



Influence of Irrigation and Fertigation Levels through Intermittent Drip Irrigation on Yield Contributing Parameters of Carrot (*Daucus carota* L.)

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Water and nutrient management are important for sustainable development of agriculture, so as to achieve higher production. This experimental study aimed to determine the influence of pulse irrigation and fertigation levels through drip irrigation on yield contributing parameters of carrot (*Daucus carota* L.), which were conducted during 2019-20 and 2020-2021 in Dapoli (17° 45' 14" N and 73° 10' 45" E), coastal Ratnagiri, Maharashtra. Three irrigation water levels of 80, 100 and 120% of crop evapotranspiration (ET_c) were applied through four number of pulses P₁, P₂, P₃ and P₄ with constant 30 minutes interval between each pulse. The recommended nutrients were applied with water-soluble fertilizer with rates 80, 100 and 120% of recommended dose of fertilizer (RDF) along-with irrigation water through drip. The highest shoulder diameter was found in P₄ pulse number, I₂ (1.0 ET_c) irrigation level and F₂ (1.0 RDF) fertigation level; and carrot root length in P₂ pulse number, I₃ (1.2 ET_c) irrigation level and F₃ (1.2 RDF) nutrient level. The largest carrot diameter was observed in treatments P₄I₂, P₄F₂, F₃I₂ and P₄I₂F₂, and treatment combinations P₁I₁, P₂F₃, F₂I₁ and P₂I₃F₃ recorded longest carrot roots. The maximum yield of 40.64 t ha⁻¹ and water productivity of 1.37 t ha⁻¹ cm⁻¹ was obtained from P₄I₂F₂ and P₄I₁F₁, respectively.

(Key words: Fertilizer level, Intermittent irrigation, Irrigation level, Root length, Shoulder diameter)

The estimated available water in the country (India) is about 199.9 Mha-m out of which 112.3 Mha-m is utilizable water. The amount of utilizable water comprises of 69 Mha-m and 43.3 Mha-m from both surface and groundwater sources, respectively. The need of fresh water in India for irrigation, domestic, energy, industries and others are 55.38, 4.26, 2.13, 3.55 and 5.68 Mha-m respectively, which sums up to a volume of 71.0 Mha-m (Vohra and Franklin, 2021). Pressure on water resources is expected to further increase as the requirements for food production and industrial needs go up with the country's rapidly growing population and its development (Webber *et al.*, 2006). The economical water resources are limited through worldwide therefore it is an urgent need to identify and adopt efficient irrigation management planning and strategies because agricultural sector accounts over 85% of worldwide water usage in terms of irrigation (Zegbe *et al.*, 2006). Sprinkler and drip systems which comes in category of pressurized irrigation systems can be used to decrease agricultural water demand by reducing water losses. Water can be saved achieved either by decreasing the

irrigation frequency or by a systematic controlling the water for irrigation (Darwish *et al.*, 2006).

Intermittent application of irrigation water (pulse irrigation) rather than all at one time can save water by giving the media time to redistribute water applied in first pulse of water thereby allowing it to absorb subsequent water more readily and reducing the total amount of water required. Increase in watering frequency might provide desirable conditions for water movement in soil media and for uptake by crop roots (Segal *et al.*, 2000). The level of control includes the ability to "pulse" irrigation events to meet the needs of soils that have less than desirable infiltration rates, thus minimizing water losses (Thompson, 2001). Single time irrigation (continuous) water application is associated with increased water percolation under root zone. Pulse based irrigation strategy could improve water management in the field and increase irrigation efficiency (Oron, 1981).

Water and nutrients are the most important inputs which directly affects the plant growth, yield and

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quality of produce. Though India, being the third largest producer and consumer of fertilizer in the world, yet nutrient consumption per unit area and fertilizer use efficiency is very low in India (Sathya *et al.*, 2008). Application of water-soluble nutrients along-with irrigation water through drip is very much effective. These inputs are effectively utilized by the plants as these are placed in the crop root zone. Fertigation technique saves fertilizer as it permits applying fertilizer in small quantities at a time matching with the plants' nutrient uptake and avoids leaching of fertilizers. According to Solaimalai *et al.* (2005), fertigation method gives nutrient use efficiency upto 90% whereas, conventional methods have 40 to 60% only. The excessive quantity of inorganic fertilizers adds more base material to native soil due to which biological dynamics, water and environmental conditions changes in soil.

