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Effect of drip irrigation scheduling on growth and seed production of fennel (*Foeniculum vulgare* Mill.) under semi-arid agro-climatic condition

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Abstract

The field experiment was conducted at S.K.N. College of Agriculture, Jobner (Rajasthan) during *rabi* season 2012-2013 to select appropriate drip irrigation schedule for maximizing productivity and profitability of fennel. The results showed that drip irrigation at different IW/CPE ratios significantly increased growth parameters, yields, nutrient content and uptake, water use efficiency and economics, except consumptive use of water over surface irrigation at IW/CPE ratio (control). The results further revealed that the drip irrigation at an IW/CPE ratio 0.8 with paired row planting, being at par with 0.8 IW/CPE ratio in normal row planting and drip irrigation at 1.0 IW/CPE ratio in normal and paired row planting, recorded significantly higher plant height and dry matter accumulation/metre row length at 35, 70, 105 DAS and at harvest. Similarly, drip irrigation at an IW/CPE ratio 0.6 with paired row planting, being at par with 0.6 IW/CPE ratio in normal row planting, also significantly increased the above parameters over 0.4 IW/CPE ratio with normal as well as paired row planting. The further analysis of data indicated that the drip irrigation at an IW/CPE ratio 0.6 with paired row planting recorded significantly higher N content in seed and straw, P content in seed over 0.4 IW/CPE ratio in normal and paired row planting and surface irrigation at IW/CPE ratio 1.0, however, it was at par with 0.6 IW/CPE ratio in normal row planting and 0.8 and 1.0 IW/CPE ratio in normal and paired row planting. Results revealed that the consumptive use was found significantly higher with drip irrigation at IW/CPE ratio 1.0 over surface irrigation at IW/CPE ratio 1.0 as well as drip irrigation at IW/CPE ratio 0.4, 0.6 and 0.8 whereas, drip irrigation with 0.4 IW/CPE ratio in paired row planting recorded statistically higher water use efficiency.

Keywords: Drip irrigation, economics, fennel, growth, IW/CPE ratio, nutrient uptake, WUE, yield

Introduction

A spice is a dried seed, fruit, root, bark or vegetative substance used in flavouring, seasoning and imparting aroma in variety of food items and beverages. India has been recognized as a land of spices and at present it is the world's largest producer, consumer and exporter of seed spices. In India, spices and seed spices occupies an area of 3.07 and 1.39 million hectare with production of 5.74 and 1.23 million tonnes, respectively. Similarly, in spices and seed spices Rajasthan occupies an area of 7.30 and 7.09 lakh hectare with production of 8.71 and 8.56 lakh tonnes, respectively (Anonymous, 2). Rajasthan and Gujarat contribute more than 80% of the total seed spices production in the country. Therefore, this region also called as seed spices bowl of the country. The usages of spices by consumers are increasing worldwide because they are completely natural, rather than artificial additives for seasoning and flavouring of foods. Thus, an increasing trend in export of spices has been observed in the last decade particularly to Asian, Latin American and Middle Eastern developing countries.

Fennel (*Foeniculum vulgare* Mill.) plant is stout, aromatic, annual herb (with potency of regeneration) and belongs to family *Apiaceae*. It is mainly cultivated in Gujarat, Rajasthan and Uttar Pradesh. India is the largest producer of fennel with area of about 100 thousand hectare and annual production of 143 thousand tonnes having the productivity of 1430 kg ha^{-1} (Spice board, India). In Rajasthan, it occupies an area of 14.79 thousand hectare and production of 14.97 thousand tonnes with average productivity of 1012 kg ha^{-1}. The average productivity of the fennel crop is low as compared to other parts of the country. The reasons for low productivity may be poor management practices including irrigation.

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Irrigation is the most important input in irrigated agriculture. Efficient use of water is the mainstay of irrigated agriculture. The conventional methods of irrigation *i.e.,* flood irrigation, furrow irrigation have efficiencies of the range of 30 to 50% whereas the overall efficiency of modern methods of irrigation such as drip irrigation and sprinkler irrigation is 90% and 60 %, respectively. The information on proper method of irrigation and its quantity is rather essential. Water is often costly and limiting input in recent years due to low rainfall, expansion in cultivated area and poor recharge of ground water, particularly in the arid and semi-arid areas of Rajasthan and needs judicious use to reap the maximum benefit of other inputs.

