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Response of European carrot (*Daucus carota*) to different irrigation schedules and sowing methods under the mid-hill conditions of north-western Himalayas, India

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ABSTRACT

Optimum irrigation scheduling and right sowing method are two main limiting factors for ensuring crop yield and is determined based on the information of yield attributing characters. The study was carried out during 2021–22 and 2022–23 at Dr Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh to determine precise irrigation schedule along with appropriate method of sowing in carrot (*Daucus carota* L.) for sandy loam soil of mid hills of north-western Himalayas. Two sowing methods (S_1, Flat-bed and S_2, Ridge) and four irrigation schedules, viz. I_1 (IW/CPE 0.6); I_2 (IW/CPE 0.8); I_3 (IW/CPE 1.0) and I_4 (IW/CPE 1.2) at 3 cm depth of irrigation were evaluated and replicated thrice in factorial randomised block design (F-RBD). Results of the study revealed that an increase in the irrigation frequency [IW/CPE 1.2 (I_4)] resulted in significant increase in plant height (30.50%), root length (33.86%), root diameter (41.79%), root:shoot ratio (36.51%), net and gross root weight (75.77 and 58.43%) and carotene content (5.71%) compared to IW/CPE 0.6 irrigation schedule. Irrigation at IW/CPE 1.2 (I_4) in ridge method of planting resulted in maximum total NPK uptake (92.40, 24.86 and 53.58 kg/ha), dry matter content (10.05%), yield (342.2 q/ha), net returns (₹ 5,22,892) and benefit:cost ratio (3.23). Hence, irrigation schedule at IW/CPE 1.2 with ridge method of sowing was proved to be the most effective approach to enhance yield, economics and efficient management of water resources.

Keywords: Economics, Irrigation scheduling, PCA, Yield, Yield attributes

Carrot (*Daucus carota* L.) is an important short-duration vegetable, grown across the world, with a wide cultivated area and the potential to improve the socio-economic growth because of its quick return on investment (Nagaz *et al.* 2012). It is an excellent source of free sugars (glucose, sucrose and fructose), iron, calcium, phosphorus, folic acid and also contains a good amount of vitamin B. Carrots have high economic as well as biological value due to the presence of various biochemical compounds such as α and β-carotene, phenolics, dietary fibres, vitamin C and antioxidants (Ciza *et al.* 2022). Various factors affect the root growth and quality of carrots, however, appropriate planting geometry and an optimum moisture regime during the growing season have prime importance for optimum proliferation of biomass, nutrient availability, dry matter content, carotenoid, carotene and total sugars (Mahmoud *et al.* 2019). Low soil moisture regime and the soil temperature are among the limiting factors that hampers production of root crops (Sharma *et al.* 2023). In a crop production system, the most crucial method for improving and amending the soil before seedlings emergence is to prepare the seedbed well. The sowing method is an essential agro-technique, which plays a crucial role in enhancing the productivity and profitability of the crop. It provides congenial conditions for germination, establishment and proper proliferation of root that leads to better growth and development of plant (Yadav *et al.* 2024). Common planting layout practices are flat-bed, ridges and furrows and the crop responses to different sowing methods is expected to vary markedly with the methods and amount of water used. In seedbeds, good aeration is provided by ridges and furrows and this method also aid in better irrigation and proper drainage of excess of water from the soil. The layout of the land is important for improving crop production. Planting in raised beds also avoid the issue of excess moisture in clayey soils (Robert *et al.* 2024).

The efficient use of water resources is critical for sustainable agriculture under increasing pressure of climate variability. Irrigation scheduling aim to determine the appropriate amount and time of water application to crops

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(Sałata *et al.* 2022), which may be based on at least one variable of the soil-plant-atmosphere system (Kang *et al.* 2021). Physiological processes of crops can be secured through adoption of adequate irrigation scheduling method and hence yield (Jha *et al.* 2019). Various patterns of planting at different irrigation schedules affect the uptake of nutrient ions and their distribution in soil, which could greatly promote the carrot yield. But there is a need to identify the suitable sowing method and irrigation combinations. Himachal Pradesh is a hilly state and farming is the primary occupation of the majority of the population. Information on the efficient use of sowing methods and effective water utilisation under different irrigation schedules combination for European carrot cultivation is scarce in many states known for quality carrot production. Scientific and field extension workers, who have made efforts to enhance irrigation scheduling have concentrated on climate-based methods rather than on soil/ plant-based methods. Therefore, present study was carried out to examine the crop response under irrigation water/cumulative pan-evaporation (IW/CPE) based irrigation scheduling with different sowing methods in carrot.