A field study carried out on a carrot crop showed higher root production, total dry matter and water use efficiency with a water application level of 100% E_{pan} (Prabhakar *et al.*, 1991). Moreover, (Gibberd *et al.*, 2003) studied water application in a carrot crop cultivated in sandy soils and determined that a higher marketable carrot yield is obtained with water application level of 151% E_{pan} . The study on white onion was carried out by Madane *et al.* (2018) and concluded that the yield contributing parameters like mean polar diameter, equatorial diameter and bulb weight were found highest in four pulses. Hajirad (2025) investigated the effects of two irrigation management strategies, pulsed and continuous, in drip irrigation systems at different irrigation levels for silage maize. Applying pulsed irrigation management at over-irrigation, full irrigation, and 80% deficit irrigation levels increased the biological and fresh yields compared to continuous irrigation management. However, under severe deficit irrigation (60% of the crop water requirement), pulsed management led to reduced biological and fresh yields compared to continuous management. Water productivity analysis showed that the maximum water productivity was observed in the 80% water requirement treatment with pulsed management, whereas the minimum was recorded in the 60% water requirement treatment with pulsed management. Yamil *et al.* (2025) concluded that the grain yield, yield components, and water use efficiency of the Haydari wheat cultivar was

achieved in the 18-hour irrigation treatment with three pulses, while the lowest grain yield was observed in the 12-hour irrigation treatment with one pulse. However, there is little information available in India regarding carrot irrigation management with high efficiency systems. Therefore, this field experimental study aimed to determining response of yield parameters by applying different irrigation and fertigation levels on a carrot crop under intermittent (pulse) drip irrigation which was conducted at Dapoli (Konkan) region of Maharashtra.

MATERIALS AND METHODS

A field experiment on carrot (*Rabi* season crop) for the years 2019-20 and 2020-21 was conducted at instructional farm of Department of Irrigation and Drainage Engineering, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli. The experimental site is situated at 17° 45' 14" N latitude and 73° 10' 45" E longitude with altitude of 250 m from mean sea level. The location is in coastal belt of Konkan region of Maharashtra. Climatic conditions are humid with average annual rainfall at Dapoli region is 3635 mm (Mandale *et al.*, 2017). The average minimum and maximum temperatures are 18.5°C to 31.0°C, respectively. The relative humidity ranges from 55 % to 99 % (Gaikwad, 2013). The soil type of experimental field was sandy clay loam textured and having pH 6.5, $EC_{1:2}$ (electrical conductivity) 0.45 dS m^{-1} , bulk density 1.68 gcm^{-3} , basic infiltration rate 6.03 $cm\ hr^{-1}$, field capacity (w/w) 26.02% and permanent wilting point (w/w) 12.50%. The reference crop evapotranspiration (ET_0) was calculated (Allen *et al.*, 1998) using equation (1)

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma(1 - 0.34u_2)} \quad \dots (1)$$

where, ET_0 , reference crop evapotranspiration ($mm\ day^{-1}$); R_n , Net radiation at the crop surface ($MJ\ m^{-2}\ day^{-1}$); G , Soil heat flux density ($MJ\ m^{-2}\ day^{-1}$); T , Mean daily air temperature at 2 m height ($^{\circ}C$); u_2 , Wind speed at 2 m height ($m\ s^{-1}$); e_s , Saturation vapour pressure (kPa); e_a , Actual vapour pressure (kPa); $e_s - e_a$, Saturation vapour pressure deficit (kPa); Δ , Slope vapour pressure ($kPa\ ^{\circ}C^{-1}$); γ , Psychometric constant ($kPa\ ^{\circ}C^{-1}$). The crop evapotranspiration (ET_c) was calculated using equation (2)

$$ET_c = K_c \times ET_0 \quad \dots (2)$$

where, K_c , crop coefficient (dimensionless); ET_c , crop evapotranspiration, mm

The experimental design was laid out in strip-split plot and replicated three times. The unit plot size was 22.0 m × 15.1m having a single bed of 2 m × 0.80 m. The plant and row spacing was 5 cm and 20 cm, respectively. The plots were fertilized with the recommended dose of water soluble fertilizer 100:60:80 Kg ha⁻¹ N, P₂O₅ and K₂O fertilizers. The inline lateral of 16 mm diameter with 4 Lph discharge having 40 cm spacing at 1.0 Kg cm⁻² operating pressure was used. The daily irrigation water applied for carrot (*Daucus carota* L.) under pulse drip irrigation was worked out based on modified Penman-Monteith method (Allen *et al.*, 1998), which was mentioned in equation (1) and (2). The amount of daily crop water requirement was divided according to number of pulse irrigation (intermittent) and then applied it by running the pump for that pulse of time with 30 minutes gap between each pulse. Quantified water amount was applied in three irrigation levels I₁ (0.8× ET_c), I₂ (1× ET_c) and I₃ (1.2× ET_c) with four pulse (intermittent) irrigation

numbers, P₁ - continuous irrigation, P₂ -Two splits irrigation, P₃ - Three splits irrigation and P₄ - Four splits irrigation. Similarly, three fertigation trial was also undertaken: F₁ - 0.8 RDF (recommended dose of fertilizer), F₂ -1.0 RDF and F₃ -1.2 RDF. The carrot cultivar used in the experiment was “Desi red” with values of K_c as 0.7, 1.05, 1.05 and 0.95 for the initial, crop development, mid and maturity stages of the carrot crop, respectively (Allen *et al.*, 1998). The yield contributing parameters such as shoulder diameter and carrot length were recorded of the 5 randomly selected plants. The shoulder diameter of roots was measured at 0.5 cm from the top of the shoulder using a vernier caliper, and measurements were recorded in cm. The root length was determined using a measuring scale starting from the shoulder to the end of the tap root. Statistical analysis for correlation of the findings was done in SAS software for the data of both years. The analysis of variance (ANOVA) of yield contributing parameters of different treatments was statistically calculated with SAS software at the 5% level of significance (Panse and Sukhatme, 1985).

