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# Optimization of Sowing Methods and Irrigation Levels on Carrot Productivity (*Daucus carota* L.) in Mid Hills of North Western Himalayas, India

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***Abstract***: The two-year study was conducted from November 2021 to February 2022 and from November 2022 to February 2023 at Dr YSP University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh, India, to evaluate the effect of different irrigation schedules and sowing methods on uptake yield and soil quality under carrot cultivation. The experiment followed a factorial randomized block design with two sowing methods: flat-bed ($S_1$) and ridge ($S_2$) and four irrigation schedules based on IW/CPE ratios: 0.6 ($I_1$), 0.8 ($I_2$), 1.0 ($I_3$) and 1.2 ($I_4$), at 3 cm depth of irrigation. Soil pH remained relatively stable across treatments, while electrical conductivity showed minor variations. Soil organic carbon (SOC) improved significantly with increased irrigation schedules and ridge sowing. The highest biological (478.0 q $ha^{-1}$) and marketable (342.4 q $ha^{-1}$) yield were under $S_2I_4$. Splitting percentage, a key physiological disorder, was lowest under moderate irrigation ($I_2$) and highest under $I_4$. Nutrient uptake (N, P, K) was significantly enhanced under ridge sowing and higher irrigation levels, with maximum uptake observed under $S_2I_4$. The ridge sowing combined with an IW/CPE ratio of 1.2 proved optimal for enhancing productivity and soil health, and is recommended for sustainable carrot cultivation in mid-hill agro-ecological conditions.

***Keywords***: Carrot, *Daucus carota* L., Irrigation schedule, North Western Himalayas

Carrot (*Daucus carota* L.) is an important biennial herbaceous vegetable belongs to family Apiaceae, extensively cultivated on a large scale in China, India, USA, Russia, Uzbekistan, England, Poland, Malaysia, Philippines, Indonesia, and various regions of Africa. Among different agronomic techniques, optimum irrigation schedule and suitable sowing plays an important role in maximizing a variety's potential since they offer the ideal conditions including aeration, moisture, temperature for proper proliferation root, nutrient availability, productivity throughout the growing season (Philippe et al., 2018).

Water is a key limiting factor and plays critical role in growth and production functions of crop. Optimum irrigation schedule is required to achieve higher yields with efficient water utilization that allows the irrigator/farmer to apply the exact amount of water needed. In-sufficient amount of water supply during the time of active growth period resulted in poor nutrient uptake, increase the wastage of limited water and lowers water use efficiency (WUE) as well as the cost of production (Sharma et al., 2023). Inadequate level of water content during crop growth period decreases not only yield, but it also affects the biochemical parameters in carrot. Proper irrigation scheduling is required to calculate the frequency and exact volume of water application, which is essential for obtaining higher crop and water productivity (Maida et al., 2020). In crop production, preparation of seed bed is also an important function that significantly affects the germination, establishment, growth and development of roots. Common sowing methods are flat bed, ridges and furrows and the crop responses is expected to vary markedly with the methods and amount of water used. It also aids in better aeration, compaction, irrigation, moisture conservation and proper drainage of excess of water from the soil (Yadav et al., 2024). The distribution of nutrients in soil and their uptake by plants are influenced by sowing methods and irrigation schedules, which may significantly affect the yield and quality of crop. However, optimization irrigation schedule with suitable sowing method helps in achieving higher crop productivity without compromising the quality of soil and crop. Keeping this in view, present study was conducted to examine the response of European carrot under irrigation water/cumulative pan-evaporation (IW/CPE) based irrigation scheduling with different sowing methods in mid hills of NW Himalayas.

## MATERIAL AND METHODS

The study was conducted during 2021-22 and 2022-23 at Dr YSP University of Horticulture and Forestry, Nauni, Solan (HP). The experimental site is situated at 30°52' N and 77° 11' E, having average altitude of 1175 m above mean sea level with 7-8 per cent average slope. The average annual precipitation in this region is 1100 mm, and there is an annual moisture deficit of around 420 mm, if accounted for yearly PET of 1520 mm. The average maximum and minimum temperatures ranged from 16-27ºC and 3-11ºC, respectively. The soil texture was sandy loam, pH 6.72, EC 0.26 dS/m, organic carbon 1.26 g kg$^{-1}$, bulk density 1.29 Mg m$^{-3}$, particle density 2.53 Mg m$^{-3}$, available N 245.4 kg ha$^{-1}$, P 26.3 kg ha$^{-1}$, K 265.5 kg ha$^{-1}$. The water retention at field capacity (FC) and permanent wilting point (PWP) was 23.9% and 7.2%, respectively.