MATERIALS AND METHODS

Study site description: The study was carried out during 2021–22 and 2022–23 at Dr Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan (30°52′ N, 77°11′ E; at an elevation of 1175 m amsl), Himachal Pradesh. Based on yearly potential evapotranspiration (PET) of 1,520 mm, the region having a 420 mm annual moisture deficit as it receives annual precipitation of 1100 mm. The average minimum and maximum temperatures ranged from 3–11ºC and 16–27ºC, respectively. According to USDA soil taxonomy classification, the study area belongs to Typic Eutrochrept at sub-group level having sandy loam in texture. Soil (0–15 cm) contained 12.6 g/kg organic carbon content and 245.4, 26.3, 265.5 kg/ha available NPK, respectively. The water retention of soil at field capacity (FC) and permanent wilting point (PWP) was 23.9% and 7.2%, respectively.

Experimental design and field management: Field experiment involved four irrigation schedules at 3 cm depth of irrigation and two sowing methods with 3 replications under factorial randomised block design (F-RBD). The four irrigation regimes included, I_1 (IW/CPE = 0.6); I_2 (IW/CPE = 0.8); I_3 (IW/CPE = 1.0) and I_4 (IW/CPE = 1.2) and sowing methods included flat-bed (S_1) and ridge (S_2). The CPE (cumulative pan evaporation) was measured by summarising the daily observed evaporation from USDB Class A open pan evaporimeter, which was 0.5 km away from the experimental site. Surface irrigation was used to apply measured amounts of irrigation water to the plots through 2 inch PVC pipes that were equipped with a water flow meter. The present investigation was carried out using the Pusa Yamdagni variety of carrot in 3 m × 2 m plots for each treatment. There was a 1 m buffer zone between plots and a 3 m buffer zone between replications. Line sowing was done and seeds were sown directly by hands at 30 cm × 10 cm spacing. Standard package of practices was followed and recommended dose of N (50 kg/ha), P_2O_5 (50 kg/ha) and K_2O (40 kg/ha) nutrients with FYM @10 t/ha were uniformly applied. At the time of sowing 1/3rd N and full doses of P, K and FYM were applied and remaining N was administered by top-dressing at earthing up stage and 30 days after earthing up stage. Ten plants from each treatment were selected for recording vegetative parameters. Dry matter content (%) was estimated by dividing oven dried root weight (65 ± 5°C) to the fresh root weight of same sample and multiplied by 100. The TSS of every sample was recorded by putting the small amount of juice on prism of digital refractrometer and carotene content was estimated by solvent extraction method (Ranganna 1986). Water footprint is the measure of volume of fresh water needed to produce each unit of the produce and it was calculated by dividing total ET_c during the growing season by yield. Whereas, water use efficiency (WUE) was calculated by dividing crop yield to irrigation water applied. Returns per unit water use was calculated as:

$$\text{Returns per unit water use} = \frac{\text{Net returns (₹/ha)}}{\text{Total water use (mm)}}$$

Nutrient uptake: NPK uptake in roots and shoots were calculated by multiplying the corresponding biomass by the respective nutrient concentration. The sum of nutrients uptake in root and shoot was used to calculate the total NPK uptake in the plant.

Data obtained during the course of investigation were analysed using the factorial randomised block design and two-way analysis of variance (ANOVA) using OPSTAT. For comparing treatment means, critical difference (CD) was calculated at the 5% level of significance. Additionally, the principal component analysis was carried out using Past 4.03 software to address the variability among variables and the principal components with eigenvalues ≥ 1.0 were selected.

RESULTS AND DISCUSSION

Growth and yield attributes: As per the pooled data over 2 years (2021–22 and 2022–23) (Table 1), a significant effect of different sowing methods, irrigation schedule and their interactions on carrot revealed that maximum plant height (64.73 cm) was observed under I_4 and minimum (49.60 cm) was under I_1 irrigation schedule. Among different sowing methods, maximum plant height (59.59 cm) was observed under S_2 and lowest (55.31 cm) was under S_1. Interaction S_2I_4 registered the maximum plant height (67.86 cm) followed by S_2I_3 (64.05 cm) and minimum was under S_1I_1 (48.59 cm) treatment. Similarly, highest average root length (20.95 and 19.35 cm) and root diameter (3.80 and 3.44 cm) were observed under I_4 irrigation schedule and S_2 sowing method, respectively. Among different interaction effects, maximum root length (22.01 cm) and root diameter (3.99 cm) were observed under S_2I_4 and minimum (14.98 and 2.58 cm) was under S_1I_1, respectively.