Table 1. Month wise and seasonal gross depth of water applied (mm) in different irrigation levels for carrot

Season	Irrigation Level	Month					Total
		November (*)	December (*)	December (**)	January	February (#)	
2019-2020	ET ₀	3.6	69.3	20.7	125.4	106.3	325.3
	ET _c	2.5	58.9	21.2	132.9	102.3	317.9
	I ₁ (0.8ET _c)	2.6	61.3	17.7	109.4	84.6	275.5
	I ₂ (1.0ET _c)	2.6	61.3	21.9	136	105	326.8
	I ₃ (1.2ET _c)	2.6	61.3	26.2	162.6	125.5	378.1
	ET ₀	20.7	56.1	36.2	96.6	87.2	296.8
2020-2021	ET _c	15.3	49.4	37.5	97.6	84.3	284.1
	I ₁ (0.8ET _c)	15.9	51.3	31.2	81.2	69.8	249.4
	I ₂ (1.0ET _c)	15.9	51.3	38.8	100.7	86.6	293.3
	I ₃ (1.2ET _c)	15.9	51.3	46.3	120.2	103.5	337.2

* General irrigation for plant establishment from 30 November to 24 December 2019 (Ist trial) and 25 November to 19 December 2020 (IInd trial)

** Water application in pulse treatments was imposed on 25 December 2019 (Ist trial) and 20 December 2020 (IInd trial)

Water application in pulse treatments was terminated on 27 February 2020 (Ist trial) and 23 February 2021 (IInd trial)

RESULT AND DISCUSSION

Gross depth of water applied

It is contemplated from Table 1, that total reference evapotranspiration during the crop growth period in year 2019-20 and 2020-21 was 325.3 mm and 296.1 mm, respectively. The crop evapotranspiration (net depth) during the year 2019 - 20 and 2020 - 21 was varied from 317.9 mm to 284.1 mm. From Table 1, total applied water under irrigation treatment I₁ (0.8 ET_c) varied from 275.5 mm to 249.4 mm in the year 2019 - 20 and 2020 - 21, while it was ranging from 326.8 mm to 393.3 mm and 378.1 mm to 337.2 mm for irrigation treatments I₂ (1.0 ET_c) and I₃ (1.2 ET_c), respectively.

Effects of different pulses, irrigation levels and fertigation levels on yield contributing parameters of carrot

The pooled effect of different pulses, irrigation levels and fertigation levels on yield parameters such as average shoulder diameter and average root length of carrot cultivated during both the years are reported in Table 2.

The pulsed irrigation affected significantly to parameters and the average shoulder diameter increases from P₁ to P₄ and average root length of carrot decreases from P₁ to P₃ and again increases from P₃ to P₄. The maximum average shoulder diameter and average root length *i.e.*, 3.96, 4.07 and 4.02 cm and 21.50, 24.65 and 23.08 was found in P₄ and P₁ pulse levels during 2020, 2021 and pooled analysis which was significantly superior than remaining pulse treatments. Further, it is observed that minimum average shoulder diameter and average root length *i.e.*, 3.15, 3.08 and 3.11 cm and 19.92, 23.42 and 21.67 cm was found in P₁ and P₃ pulse levels during 2020, 2021 and pooled analysis, respectively. These results have related findings with (Madane *et al.*, 2018) in case of white onion crop where geometric and polar diameter of an onion was increased by increasing number of irrigation pulses from P₁ to P₄ especially at 100 % of total applied water.

The average shoulder diameter increases from I₁ to

I₂ and then decreases from I₂ to I₃ whereas, the average root length decreases from I₁ to I₃. The maximum average shoulder diameter and average root length was observed to be 3.74, 3.75 and 3.75 cm in I₂ and 20.86, 24.39 and 22.63 cm in I₁ irrigation levels during 2020, 2021 and pooled analysis. It is also observed that minimum average shoulder diameter and average length *i.e.*, 3.35, 3.45 and 3.40 cm and 20.19, 24.02 and 22.10 cm was found in irrigation levels I₁ and I₃ during 2020, 2021 and pooled analysis, respectively. The result on effect of irrigation levels on diameter of carrot have similar trends with (Almoayyad *et al.*, 2019) in case of carrot where root diameter was increased up to certain level of irrigation and then decreased with further increase in total applied water. Further, the results on influence of irrigation levels on average root length of carrot in the present study are in agreement with the findings of Quezada *et al.* (2011), who reported that carrot root length decreased with increasing level of irrigation from 25 to 125% ET_c.