Among the irrigation system, drip irrigation helps in maintaining the optimum soil moisture in soil root zone with increased yield and water use efficiency. Efficient use of water is highly critical to sustain agricultural production, more particularly in the context of declining per capita land and water availability. Drip method of irrigation also helps to reduce the over exploitation of ground water and environmental problems associated with the surface method of irrigation like water logging and salinity. Drip irrigation system optimize the irrigation water and put it uniformly and directly to the root zone of the plants at frequent interval based on crop water requirement through a closed net work of pressure plastic pipes. Drip irrigation system improves the WUE because of improving the yield and quality of produce (Singh *et al.,* 15). Irrigation scheduling based on climatological approach (IW/CPE ratio) is now considered as most scientific since it integrate all the weather parameters giving them natural weightage in a given climate-water-plant continuum. There is urgent need to work out optimum irrigation schedule based on various IW/CPE ratios for optimum utilization of limited water resources of this state. With a view of above facts, present investigation was undertaken to find out optimum drip irrigation schedule for fennel.

Materials and methods

An experiment was conducted during winter (*rabi*) season 2012-13 at Agronomy Farm, S.K.N. College of Agriculture, Jobner ($26^0$05' North latitude, $75^0$28' East longitude and at an altitude of 427 metres above mean sea level) situated in agro-climatic zone III A (Semi-arid Eastern Plain Zone) of Rajasthan. The soil was loamy sand in texture, alkaline in reaction (pH 8.15), poor in organic carbon (0.16%) with low available nitrogen (127.11 kg N ha^{-1}) and phosphorus (16.9 kg P_2O_5 ha^{-1}) and medium in potassium content (175.1 kg K_2O ha^{-1}). The field capacity and permanent wilting point of soil was 10.35% and 3.9% on dry weight basis (w/w) with bulk density of 1.46 mg m^{-3}. The total rainfall received during crop season was 31.4 mm. Pan evaporation during crop season was 609.4 mm. The experiment consisted of nine treatments of irrigation levels and planting pattern *viz.,* Surface irrigation at 1.0 IW/CPE ratio with normal row planting (Control, I_1), drip irrigation at 1.0 IW/CPE ratio with normal row planting (I_2), drip irrigation at 1.0 IW/CPE ratio with paired row planting (I_3), drip irrigation at 0.8 IW/CPE ratio with normal row planting (I_4), drip irrigation at 0.8 IW/CPE ratio with paired row planting (I_5), drip irrigation at 0.6 IW/CPE ratio with normal row planting (I_6), drip irrigation at 0.6 IW/CPE ratio with paired row planting (I_7), drip irrigation at 0.4 IW/CPE ratio with normal row planting (I_8) and drip irrigation at 0.4 IW/CPE ratio with paired row planting (I_9). The experiment was laid out in Randomized Block Design with three replications. The plot size was 24 m^2 (6x4 m). A uniform basal dose of 45 kg N + 45 kg P_2O_5/ha through urea and DAP was drilled prior to sowing. The remaining 45 kg N/ha was given at 40 DAS through urea. The crop variety RF 143 sown on October 30, 2012 using 10 kg ha^{-1} seed at a depth of 2-3 cm and harvested on April 17, 2013. In normal row planting, the crop was planted at 50 cm row spacing. In paired row planting, the two row of crop was paired at space of 33 cm leaving a space of 67 cm in between pair. After sowing a common irrigation of 30 mm was applied to ensure germination and subsequent irrigations with the measured quantity of water in each irrigation were given as per irrigation treatment at alternate days in drip irrigation treatments and when CPE reached 50 mm in surface irrigation. The irrigation water was supplied by drip irrigation in drip irrigation treatments and by surface irrigation according to IW/CPE ratios determined by cumulative pan evaporation situated on the farm. The required pressure and discharge in drip system was maintained with overflow valve with the supply source. The separate valve was provided for regulating water supply in each plot. Five plants were selected from net plot and tagged for measurement of plant height. Height of each tagged plant was measured periodically at 35, 70, 105 DAS and at harvest from base of the plant to the tip of the main shoot by metre scale and average of five plants was computed as mean plant height. Dry matter production was recorded at 35, 70, 105 DAS and at harvest. For this, plants from one metre row length were uprooted randomly from sample rows of each plot. After removal of root portion, the samples were first air dried for some days and finally dried in an electric oven at 70 ^{0}C till constant weight. The weight was recorded and expressed as average dry matter (g) per metre row length. At maturity, the net plots were harvested, sun-dried and total biological yield was recorded. After threshing, cleaning and drying, the seed yield was recorded. Straw yield was obtained by subtracting seed yield from the total biological yield. Harvest index was calculated by dividing the seed yield with biological yield (Singh and Stoskopf, 14). The nitrogen was estimated by digesting the samples with sulphuric acid using hydrogen peroxide to remove black colour. Estimation of nitrogen was done by colorimetric method using Nessler's reagent to develop colour (Snell and Snell, 16) and expressed as per cent nitrogen content. Phosphorus content was estimated by using Vanadomolybdo phosphoric acid to develop yellow colour after wet digestion of plant sample (Richards, 13). The uptake of nitrogen and phosphorus was computed from nitrogen and phosphorus content in seed and straw by multiplying seed and straw yield, respectively. Water use efficiency was calculated by dividing the seed yield of fennel by seasonal consumptive use of water. The economics of different treatments was workout based on the prevailing market price of input during the respective crop season. Gross returns were calculated based on the seed and straw yield and their prevailing market price during the respective crop season. Net returns were calculated by subtracting cost of cultivation from gross returns. B:C ratio was calculated by dividing the net returns with cost of cultivation. The analysis and interpretation of data were done using the Fischer's method of analysis of variance technique as described by Gomez and Gomez (7). The levels of significance used in 'F' test were P = 0.05 and critical values were calculated wherever the 'F' test was found significant.