**Experimental design and field management:** The current study involved 4 irrigation schedules and two sowing methods with 3 replications under factorial randomized block design. The 4 irrigation schedules 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) at 3 cm depth of irrigation and sowing methods *viz.* flat-bed ($S_1$) and ridge ($S_2$). The cumulative pan evaporation (CPE) was measured by summarizing the daily observed evaporation from USWB Class-A pan evaporimeter, which was 0.5 km away from experimental site. Surface irrigation was used to apply measured amounts of irrigation water to the plots through PVC pipes that were equipped with a water flow meter. The study was carried out with *Pusa Yamdagni* variety of carrot (*Daucus carota* L.) in 3 m × 2 m plots of 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 were followed and recommended dose of N (50 kg ha$^{-1}$), $P_2O_5$ (50 kg ha$^{-1}$) and $K_2O$ (40 kg ha$^{-1}$) nutrients with FYM @ 10 t ha$^{-1}$ were uniformly applied. At the time of sowing 1/3$^{rd}$ 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.

**Nutrient uptake**: NPK uptake in root and shoot was calculated by multiplying the corresponding dry matter biomass by the corresponding nutrient concentration.

**Statistical analysis**: Data were analyzed by OPSTAT.

## RESULTS AND DISCUSSION

**Soil chemical properties:** The effect of different irrigation schedules and sowing methods on soil pH, electrical conductivity and soil organic carbon stock at two different depths were evaluated (Table 1). At the 0–15 cm soil depth, the mean soil pH ranged from 6.65 to 6.76 across different irrigation schedules and sowing methods. The flat-bed method exhibited a slightly lower pH compared to ridge method. Among irrigation schedules, pH showed a marginal decrease in pH with increasing irrigation level. Similarly at 15-30 cm depth, the mean pH values varied from 6.79 – 6.88 with no significant differences observed. EC values showed a minor variation across treatments, with significant effects observed for irrigation schedules and non-significant effect for sowing methods or their interactions. At 0–15 cm depth, EC ranged between 0.24 and 0.26 dS m$^{-1}$, with the highest value recorded under highest irrigation schedule at IW/CPE 1.2 (0.26 dS m$^{-1}$). Similar trend was observed at 15–30 cm depth, where EC values increased slightly with irrigation intensity, reaching a maximum of 0.31 dS m$^{-1}$ at IW/CPE 1.2.

**Table 1.** Effect of different irrigation schedules and sowing methods on available pH, EC and SOC at 0-15 and 15-30 cm soil depth

| Sowing methods | Soil depth 0-15 cm | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | pH | | | | | EC | | | | | SOC | | | | |
| | Irrigation schedules | | | | | | | | | | | | | | |
| | IW/CPE 0.6 | IW/CPE 0.8 | IW/CPE 1.0 | IW/CPE 1.2 | Mean | IW/CPE 0.6 | IW/CPE 0.8 | IW/CPE 1.0 | IW/CPE 1.2 | Mean | IW/CPE 0.6 | IW/CPE 0.8 | IW/CPE 1.0 | IW/CPE 1.2 | Mean |
| Flat-bed | 6.76 | 6.73 | 6.70 | 6.61 | 6.70 | 0.25 | 0.23 | 0.24 | 0.25 | 0.24 | 10.65 | 12.65 | 14.30 | 14.82 | 13.11 |
| Ridge | 6.75 | 6.65 | 6.68 | 6.74 | 6.71 | 0.24 | 0.24 | 0.25 | 0.26 | 0.25 | 11.94 | 13.80 | 14.73 | 14.69 | 13.79 |
| Mean | 6.76 | 6.69 | 6.69 | 6.65 | | 0.25 | 0.24 | 0.24 | 0.26 | | 11.30 | 13.23 | 14.52 | 14.76 | |
| CD (p=0.05) | S: NS I: NS S×I: NS | | | | | S: 0.01 I: 0.01 S×I: NS | | | | | S: 0.48 I: 0.68 S×I: NS | | | | |
| Sowing methods | Soil depth 15-30 cm | | | | | | | | | | | | | | |
| | pH | | | | | EC | | | | | SOC | | | | |
| | IW/CPE 0.6 | IW/CPE 0.8 | IW/CPE 1.0 | IW/CPE 1.2 | Mean | IW/CPE 0.6 | IW/CPE 0.8 | IW/CPE 1.0 | IW/CPE 1.2 | Mean | IW/CPE 0.6 | IW/CPE 0.8 | IW/CPE 1.0 | IW/CPE 1.2 | Mean |
| Flat-bed | 6.89 | 6.82 | 6.80 | 6.77 | 6.82 | 0.28 | 0.27 | 0.28 | 0.31 | 0.29 | 8.24 | 8.94 | 9.70 | 10.14 | 9.26 |
| Ridge | 6.86 | 6.81 | 6.80 | 6.81 | 6.82 | 0.27 | 0.28 | 0.30 | 0.31 | 0.29 | 8.71 | 9.22 | 10.47 | 10.10 | 9.63 |
| Mean | 6.88 | 6.82 | 6.80 | 6.79 | | 0.28 | 0.28 | 0.29 | 0.31 | | 8.48 | 9.08 | 10.09 | 10.12 | |
| CD (p=0.05) | S: NS I: NS S×I: NS | | | | | S: NS I: 0.02 S×I: NS | | | | | S: 0.23 I: 0.32 S×I: NS | | | | |