It is reported that the trend of average shoulder diameter and average root length increases from F₁ to F₃. The maximum average shoulder diameter and average root length were found 3.71, 3.75 and 3.73 cm and 20.89, 24.57 and 22.73 cm in F₃ fertigation level during 2020, 2021 and pooled analysis, respectively. It is also observed that minimum average shoulder diameter and average root length *i.e.*, 3.34, 3.42 and 3.38 cm and 20.08, 23.80 and 21.94 cm was found in F₁ fertigation level during 2020, 2021 and pooled analysis, respectively. This might be due to the adequate amounts of nutrient obtained from higher levels of NPK fertilizer applied to the soil which was directly responsible for growth of carrot. These results have similar findings with (Murthy *et al.*, 2016) and (Kharsan *et al.*, 2019) in case of carrot crop where diameter and length per root were found to be increased with increase in quantity of fertigation level.

Interaction effect of pulse and irrigation levels on yield contributing parameters of carrot

The interaction effect of pulse and irrigation levels

Table 2. *Effects of different pulses, irrigation levels and fertigation levels on yield contributing parameters of carrot*

Pulses	Average shoulder diameter (cm)			Average root length (cm)			Irrigation Level	Average shoulder diameter (cm)			Average root length (cm)			Fertigation Levels	Average shoulder diameter (cm)			Average root length (cm)		
	2020	2021	Pooled	2020	2021	Pooled		2020	2021	Pooled	2020	2021	Pooled		2020	2021	Pooled	2020	2021	Pooled
P ₁	3.15	3.08	3.11	21.50	24.65	23.08	I ₁	3.35	3.45	3.40	20.86	24.39	22.63	F ₁	3.34	3.42	3.38	20.08	23.80	21.94
P ₂	3.46	3.48	3.47	20.86	24.43	22.65	I ₂	3.74	3.75	3.75	20.81	24.08	22.44	F ₂	3.69	3.72	3.71	20.88	24.13	22.50
P ₃	3.75	3.89	3.82	19.92	23.42	21.67	I ₃	3.65	3.69	3.67	20.19	24.02	22.10	F ₃	3.71	3.75	3.73	20.89	24.57	22.73
P ₄	3.96	4.07	4.02	20.19	24.15	22.17														
S.E.(m)±	0.04	0.04	0.02	0.11	0.11	0.07		0.03	0.04	0.02	0.09	0.10	0.06		0.04	0.02	0.02	0.11	0.09	0.06
C.D. at 5%	0.11	0.12	0.06	0.32	0.33	0.22		0.10	0.11	0.05	0.28	0.29	0.19		0.16	0.08	0.09	0.44	0.37	0.22

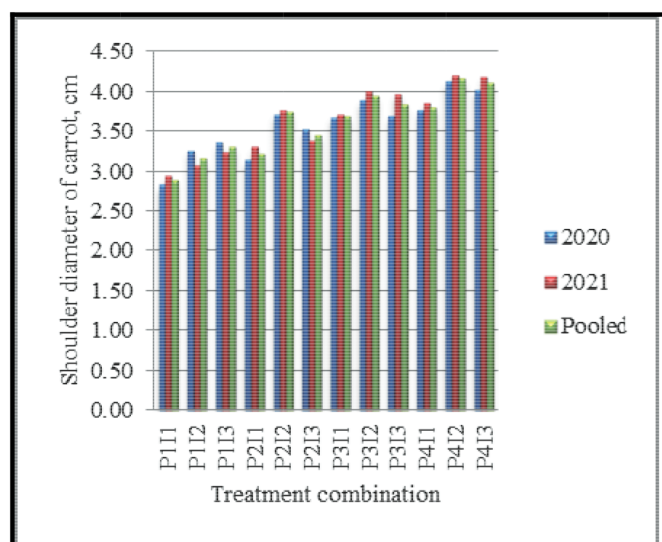


Fig. 1a. Interaction effect of pulse and irrigation levels on average shoulder diameter

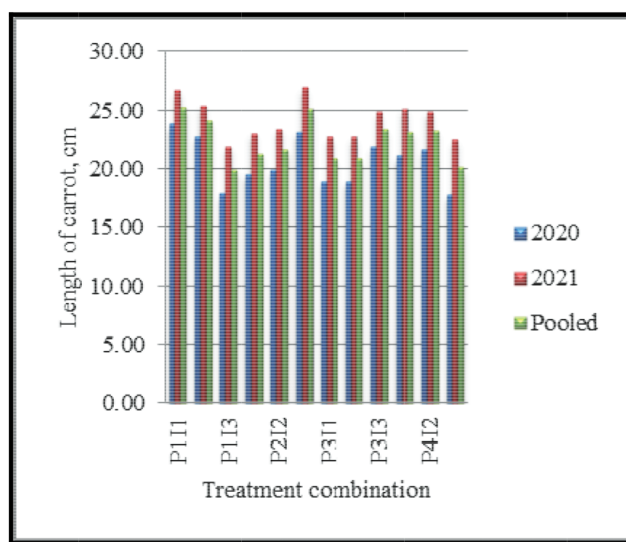


Fig. 1b. Interaction effect of pulse and irrigation levels on average root length

on parameters of carrot were worked out statistically and results are depicted graphically in Fig. 1a and b. The interaction effect of pulse and irrigation levels on parameters of carrot during the year 2020, 2021 and pooled data of both the years were found significant. It is observed that values of parameters during 2020, 2021 and pooled data were found maximum in treatment

combination P_4I_2 and P_1I_1 which are 4.12, 4.19 and 4.15 cm and 23.85, 26.70 and 25.28 cm, respectively except 2021 where the root length in P_2I_3 (26.91 cm) was found highest. The results further revealed that the minimum value was found in treatment combination P_1I_1 (2.83, 2.93 and 2.88 cm) and P_1I_3 (17.88, 21.90 and 19.89 cm), respectively. These results are in line with Madane *et al.* (2018).