Results and discussion

Growth attributes and yield

Drip irrigation levels up to 0.8 IW/CPE ratios significantly increased growth attributes viz., plant height and dry matter production at 35, 70, 105 DAS and at harvest over surface irrigation at 1.0 IW/CPE ratio (Table 1). The drip irrigation at an IW/CPE ratio 0.8 with paired row planting (I_5) recorded significantly higher growth attributes viz., plant height and dry matter production at 35, 70, 105 DAS and at harvest over lower irrigation level at 0.4 and 0.6 IW/CPE ratios with normal and paired planting (I_9 to I_6) but remained at par to 0.8 IW/CPE ratio in normal row planting (I_4) and 1.0 IW/CPE ratio in normal and paired row planting (I_2 and I_3). The drip irrigation at IW/CPE ratio 0.6 with paired row planting (I_7), being at par with 0.6 IW/CPE ratio in normal row planting (I_6), also significantly increased growth attributes over 0.4 IW/CPE ratio with normal as well as paired planting (I_8 and I_9). The percent increase in plant height at harvest with drip irrigation at IW/CPE ratio 0.8 in paired row planting was 89.7, 56.4, 42.5, 27.0 and 17.7 over surface irrigation in normal row planting at IW/CPE ratio 1.0, drip irrigation at 0.4 IW/CPE ratio in normal and paired row planting and 0.6 IW/CPE ratio in normal and paired row planting, respectively. Drip irrigation at an IW/CPE ratio 0.8 in paired row planting increased dry matter accumulation/meter row length at harvest to the tune of 94.4, 58.0, 35.4, 29.1 and 17.1 percent over surface irrigation in normal row planting at IW/CPE ratio 1.0, drip irrigation at 0.4 IW/CPE ratio in normal and paired row planting and 0.6 IW/CPE ratio in normal and paired planting, respectively.

Chetti *et al.* (6) reported that relative water content of leaf decreases with decrease in soil moisture content and results in an increase in leaf temperature and consequently reduction in the source capacity, which results in decreased net photosynthesis due to increase in the rate of photorespiration resulting in decreased crop growth rate. The leaf expansion rate is one of the important growth character adversely affected by slight decrease in tissue water potential. Water stress affects practically every aspect of plant growth, modifies anatomy, morphology and physiology and biochemistry. The fundamental physiological processes involved in the growth and development of leaves are cell division and cells expansion. Both the number and volume of cells were reduced in individual leaves as the soil metric potential dropped (Alhedi *et al.*, 1).

The seed, straw and biological yield (Table 2) significantly increased with each increase drip irrigation level up to 0.8 IW/CPE ratio over surface irrigation at 1.0 IW/CPE ratio (I_1). The drip irrigation at an IW/CPE ratio 0.8 with paired row planting (I_5), being at par with 0.8 IW/CPE ratio in normal row planting (I_4) and 1.0 IW/CPE ratio in normal as well as paired row planting (I_2 and I_3), recorded significantly higher seed (33.50 q ha^{-1}), straw (79.16 q ha^{-1}) and biological yields (110.67 q ha^{-1}) over 0.4 and 0.6 IW/CPE ratios with normal and paired row planting (I_6 to I_9). Results further revealed that the drip irrigation at an IW/CPE ratio 0.6 with paired row planting (I_7), being at par with 0.6 IW/CPE ratio in normal row planting (I_6), also significantly increased seed, straw and biological yield over 0.4 IW/CPE ratio with normal and paired row planting (I_8 and I_9).The seed, straw and biological yields were increased by 117.5, 95.7 and 130.7 percent with drip irrigation at 0.8 IW/CPE ratio in paired row planting over surface irrigation at 1.0 IW/CPE ratio in normal row planting, respectively. The percent increase in seed yield with drip irrigation at IW/CPE ratio 0.8 in paired row planting was also 117.5, 67.0, 38.8, 26.3 and 15.2 over surface irrigation in normal row planting at IW/CPE ratio 1.0, drip irrigation at 0.4 IW/CPE ratio in normal and paired row planting and 0.6 IW/CPE ratio in normal and paired row planting, respectively. The harvest index of fennel remained statistically same with irrigation at different IW/CPE ratios. Yield of a crop is the result of many physiological processes under which the crop is grown. It is mainly due to drip irrigation resulting in availability of higher soil moisture in the root zone throughout the crop period which resulted in higher relative leaf water content, growth parameters and dry matter production and subsequently in development of yield components and the yield. Nalayani *et al.* (9) also reported that scheduling of irrigation through drip at 0.8 etc was *at par* with 1.0 Etc with respect to seed cotton yield in upland cotton. The yield enhancement due to drip system during summer was 28.9, 44.5 and 61.5, at 0.6, 0.8 and 1.0 Etc over conventional method of irrigation, respectively. The decrease in the yield with surface irrigation was due to lower relative leaf water content and water potential.