Table 1 Effect of irrigation schedules and sowing methods on growth and biochemical parameters of European carrot

Irrigation regimes	Plant height (cm)			Root length (cm)			Root diameter (cm)			Net root weight (g)		
	Flat-bed (S_1)	Ridge (S_2)	Mean	Flat-bed (S_1)	Ridge (S_2)	Mean	Flat-bed (S_1)	Ridge (S_2)	Mean	Flat-bed (S_1)	Ridge (S_2)	Mean
I_1, IW/CPE 0.6	48.59	50.61	49.60	14.98	16.33	15.65	2.58	2.79	2.68	70.3	85.0	77.6
I_2, IW/CPE 0.8	53.38	55.83	54.61	17.04	18.07	17.56	3.23	3.41	3.32	96.0	103.3	99.6
I_3, IW/CPE 1.0	57.65	64.05	60.85	18.64	20.97	19.81	3.47	3.59	3.53	118.5	133.6	126.0
I_4, IW/CPE 1.2	61.61	67.86	64.73	19.90	22.01	20.95	3.61	3.99	3.80	130.3	142.7	136.4
Mean	55.31	59.59		17.64	19.35		3.23	3.44		103.7	116.2	
CD (p=0.05)	S: 0.74 I: 1.05 S×I: 1.48			S: 0.25 I: 0.36 S×I: 0.51			S: 0.04 I: 0.06 S×I: 0.08			S: 1.38 I: 1.95 S×I: 2.76		
Irrigation regimes	Gross root weight (g)			Root:shoot ratio			TSS (°B)			Carotene content (mg/100 g)		
	Flat-bed	Ridge	Mean	Flat-bed	Ridge	Mean	Flat-bed	Ridge	Mean	Flat-bed	Ridge	Mean
I_1, IW/CPE 0.6	114.7	128.3	121.5	1.58	1.98	1.78	10.22	10.12	10.17	6.95	7.05	7.00
I_2, IW/CPE 0.8	141.2	156.2	148.7	2.12	1.95	2.04	10.33	10.12	10.23	7.19	7.28	7.24
I_3, IW/CPE 1.0	170.7	187.2	179.0	2.27	2.49	2.38	9.80	9.35	9.57	7.28	7.41	7.34
I_4, IW/CPE 1.2	185.8	199.2	192.5	2.34	2.52	2.43	9.35	9.13	9.24	7.36	7.45	7.40
Mean	153.1	167.7		2.08	2.24		9.92	9.68		7.19	7.30	
CD (p=0.05)	S: 1.62 I: 2.30 S×I: NS			S: 0.05 I: 0.07 S×I: 0.09			S: NS I: 0.41 S×I: NS			S: NS I: 0.17 S×I: NS		

S, Sowing method; I, Irrigation schedule; NS, Non-significant.

As per pooled data enumerated in Table 1, maximum net root weight (136.4 g), gross weight (192.5 g) and root:shoot ratio (2.43) was observed under I_4, while minimum net root weight (77.6 g), gross weight (121.5 g) and root:shoot ratio (1.78) was under I_1 irrigation schedule. Among sowing methods, the maximum net root weight (116.2 g), gross weight (167.7 g) and root shoot ratio (2.24) was observed under S_2. Among different treatment combinations, highest net root weight and root:shoot ratio (142.7 cm and 2.52) was recorded under S_2I_4 followed by S_2I_3 (133.6 cm and 2.49) and lowest were under S_1I_1 (70.3 cm and 1.58), respectively. Whereas, interaction had a non-significant effect on gross root weight.