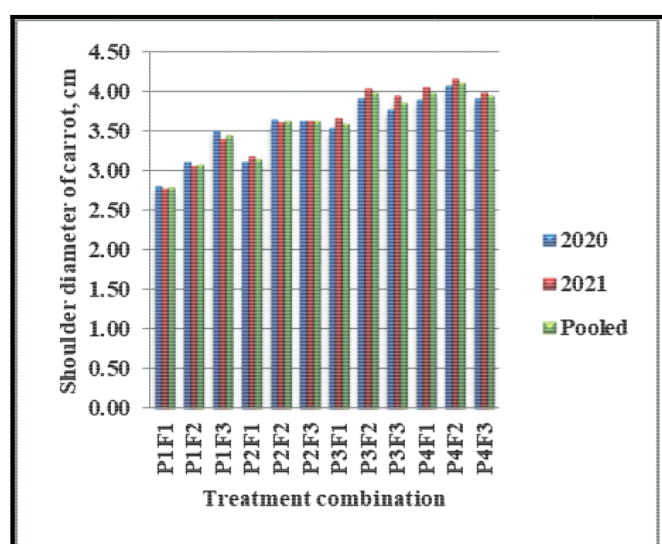


Fig. 2a. Interaction effect of pulse and fertigation levels on average shoulder diameter

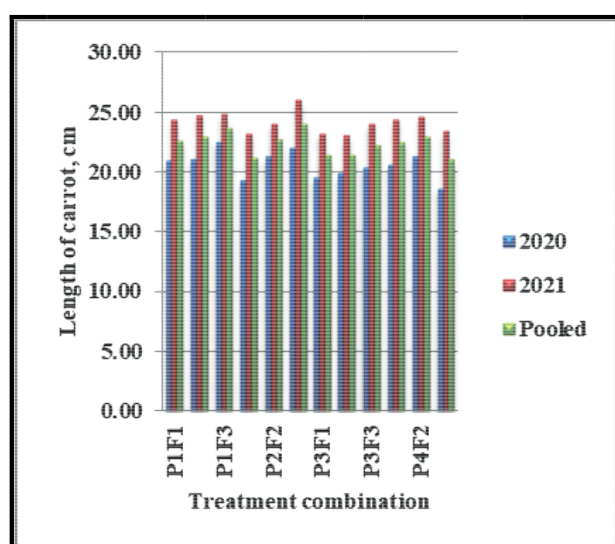


Fig. 2b. Interaction effect of pulse and fertigation levels on average root length

Interaction effect of pulse and fertigation levels on yield contributing parameters of carrot

The interaction effect of pulse and fertigation levels on parameters were worked out statistically and found significant, results are depicted graphically in Fig. 2a and b. The maximum value of average shoulder diameter and average root length were found in P_4F_2 and P_2F_3 during 2020, 2021 and pooled data which were 4.08, 4.17 and 4.12 cm and 22.04, 26.02 and 24.03 cm, respectively except during 2020 where value in P_1F_3 (22.53 cm) found maximum of root length. The results further revealed that minimum average shoulder diameter and average root length 2.81, 2.77 and 2.79 cm and 18.63, 23.41 and 21.02 cm were found in treatment combinations of P_1F_1 and P_4F_3 . This may be consequence of decrease in soil compaction and increase in lateral spread of water at pulse P_4 and optimum nutrient availability at fertigation level F_2 . These results have similar findings with Madane *et al.* (2018) and Murthy *et al.* (2016) by considering individual variable out of pulse irrigation and fertigation level.

Interaction effect of fertigation and irrigation levels on yield contributing parameters of carrot

The interaction effect of irrigation and fertigation

levels on average shoulder diameter and average root length was worked out statistically and results are reported in Fig. 3a and b. The interaction effect on average shoulder diameter and average root length was found significant during the year 2020, 2021 and pooled data of both the years. Also, the maximum value of average shoulder diameter and average root length was found in F_3I_2 and F_2I_1 during 2020, 2021 and pooled data were 3.97, 4.01 and 3.99 cm and 22.44, 24.44 and 23.94 cm, respectively. The results further revealed that minimum average shoulder diameter and average root length *i.e.*, 3.22, 3.26 and 3.24 cm and 18.57, 22.51 and 20.54 cm were found in treatment combinations F_3I_1 and F_2I_3 , respectively. It might happen due to optimum moisture availability at I_2 irrigation level and more nutrient availability at F_3 fertigation level. These findings have some similarities with findings of Mankotia and Sharma (2020).