SOC content exhibited significant variation in response to irrigation schedules and sowing methods at both soil depths (0–15 cm and 15–30 cm). SOC contents were increased with increasing irrigation levels, with the highest SOC (14.76 and 10.12 g kg$^{-1}$) was at IW/CPE 1.2, which was statistically at par with IW/CPE 1.0 (14.52 and 10.09 g kg$^{-1}$) at 0-15 and 15-30 cm depths, respectively. Among sowing methods, ridge method of sowing exhibits significantly higher level of SOC (13.79 and 9.63 g kg$^{-1}$) at 0-15 and 15-30 cm, respectively.

Soil pH remained relatively stable across treatments, indicating that irrigation and sowing methods had minimal influence on soil acidity. Electrical conductivity (EC) increased slightly with higher irrigation level, likely due to enhanced nutrient dissolution and ion mobility. SOC was significantly affected, with higher values under higher irrigation schedule and ridge sowing method which was attributed to improved moisture retention, aeration and microbial activity.

**Yield:** The biological and marketable yield were significantly influenced by both irrigation schedules and sowing methods (Table 2). Among irrigation schedules, maximum biological (462.0 q ha$^{-1}$) and marketable yield (324.2 q ha$^{-1}$) was under $I_4$ (IW/CPE 1.2), followed by IW/CPE 1.0 (429.5 and 304.0 q ha$^{-1}$), respectively, indicating positive response to increased irrigation schedules. The ridge sowing outperformed flat-bed method, achieving higher biological (402.5 q ha$^{-1}$) and marketable yield (279.5 q ha$^{-1}$) compared to flat-bed method, indicating the superiority of ridge planting in optimizing growth conditions and resource use efficiency. The ridge sowing method under IW/CPE 1.2 produced the highest marketable yield (342.4 q ha$^{-1}$), followed by ridge at IW/CPE 1.0 irrigation schedule.

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 (Ciza et al., 2022). Higher frequencies of irrigation reduce soil strength in the root zone and improving nutrient availability which make conducive conditions for proper growth and development of carrot crop (Pal et al., 2020).

**Splitting (%):** The splitting was observed significantly higher under $I_4$ (5.50%) and minimum was under $I_2$ (2.44%) (Table 2). Sowing methods and interaction effect showed a non-significant effect on splitting in carrots. Splitting in carrots is primarily caused by fluctuations in soil moisture at varying irrigation schedules. Excessive irrigation led to rapid uptake of water, causing sudden root expansion and rupture, while irregular watering creates alternating drought and rehydration cycles, increasing mechanical stress and making roots more prone to splitting. Conversely, the lowest splitting was observed under the moderate irrigation schedule ($I_2$), suggesting that optimal soil moisture conditions reduced mechanical stress on roots, thereby maintaining structural integrity and minimizing splitting (Gutezeit 2001).