The yield attributes were maximum under ridge method which might be due to higher aeration status and moisture availability in ridges that improve soil quality and facilitates better nutrient uptake from soil (Babu *et al.* 2020, Solanki *et al.* 2020). For healthy root growth, carrots require loose soil and less compaction that permits taproot development to proceed unhindered and it is made possible under ridge method (Robert *et al.* 2024). Another possible reason will be ascribed to improved microclimate by switching from flood irrigation to targeted irrigation which leads to better growth of plants. Higher irrigation schedule led to appropriate moisture content in the root zone which improves nutrient uptake and reduces soil strength which creates better physical conditions for proper proliferation of roots in the root zone. It also plays an important role in transpiration, stomatal opening, growth and expansion of leaves that led to increased crop growth under higher irrigation schedule (Alam *et al.* 2010).

Dry matter content (%) and yield (q/ha): Pooled analysis showed that different irrigation schedules and sowing methods had a significant effect on dry matter content and yield (Fig. 1). Under different irrigation schedules, maximum dry matter content (10.05%) and yield (324.2 q/ha) were achieved under I_4 irrigation level, followed by I_3 (9.41% and 304.0 q/ha) and minimum (7.69% and 186.3 q/ha) was under I_1 irrigation level, respectively. Among sowing methods, ridge method (9.10% and 279.4 q/ha) had maximum dry matter content and yield as compared to flat-bed method, respectively. Among different treatments, maximum dry matter content (10.53%) and yield (342.4 q/ha) were under S_2I_4 followed by S_2I_3 (9.80% and 323.6 q/ha) and lowest were under S_1I_1 (7.62% and 168.6 q/ha), respectively. The carrot yield increased at higher irrigation schedules which might be due to higher frequency of irrigation, more water application and absorption of adequate amount of water and nutrients. Higher frequencies of irrigation reduce soil strength in the root zone and improve nutrient availability which make conducive conditions for proper growth and development of carrot crop (Pal *et al.* 2020). Adequate moisture content improves nutrient uptake, particularly nitrogen, phosphorus and potassium, that aids to optimal nutrient mobility and availability (Maida *et al.* 2020). Maximum yield under ridge method of sowing might be due to higher aeration and moisture availability in ridges which improve soil quality and facilitates better nutrient uptake from soil (Singh *et al.* 2021). Irrigation and sowing method positively influence root development and soil physical properties and contribute to increased crop productivity (Das *et al.* 2020).

Biochemical parameters

Total soluble solids (TSS) and carotene content (mg/100g): As per pooled data (Table 1), irrigation

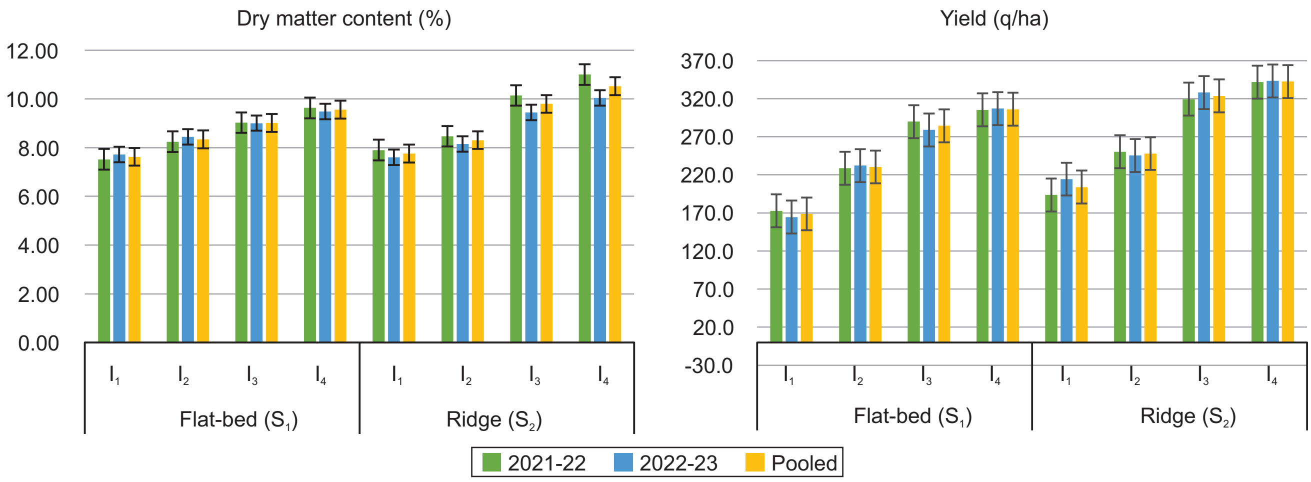

Fig. 1 Effect of irrigation schedules and sowing methods on dry matter content and yield of carrot. Treatment details are given under Materials and Methods.