Interaction effect of pulse, irrigation and fertigation levels on yield contributing parameters of carrot

The overall interaction effect of pulse, irrigation and fertigation levels on average shoulder diameter and average root length of carrot was worked out statistically and results are reported in Table 3. It is reported that the average shoulder diameter and average root length were

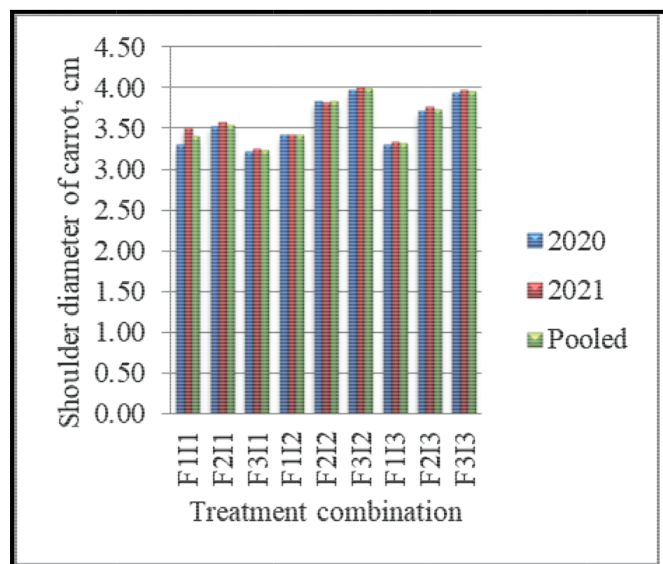


Fig. 3a. Interaction effect of irrigation and fertigation levels on average shoulder diameter

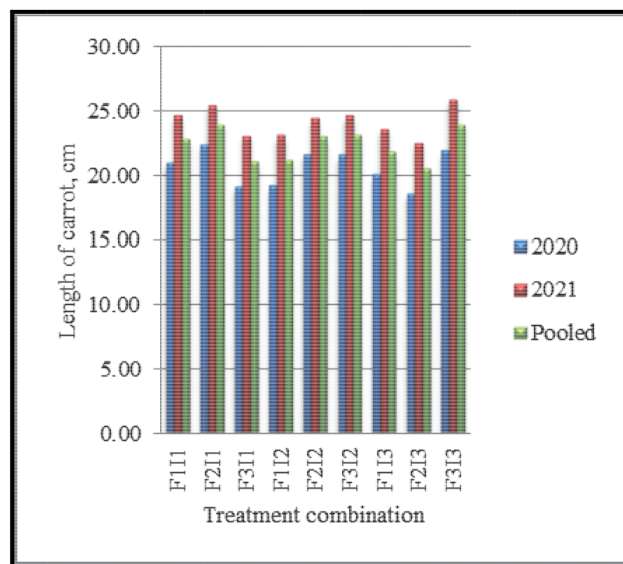


Fig. 3b. Interaction effect of irrigation and fertigation levels on average root length

Table 3. Interaction effect of pulse, irrigation and fertigation levels on average shoulder diameter and average root length of carrot

Treatment combination	Average shoulder diameter (cm)			Average root length (cm)		
	2020	2021	Pooled	2020	2021	Pooled
P ₁ I ₁ F ₁	2.48	2.78	2.63	24.00	26.20	25.10
P ₁ I ₁ F ₂	2.87	2.97	2.92	25.27	28.94	27.10
P ₁ I ₁ F ₃	3.12	3.05	3.09	22.28	24.97	23.62
P ₁ I ₂ F ₁	2.98	2.76	2.87	22.19	24.97	23.58
P ₁ I ₂ F ₂	3.08	2.90	2.99	22.20	24.95	23.58
P ₁ I ₂ F ₃	3.70	3.52	3.61	23.93	26.14	25.04
P ₁ I ₃ F ₁	2.98	2.78	2.88	16.53	21.99	19.26
P ₁ I ₃ F ₂	3.38	3.29	3.34	15.73	20.33	18.03
P ₁ I ₃ F ₃	3.72	3.63	3.68	21.39	23.38	22.38
P ₂ I ₁ F ₁	2.80	3.15	2.98	19.73	23.17	21.45
P ₂ I ₁ F ₂	3.44	3.53	3.49	20.13	23.37	21.75
P ₂ I ₁ F ₃	3.17	3.20	3.19	18.77	22.51	20.64
P ₂ I ₂ F ₁	3.34	3.39	3.36	16.13	21.93	19.03
P ₂ I ₂ F ₂	3.89	3.92	3.90	21.67	24.01	22.84
P ₂ I ₂ F ₃	3.91	3.96	3.93	21.87	24.17	23.02
P ₂ I ₃ F ₁	3.18	2.99	3.09	21.90	24.55	23.23
P ₂ I ₃ F ₂	3.62	3.40	3.51	22.07	24.81	23.44
P ₂ I ₃ F ₃	3.79	3.76	3.77	25.50	31.37	28.44
P ₃ I ₁ F ₁	3.91	3.93	3.92	16.00	21.26	18.63
P ₃ I ₁ F ₂	3.88	3.81	3.85	21.53	23.89	22.71
P ₃ I ₁ F ₃	3.21	3.38	3.30	19.30	22.94	21.12
P ₃ I ₂ F ₁	3.45	3.60	3.52	20.10	23.24	21.67
P ₃ I ₂ F ₂	4.11	4.15	4.13	19.07	22.65	20.86
P ₃ I ₂ F ₃	4.09	4.23	4.16	17.53	22.32	19.93
P ₃ I ₃ F ₁	3.24	3.49	3.37	22.60	25.09	23.85
P ₃ I ₃ F ₂	3.79	4.18	3.98	18.93	22.57	20.75
P ₃ I ₃ F ₃	4.05	4.23	4.14	24.23	26.81	25.52
P ₄ I ₁ F ₁	3.98	4.19	4.08	24.23	27.98	26.11
P ₄ I ₁ F ₂	3.92	3.96	3.94	22.83	25.55	24.19
P ₄ I ₁ F ₃	3.38	3.39	3.39	16.23	21.93	19.08
P ₄ I ₂ F ₁	3.91	3.92	3.92	18.33	22.37	20.35
P ₄ I ₂ F ₂	4.25	4.33	4.29	23.60	26.13	24.86
P ₄ I ₂ F ₃	4.18	4.32	4.25	23.07	26.10	24.58
P ₄ I ₃ F ₁	3.82	4.07	3.94	19.23	22.79	21.01
P ₄ I ₃ F ₂	4.06	4.21	4.13	17.53	22.32	19.93
P ₄ I ₃ F ₃	4.17	4.27	4.22	16.60	22.19	19.40
S.E.(m)±	0.14	0.08	0.08	0.34	0.37	0.24
C.D. at 5%	0.39	0.22	0.23	0.98	1.04	0.67