**NPK uptake:** The effect of irrigation schedules, sowing methods and their interaction was significant on the uptake of nitrogen (N), phosphorus (P), and potassium (K) in both roots and shoots of carrot plants (Table 3). The $I_4$ irrigation schedule (IW/CPE ratio of 1.2) resulted highest nutrient uptake, with significantly greater absorption of N (38.49 kg ha$^{-1}$ in roots and 47.12 kg ha$^{-1}$ in shoots), P (4.39 kg ha$^{-1}$ in roots and 17.07 kg ha$^{-1}$ in shoots), and K (22.14 kg ha$^{-1}$ in roots and 27.29 kg ha$^{-1}$ in shoots). Among sowing methods, ridge method demonstrated superior performance, with maximum uptake of N (30.83 kg ha$^{-1}$ in roots and 39.00 kg ha$^{-1}$ in shoots), P (3.55 kg ha$^{-1}$ in roots and 13.00 kg ha$^{-1}$ in shoots) and K (17.87 kg ha$^{-1}$ in roots and 23.39 kg ha$^{-1}$ in shoots). $S_2I_4$ combination (ridge sowing under $I_4$ irrigation) exhibited the highest uptake of all primary nutrients: N uptake of 42.28 kg ha$^{-1}$ in roots and 50.11 kg ha$^{-1}$ in shoots, P uptake of 4.95 kg ha$^{-1}$ in roots and 19.91 kg ha$^{-1}$ in shoots, and K uptake of 24.20 kg ha$^{-1}$ in roots and 29.39 kg ha$^{-1}$ in shoots.

**Table 2.** Effect of different irrigation schedules and sowing methods on biological yield, marketable yield and splitting

| Sowing methods | Biological yield | | | | | Marketable yield | | | | | Splitting (%) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Irrigation schedules | | | | | | | | | | | | | | |
| | IW/CPE 0.6 | IW/CPE 0.8 | IW/CPE 1.0 | IW/CPE 1.2 | Mean | IW/CPE 0.6 | IW/CPE 0.8 | IW/CPE 1.0 | IW/CPE 1.2 | Mean | IW/CPE 0.6 | IW/CPE 0.8 | IW/CPE 1.0 | IW/CPE 1.2 | Mean |
| Flat-bed | 275.2 | 338.8 | 409.7 | 445.9 | 367.4 | 168.6 | 230.3 | 284.4 | 306.1 | 247.3 | 3.05 | 2.75 | 3.37 | 5.74 | 3.73 |
| Ridge | 307.8 | 374.9 | 449.4 | 478.0 | 402.5 | 203.9 | 247.9 | 323.6 | 342.4 | 279.5 | 2.83 | 2.13 | 3.04 | 5.26 | 3.32 |
| Mean | 291.5 | 356.8 | 429.5 | 462.0 | | 186.2 | 239.1 | 304.0 | 324.2 | | 2.94 | 2.44 | 3.20 | 5.50 | |
| CD (p=0.05) | S: 3.90 I: 5.52 S×I: NS | | | | | S: 2.70 I: 3.82 S×I: 5.41 | | | | | S: NS I: 0.60 S×I: NS | | | | |

Nutrient use is regulated by soil moisture status during the growing season (Maida et al 2020). Higher irrigation schedules (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, mobility and availability of nutrients which might have been efficiently utilized by the crop and resulting in higher nutrient uptake (Kemal 2013). Another reason for higher uptake in $I_4$ irrigation level might be due to higher vegetative growth in plants (Sharma et al 2023). 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 (Das et al 2020; Singh et al 2021).

**Correlation:** The correlation matrix was employed to assess the interrelationship among soil physico-chemical properties, microbial populations and yield (Fig. 1). The plot combined pie chart (lower triangle) and elliptical correlation visuals (upper triangle) to effectively communicate both the directions and strength of associations. Intensity of color is directly proportional to correlation coefficient. Red color signifies negative correlation and blue color signifies positive correlation. Circle of pie signifies correlation coefficient, complete circles mean correlation coefficient 1. Yield exhibited very strong positive correlations with microbial population including bacteria, fungi and actinomycetes, suggesting a critical role of soil microbiota in enhancing crop productivity. Similarly, essential nutrients such as soil available nitrogen, phosphorus, potassium, calcium, magnesium, sulphate sulphur and soil organic carbon showed strong positive associations with yield. Conversely, soil pH and EC were exhibited strong negative correlations with yield and soil health indicators, indicating that within the test range, these factors had limited direct impact. These findings highlight the interdependence among chemical and biological soil fertility to carrot yield, offering a robust basis for selecting key indicators in optimizing carrot yield under varying sowing methods and irrigation schedules.