scheduling had a significant effect on TSS and carotene content. Maximum TSS content was recorded under I_2 (10.23°B) which was statistically at par with I_1 (10.17°B) and minimum TSS content was under I_4 (9.24°B) irrigation schedule. Whereas, highest carotene content was recorded under I_4 (7.40 mg/100 g) was statistically at par with I_3 (7.34 mg/100g) and I_2 (7.24 mg/100g) irrigation schedules. TSS was higher under lower irrigation schedule due to redistribution of photosynthate and increased sugar content under water deficit conditions (Maida *et al.* 2020, Ciza *et al.* 2022). The increased carotene content with IW/CPE 1.2 (ridge) reflects the impact on the growth, metabolism and growth regulators production like auxin, gibberellins, and cytokinin, along with its enhancement of essential macro and micronutrient availability for plant growth (Ombodi *et al.* 2015).

NPK uptake (kg/ha) in carrot: Appraisal of data in Table 2 showed that effect of irrigation schedules, sowing methods and their interaction was significant on N, P and K uptake in carrot. Significantly higher N (85.61 kg/ha), P (21.47 kg/ha) and K (49.42 kg/ha) uptake was under I_4 irrigation level and lower N (41.89 kg/ha), P (7.67 kg/ha) and K (25.81 kg/ha) uptake at I_1 irrigation level. Among sowing methods, highest N (69.83 kg/ha), P (16.55 kg/ha) and K (41.26 kg/ha) uptake was recorded under ridge method of sowing. Among interactions, S_2I_4 had significantly higher N (92.40 kg/ha), P (24.86 kg/ha) and K (53.58 kg/ha) uptake, whereas lowest N (38.34 kg/ha), P (7.04 kg/ha) and K (23.82 kg/ha) uptake was recorded under S_1I_1. Nutrient use is regulated by soil moisture status during the growing season. Irrigation schedules at IW/CPE 1.2 and 1.0 led to frequent irrigation. As a result optimum moisture level is maintained during the growing season and it led to higher translocation of nutrients which might have been efficiently utilized by the crop, resulting in higher nutrient uptake (Kemal 2013). Lower uptake of nutrients in I_1 irrigation level might be due to lower frequency of irrigation and low moisture content in the soil. Another reason for higher uptake in I_4 irrigation level might be due to higher vegetative growth in plants (Sharma *et al.* 2023).

Economics and water indices: The economics and water indices of European carrot were significantly affected by different treatments (Table 3). Higher cost of cultivation of carrot (₹1,63,263) was recorded in S_1I_4 followed by S_2I_4 (₹1,61,969) and S_1I_3 (₹1,60,621) treatment. This could be ascribed to more water application in IW/CPE 1.2 and higher number of interculture operations in flat-bed method. Gross and net income were highest (₹6,84,860 and ₹5,22,892)

Table 2 Effect of irrigation schedules and sowing methods on total NPK uptake of European carrot

Irrigation regimes	Total uptake (kg/ha)								
	N			P			K		
	Flat-bed (S_1)	Ridge (S_2)	Mean	Flat-bed (S_1)	Ridge (S_2)	Mean	Flat-bed (S_1)	Ridge (S_2)	Mean
I_1, IW/CPE 0.6	38.34	45.45	41.89	7.04	8.293	7.67	23.82	27.80	25.81
I_2, IW/CPE 0.8	51.71	56.49	54.10	10.46	11.30	10.88	30.22	34.10	32.16
I_3, IW/CPE 1.0	66.10	84.98	75.54	13.95	21.75	17.85	37.95	49.55	43.75
I_4, IW/CPE 1.2	78.82	92.40	85.61	18.08	24.86	21.47	45.26	53.58	49.42
Mean	58.74	69.83		12.38	16.55		34.31	41.26	
CD (p=0.05)	S: 1.25 I: 1.77 S×I: 2.50			S: 0.39 I: 0.55 S×I: 0.78			S: 0.64 I: 0.90 S×I: 1.27		

S, Sowing method; I, Irrigation schedule.

