core thickness. Nutrient combinations were found to significantly impact the organoleptic score of carrots, with the highest score of 7.6 indicating the best flavor. The highest weight loss was observed in carrots with 50% RDF + 50% FYM, indicating that higher organic nutrients lead to less storage weight loss and better shelf life. Conversely, higher inorganic fertilizers result in greater weight loss and shorter shelf life. Similar findings on the shelf life and postharvest quality of carrots are also reported by Naik & Sreedhar (2018), and Ierna et al. (2020). However, the evidence on root disorders suggested its highest average appearance at 100% RDF with higher evidence of cracking and purpling, but malformation was higher in the respective treatments of 25% RDF + 75% FYM, and least in 50% RDF + 50% FYM. In correspondence, Afsar Ali et al. (2003) reported significant and progressive increment of root cracking and forking at increased root diameter and yield at higher level of nitrogen. The possible reason behind root cracking can be attributed to the occurrence of pre-monsoon shower right after the side dressing of nitrogen in the field, and the larger roots resulted in the plot containing 50% RDF + 50% FYM (RHS, 2020). It has been evident that the larger the roots, the higher amount of moisture they tend to absorb. This sudden absorption of excess of water after a period of drought leads to splitting and shattering of roots. Excess nitrogen fertilizer and shifts in temperature may also have an effect on splitting (RHS, 2020).

4.4. Economics of production

In the nutrient trial of carrot, the respectively highest and lowest yields of carrot were reported in 50% RDF + 50% FYM and 100% FYM. The cost of cultivation also varied significantly with the treatments, the highest in 100% RDF to the least in 100% FYM. Furthermore, significantly maximum values of gross return, net return and B:C ratio was observed in 50% RDF + 50% FYM, while the minimum gross return was evident in the treatment 100% FYM. Similar findings were independently reported by Mehedi et al. (2012) and Ghimire et al. (2023). However, the minimum net return and B:C ratio was recorded in 75% RDF + 25% FYM during the course of investigation. Such a higher values of gross return in partial integrated nutrient combinations was mainly due to apparently higher yield, while enhanced net return and B:C ratio was due to decreased cost of cultivation. These results are in conformity with the findings of Pandey and Sharma (2017) and Singh et al. (2007). The BC ratio is a valuable for the decision making among the available choices with the farmers (Buckley & Peterson, 2011).

4.5. Pearson correlation analysis among various parameters

The Pearson correlation method was employed to analyze the direction and strength of the linear relationship between two variables.

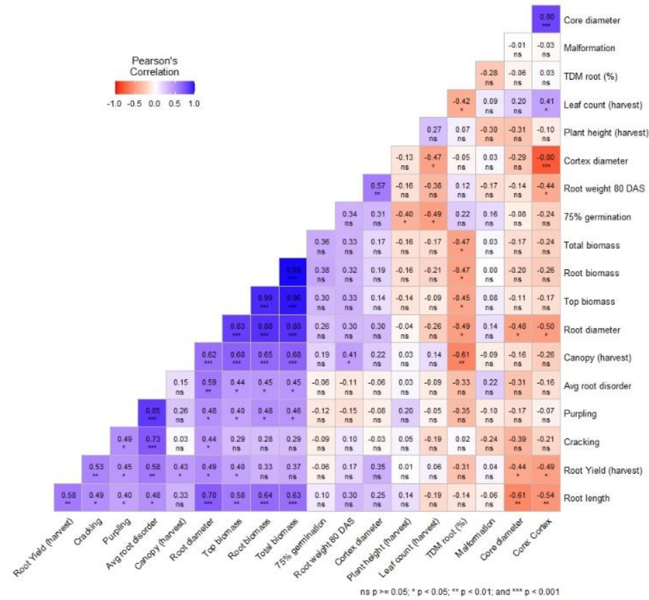

Figure 3. A chart showing correlation among various parameters taken under consideration.

Figure 3 below shows the correlation coefficients, whose values range from -1 to +1 between different pairs of varying parameters, where the value 1 indicates a perfect linear relationship (Minitab, 2021). Days to 75% germination had a negative and significant association with leaf count (0.49) and plant height (0.40) at harvest. However, it had positive, yet non-significant relationship with the root biomass, total biomass as well as the dry matter content of the roots. Similarly, root yield at harvest is strongly correlated with the plant height (0.58), cortex diameter (0.30), while the appearance of average root disorder is also significant, and positively related to root yield (0.58). Furthermore, the factors like root biomass (0.90), top biomass (0.83), total plant biomass (0.99), root diameter (0.62) and plant canopy (0.62) are found to be highly significant and positively interrelated with one another. For instance, the plant canopy factor was recorded to have positively influenced root diameter (0.62), root biomass (0.65), total biomass (0.68), and hence the root yield at harvest (0.43). Nevertheless, the TDM accumulation in roots is also correlated to days to 75% germination and root weight (80 DAS). This implies that the earlier the germination, higher shall be the dry matter accumulation in carrot, and vice versa. These findings are in close correspondence with several independent studies done on correlation analysis of yield attributing characteristics of carrot (Kaurav et al., 2018; Mapari et al., 2009; Wendling et al., 2016).

5. Conclusion

Carrot (*Daucus carota* L.) is one of the key root crops of Nepal. According to this research, it can be concluded that for the cultivar New Kuroda, the plant growth parameters, yield, and post-harvest quality parameters differed significantly at varying doses and combinations of nitrogen fertilization.

The study revealed that the cumulative effect of the treatment 50% RDF + 50% FYM significantly increased plant height and plant canopy, along with total fresh weight and dry weight of the roots as well as leaves, although the leaf count increased proportionately with increasing RDF at all growth phases. Alternatively, it can be inferred that the application of 50% nitrogen via FYM at 15 Mt ha^{-1} along with RDF resulted in the maximum yield of carrots, but with a minimum occurrence of root disorders, having a significantly superior produce quality. Although the total returns are proportionate with increasing supply of nitrogen via chemical fertilizers (e.g., RDF), farmers are advised to substitute it with the integrated application of RDF as well as FYM in 50/50 proportions simultaneously to ensure maximum net returns and longer shelf life of the produce, thereby countering the damaging consequences of chemical fertilizers on soils and on human health. This indicates that the partial incorporation of FYM in addition to RDF is economically profitable, environmentally just, and sustainable. The humane and ecological implications vis-à-vis the over-chemicalization or haphazard use of inorganic fertilizers in our agricultural system must be highlighted, while the benefits of organic production systems that utilize FYM and other organic sources for fertilization cannot be exaggerated.

Acknowledgements

The author heartly acknowledges the advisory team of Prof. Dr Keshab Raj Pandey and Asst. Prof. Madhav Dhital for technical collaboration and generous assistance. CNRM- Sindhuli deserves special thanks for their collaboration and laboratory assistance. Sincere thanks are due to the fellow confidantes Raja Chaudhary, Santosh Kumar Bogati and other colleagues for their tiring efforts and generous support during the field preparation and cultivation practices.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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