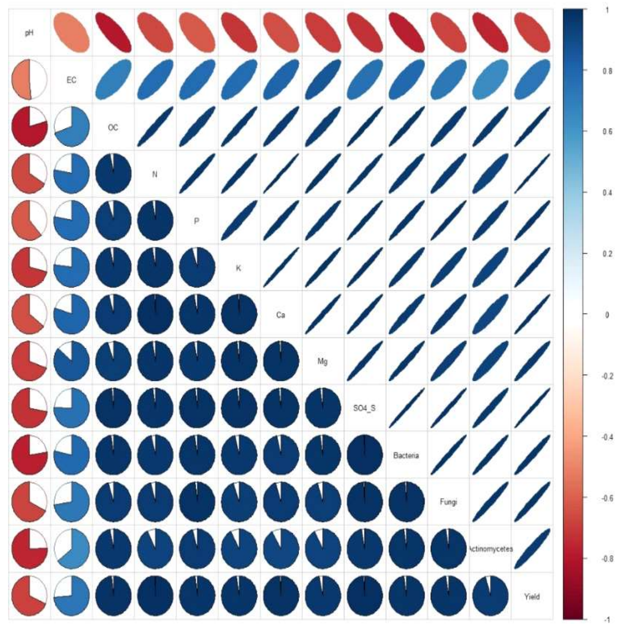


**Fig. 1.** Correlation matrix of soil properties and carrot yield

**Table 3.** Effect of different irrigation schedules and sowing methods on NPK uptake (kg $ha^{-1}$) in roots and shoots

| Sowing methods | NPK uptake in roots | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N | | | | | P | | | | | K | | | | |
| | Irrigation schedules | | | | | | | | | | | | | | |
| | IW/CPE 0.6 | IW/CPE 0.8 | IW/CPE 1.0 | IW/CPE 1.2 | Mean | IW/CPE 0.6 | IW/CPE 0.8 | IW/CPE 1.0 | IW/CPE 1.2 | Mean | IW/CPE 0.6 | IW/CPE 0.8 | IW/CPE 1.0 | IW/CPE 1.2 | Mean |
| Flat-bed | 14.99 | 21.28 | 30.05 | 34.69 | 25.25 | 1.70 | 2.39 | 3.42 | 3.84 | 2.84 | 8.42 | 12.35 | 16.80 | 20.08 | 14.41 |
| Ridge | 19.27 | 24.22 | 37.53 | 42.28 | 30.83 | 2.18 | 2.73 | 4.34 | 4.95 | 3.55 | 11.48 | 14.19 | 21.60 | 24.20 | 17.87 |
| Mean | 17.13 | 22.75 | 33.79 | 38.49 | | 1.94 | 2.56 | 3.88 | 4.39 | | 9.95 | 13.27 | 19.20 | 22.14 | |
| CD (p=0.05) | S: 0.49 I: 0.69 S×I: 0.97 | | | | | S: 0.19 I: 0.27 S×I: 0.38 | | | | | S: 0.44 I: 0.62 S×I: 0.88 | | | | |
| Sowing methods | NPK uptake in shoots | | | | | | | | | | | | | | |
| | N | | | | | P | | | | | K | | | | |
| | IW/CPE 0.6 | IW/CPE 0.8 | IW/CPE 1.0 | IW/CPE 1.2 | Mean | IW/CPE 0.6 | IW/CPE 0.8 | IW/CPE 1.0 | IW/CPE 1.2 | Mean | IW/CPE 0.6 | IW/CPE 0.8 | IW/CPE 1.0 | IW/CPE 1.2 | Mean |
| Flat-bed | 23.35 | 30.42 | 36.06 | 44.13 | 33.49 | 5.34 | 8.08 | 10.53 | 14.23 | 9.54 | 15.40 | 17.87 | 21.15 | 25.18 | 19.90 |
| Ridge | 26.17 | 32.27 | 47.46 | 50.11 | 39.00 | 6.11 | 8.57 | 17.41 | 19.91 | 13.00 | 16.32 | 19.90 | 27.95 | 29.39 | 23.39 |
| Mean | 24.76 | 31.35 | 41.76 | 47.12 | | 5.72 | 8.32 | 13.97 | 17.07 | | 15.86 | 18.89 | 24.55 | 27.29 | |
| CD (p=0.05) | S: 1.11 I: 1.57 S×I: 2.21 | | | | | S: 0.37 I: 0.52 S×I: 0.73 | | | | | S: 0.49 I: 0.70 S×I: 0.98 | | | | |

## CONCLUSION

The irrigation and sowing methods are two important factors for crop production. Ridge sowing combined with higher irrigation schedule (IW/CPE 1.2) significantly enhanced soil organic carbon, nutrient uptake and yield in carrots without adversely affecting pH. Higher irrigation levels improved both yield components but slightly increased splitting percentage. Therefore, it recommended to adopt ridge sowing along with IW/CPE 1.2 for obtaining optimal carrot yield. This combination improved aeration, moisture availability and ensures better soil health, nutrient availability and making it suitable for sustainable crop production.

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