Table 3 Effect of irrigation schedules and sowing methods on economics and water indices under European carrot cultivation

Treatment		Fixed cost (₹)	Variable cost (₹)	Total cost (₹/ha)	Gross income (₹/ha)	Net returns (₹/ha)	B:C ratio	Return per unit water use (₹/ha/mm)	Water footprint (mm/t ha)	WUE (kg/ha/mm)
S_1, Flat-bed	I_1, IW/CPE 0.6	18,000	1,39,931	1,57,931	3,37,190	1,79,260	1.14	6,61.2	9.595	110.05
	I_2, IW/CPE 0.8	18,000	1,40,630	1,58,630	4,60,690	3,02,061	1.90	1,131.5	7.023	149.90
	I_3, IW/CPE 1.0	18,000	1,42,621	1,60,621	5,68,720	4,08,099	2.54	1,375.7	5.697	154.97
	I_4, IW/CPE 1.2	18,000	1,45,263	1,63,263	6,25,380	4,62,117	2.83	1,300.5	5.285	125.37
S_2, Ridge	I_1, IW/CPE 0.6	18,000	1,38,441	1,56,441	4,07,790	2,51,349	1.61	934.4	7.933	132.13
	I_2, IW/CPE 0.8	18,000	1,39,151	1,57,151	4,95,710	3,38,559	2.15	1,279.0	6.526	161.57
	I_3, IW/CPE 1.0	18,000	1,41,238	1,59,238	6,41,120	4,81,882	3.03	1,617.3	4.999	175.86
	I_4, IW/CPE 1.2	18,000	1,43,969	1,61,969	6,84,860	5,22,892	3.23	1,476.7	4.724	140.27

ET_C during 1st crop growing period = 152.76 mm and ETC during 2nd crop growing period = 170.76 mm. Irrigation water applied = I_1 (170 mm), I_2 (170 mm), I_3 (200 mm) and I_4 (260 mm).

in S_2I_4 followed by S_2I_3 (₹6,41,120 and ₹4,81,882), respectively. Whereas, lowest gross income (₹3,37,190) and net income (₹1,79,260) were recorded under S_1I_1 treatment. Higher yield attributed to highest gross income, as root is the only source of income from carrot cultivation. Similarly, among different treatment combinations, highest B:C ratio was obtained under S_2I_4 (3.23). Returns per unit water use was highest under S_2I_3 (₹1,617.3) followed by S_2I_4 (₹1,476.7) and S_1I_3 (₹1,375.7). This could be attributed to application of adequate amount of irrigation water at appropriate time that leads to maintenance of optimum soil moisture content during the growing season and adoption of suitable sowing method that interwined with nutrient dynamics in soil and plant. It resulted in increased yield with better quality of roots which helps in improving the profitability of farmer (Singh *et al.* 2017).

Water footprint was highest in S_1I_1 (9.595 mm/t ha) and lowest was under S_2I_4 (4.724 mm/t ha) due to lesser moisture content in root zone that reduces soil strength, nutrient uptake and vegetative growth, as a result, higher amount of water needed to produce each unit of the produce in lowest irrigation schedule. Among different treatments, maximum water use efficiency (WUE) was obtained under S_2I_3 (175.86 kg/ha/mm) followed by S_2I_2 (161.57 kg/ha/mm) and S_1I_3 (154.97 kg/ha/mm), whereas, minimum WUE was recorded under S_1I_1 (110.05 kg/ha/mm). There was inverse relation between WUE and amount of irrigation applied, higher irrigation level decreased WUE because of more amount of water applied for per unit quantity of produce (Schiattone *et al.* 2018, Singh *et al.* 2021).