found significantly influenced with pulse, irrigation and fertigation levels. The average shoulder diameter was found to increase with increase in pulses and fertigation levels; however, it is found to increase up to optimum irrigation level and then started to decrease. The average root length was found decrease with increase in irrigation level and pulses up to P_3 and again increase in P_4 and with increase in fertigation level it is found to increase. The maximum average shoulder diameter is found in $P_4I_2F_2$ i.e., 4.25, 4.33 and 4.29 cm during the year 2020, 2021 and pooled data, which is at par with $P_4I_2F_3$ (4.18, 4.32 and 4.25 cm) during the year 2020, 2021 and pooled data, respectively. The table also revealed that maximum average root length was found in $P_2I_3F_3$ (25.50, 31.37 and 28.44 cm), which were superior to other treatment combinations except during 2020 where it is at par with $P_1I_1F_2$ (25.27 cm).

Further, it is observed that the minimum average shoulder diameter and average root length is found in $P_1I_1F_1$ and $P_1I_3F_2$ which were 2.48, 2.76 and 2.62 cm and 15.73, 20.33 and 18.03 cm during the year 2020, 2021 and pooled data, respectively. It is clearly indicated that the carrot crop found congenial condition in root zone of four pulses (P_4) with optimum irrigation level I_2 under fertigation level F_2 , therefore carrot diameter value was more. Whereas, the root zone was found influenced with water scarcity in one pulse P_1 with lower irrigation level I_1 and fertigation level F_1 so, shoulder diameter value was found lower in treatment combination $P_1I_1F_1$. The treatment combination $P_2I_3F_3$ revealed maximum carrot length, it might be due to availability of ample water and nutrients in the soil which provided favorable condition for root elongation at moderate pulse irrigation.

The interaction effects of pulse, irrigation and fertigation levels on yield ($t\ ha^{-1}$) and water productivity ($t\ ha^{-1}\ cm^{-1}$) of carrot is presented in Table 4. In the present study maximum crop water productivity was obtained in treatment combination of $P_4I_1F_1$ which was highest level of pulse number and lowest level of fertigation and irrigation.

The research work on interaction effect of different pulse irrigation and fertigation levels on water productivity of carrot has some similarities with findings

of the scientists Madane *et al.* (2018) and Mankotia and Sharma (2020). Madane *et al.* (2018) found for white onion crop that water productivity was increased by increasing number of irrigation pulses from P_1 (one time) to P_4 (four time) and decreasing with irrigation level from 120% to 80 % ET_c of total applied water. Whereas, the result of Mankotia and Sharma (2020) revealed that water productivity was found maximum at optimum level of fertigation and lowest level of irrigation water. The research study revealed highest value of yield contributing parameters i.e., average shoulder diameter and average weight of carrot roots in $P_4I_2F_2$ (Four number of pulses, irrigation equivalent to crop evapotranspiration, and recommended dose of fertilizer) due to which highest value of yield obtained from treatment combination $P_4I_2F_2$ which was $40.64\ t\ ha^{-1}$. These results have similarity with findings of (Kharsan *et al.*, 2019; Madane *et al.*, 2018). Similarly, the highest water productivity of $1.37\ t\ ha^{-1}\ cm^{-1}$ was obtained from the treatment combination of $P_4I_1F_1$ (four number of pulses, 80% of ET_c and 80% of RDF).