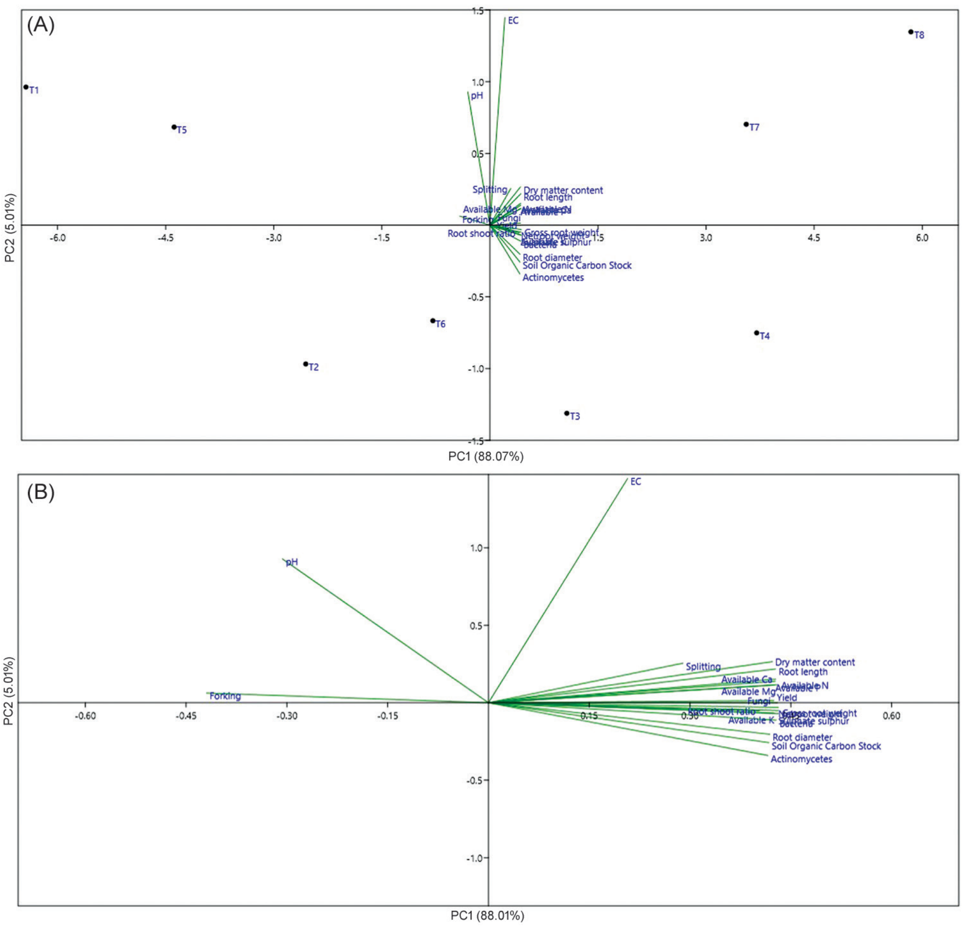

Fig. 2 Principal Component Analysis (PCA). A) Bi-plot, B) Loading plot.

Table 4 Principal component analysis to address variability among variables

Traits	PC1	PC2
Eigenvalue	18.49	1.05
% variance	88.01	5.01
Cumulative variance %	88.01	93.02
Available N	0.232	0.063
Available P	0.229	0.075
Available K	0.228	-0.036
Available Ca	0.230	0.082
Available Mg	0.229	0.061
Sulphate sulphur	0.232	-0.038
Bacteria	0.230	-0.060
Fungi	0.228	0.008
Actinomycetes	0.223	-0.183
Soil organic carbon stock	0.224	-0.138
*p*H	-0.165	0.499
EC	0.111	0.777
Yield	0.231	-0.001
Splitting	0.155	0.137
Forking	-0.225	0.034
Root length	0.230	0.117
Root diameter	0.225	-0.109
Root:shoot ratio	0.217	-0.028
Net root weight	0.232	-0.016
Gross root weight	0.232	-0.027
Dry matter content	0.227	0.143

Principal component analysis: Pooled analysis showed that 2PC's (PC1 and PC2) were found to be significant and it accounts cumulative variation of 93.02% and PC1 showed a total 88.01% variation. PC1 and PC2 showed a significant variability with eigen value ≥ 1.0 (Table 4). In PC1, maximum contribution (0.232) towards variation was shown by available N, sulphate sulphur, net root weight and gross root weight, whereas, in PC2 *p*H (0.777) followed by EC (0.498) contributed most to variation. These traits were the major source of diversity and contributed maximum towards the carrot yield. The alignment of the trait vectors in the direction of treatments indicates that the treatments positively influence the traits (Fig. 2). This directionality revealed that these treatments are most efficient for augmenting the traits considered.

This study clarified that irrigation and land configurations are two important factors for crop production. In this study, ridge method with IW/CPE 1.2 recorded higher growth, yield, carotene content, uptake and net returns. However, ridge with IW/CPE 1.0 significantly increase the WUE and returns per unit water use. But, its performance in terms of growth, yield, nutrient availability, uptake and profitability was inferior to IW/CPE 1.2. Therefore, scheduling of irrigation at IW/CPE 1.2 under ridge method could be safely concluded and recommended for achieving higher and better quality of carrot production.

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