CONCLUSIONS

The research concluded that yield contributing parameters like average shoulder diameter and root length has shown highest value in the treatment $P_4I_2F_2$ and $P_2I_3F_3$. Furthermore, the average shoulder diameter has shown highest value in $P_4I_2F_2$ (Four number of pulses, irrigation equivalent to crop evapotranspiration, and recommended dose of fertilizer) where soil moisture observed near to field capacity after 2 hours of irrigation about the emitter at 30 cm depth, and at same time the nutrient availability was more, which might have created congenial condition for plant root growth. The favorable condition for parameter growth resulted in highest yield contribution from treatment $P_4I_2F_2$. The maximum yield of $40.64\ t\ ha^{-1}$ and water productivity of $1.37\ t\ ha^{-1}\ cm^{-1}$ was obtained from $P_4I_2F_2$ and $P_4I_1F_1$, respectively.

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Table 4. Interaction effects of pulse, irrigation and fertigation levels on yield ($t\ ha^{-1}$) and water productivity ($t\ ha^{-1}\ cm^{-1}$) of carrot

Treat- ment combi- nation	Carrot yield ($t\ ha^{-1}$)			water productivity ($t\ ha^{-1}\ cm^{-1}$)			Treat- ment combi- nation	Carrot yield ($t\ ha^{-1}$)			water productivity ($t\ ha^{-1}\ cm^{-1}$)		
	2020	2021	Pooled	2020	2021	Pooled		2020	2021	Pooled	2020	2021	Pooled
P ₁ I ₁ F ₁	21.49	24.76	23.13	0.78	0.99	0.88	P ₃ I ₁ F ₁	32.58	35.49	34.04	1.18	1.42	1.30
P ₁ I ₁ F ₂	26.76	29.47	28.11	0.97	1.18	1.07	P ₃ I ₁ F ₂	31.58	34.10	32.84	1.15	1.37	1.25
P ₁ I ₁ F ₃	30.69	30.98	30.83	1.11	1.24	1.17	P ₃ I ₁ F ₃	31.15	31.93	31.54	1.13	1.28	1.20
P ₁ I ₂ F ₁	28.12	31.02	29.57	0.86	1.06	0.95	P ₃ I ₂ F ₁	31.18	33.55	32.36	0.95	1.14	1.04
P ₁ I ₂ F ₂	30.09	32.34	31.21	0.92	1.10	1.01	P ₃ I ₂ F ₂	37.09	37.28	37.18	1.13	1.27	1.20
P ₁ I ₂ F ₃	32.47	34.03	33.25	0.99	1.16	1.07	P ₃ I ₂ F ₃	37.47	39.23	38.35	1.15	1.34	1.24
P ₁ I ₃ F ₁	29.35	30.33	29.84	0.78	0.90	0.83	P ₃ I ₃ F ₁	32.72	33.32	33.02	0.87	0.99	0.92
P ₁ I ₃ F ₂	30.45	33.22	31.84	0.81	0.99	0.89	P ₃ I ₃ F ₂	35.63	37.45	36.54	0.94	1.11	1.02
P ₁ I ₃ F ₃	31.98	34.03	33.00	0.85	1.01	0.92	P ₃ I ₃ F ₃	36.73	38.00	37.37	0.97	1.13	1.04
P ₂ I ₁ F ₁	26.70	29.16	27.93	0.97	1.17	1.06	P ₄ I ₁ F ₁	34.99	36.74	35.87	1.27	1.47	1.37
P ₂ I ₁ F ₂	31.18	33.40	32.29	1.13	1.34	1.23	P ₄ I ₁ F ₂	35.06	35.37	35.22	1.27	1.42	1.34
P ₂ I ₁ F ₃	31.11	31.67	31.39	1.13	1.27	1.20	P ₄ I ₁ F ₃	33.22	32.62	32.92	1.21	1.31	1.25
P ₂ I ₂ F ₁	29.39	32.41	30.90	0.90	1.10	1.00	P ₄ I ₂ F ₁	32.23	34.87	33.55	0.99	1.19	1.08
P ₂ I ₂ F ₂	32.08	34.83	33.45	0.98	1.19	1.08	P ₄ I ₂ F ₂	39.29	41.98	40.64	1.18	1.43	1.30
P ₂ I ₂ F ₃	35.90	35.10	35.50	1.10	1.20	1.15	P ₄ I ₂ F ₃	37.83	41.05	39.44	1.16	1.40	1.27
P ₂ I ₃ F ₁	30.81	31.16	30.98	0.81	0.92	0.87	P ₄ I ₃ F ₁	34.96	36.00	35.48	0.92	1.07	0.99
P ₂ I ₃ F ₂	31.53	33.76	32.64	0.83	1.00	0.91	P ₄ I ₃ F ₂	36.17	38.64	37.41	0.96	1.15	1.05
P ₂ I ₃ F ₃	33.82	35.24	34.53	0.89	1.04	0.97	P ₄ I ₃ F ₃	37.18	39.39	38.29	0.98	1.17	1.07

CONFLICTS OF INTEREST

There is no conflict of interest among the authors.

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