In case of drip irrigation system the water is applied directly to the root zone of the plants. It delivers precise and desired amount of water in at very low rates of application to the individual or groups of plants. The emitter applies the water as continuous drops, through a low-pressure delivery system. It helps in maintenance of precise amount of the moisture in the root zone of the plants that help in maintaining the stress free conditions for optimum growth and development of the plants. Bhunia *et al.* (5) also observed that irrigating fennel at an IW/CPE ratio of 0.8 recorded significantly higher plant height, seed and stover yields over lower IW/CPE ratios. Parihar *et al.* (10) also reported that groundnut planted on raised bed in paired row configuration not only produce more pod yield but also gave higher water use and irrigation efficiencies under drip irrigation as compared to flat bed. Patel *et al.* (11) at Anand (Gujarat), reported that scheduling of irrigation under drip system at 0.8 ADFPE recorded significantly higher seed yield of castor (2841 kg ha^{-1}) as compared to conventional method of irrigation.

Nutrient content and uptake

It is evident that the nitrogen content in seed and straw and phosphorus content in seed significantly increased with drip irrigation at an IW/CPE ratio 0.6, 0.8 and 1.0 (I_7 to I_2) in normal and paired row planting over surface irrigation at 1.0 IW/CPE ratio (Table 3). However, drip irrigation at IW/CPE ratio 0.4 in normal and paired row planting (I_8 to I_9) could not bring perceptible increase over surface irrigation at 1.0 IW/CPE ratio (I_1). The drip irrigation at an IW/CPE ratio 0.6 with paired row planting (I_7), being at par with 0.6 IW/CPE ratio in normal row planting (I_7) and 0.8 and 1.0 IW/CPE ratios in normal and paired row planting (I_5 to I_2), observed significantly higher nitrogen content in and straw and phosphorus content in seed over 0.4 IW/CPE ratio in normal and paired row planting (I_8 to I_9). Drip irrigation at different IW/CPE ratios significantly increased total uptake of nitrogen and phosphorus over surface irrigation at 1.0 IW/CPE ratio (I_1). The drip irrigation at an IW/CPE ratio 0.8 with paired row planting (I_5), being at par with 0.8 IW/CPE

Table 1: Effect of drip irrigation scheduling on growth attributes of fennel

Treatment	Plant height (cm)				Dry matter accumulation (g m^{-1} row length)			
	35 DAS	70 DAS	105 DAS	At harvest	35 DAS	70 DAS	105 DAS	At harvest
I_1	5.81	23.13	50.13	69.13	6.25	24.28	47.65	126.56
I_2	10.45	44.14	86.25	125.19	10.71	46.23	89.21	233.84
I_3	10.97	44.18	86.38	128.38	10.79	48.31	95.65	245.36
I_4	9.86	43.04	85.01	123.04	9.96	46.06	89.76	228.61
I_5	10.92	45.13	89.17	131.17	10.05	48.18	95.08	246.08
I_6	8.53	38.04	74.13	103.31	8.67	36.94	70.70	190.64
I_7	9.07	40.10	78.30	111.45	8.73	39.05	77.97	210.15
I_8	7.11	29.14	60.85	83.85	7.38	29.31	58.81	155.74
I_9	7.35	32.25	66.05	92.05	7.45	33.46	67.08	181.70
Sem (±)	0.40	1.63	3.25	4.39	0.41	1.78	3.40	8.99
CD (P=0.05)	1.19	4.86	9.70	13.12	1.22	5.31	10.16	26.89

Table 2: Effect of drip irrigation scheduling on yield water use and economics of fennel.

Treatments	Yield (q ha^{-1})			Harvest index (%)	Consumptive use (mm)	Water use efficiency (kg ha^{-1}mm)	Net returns (₹ ha^{-1})	B:C ratio
	Seed	Straw	Biological					
I_1	15.40	38.91	54.31	28.89	468.6	3.29	80626	2.31
I_2	33.00	77.59	108.59	29.93	522.4	6.32	213659	6.31
I_3	33.51	78.74	110.24	29.98	527.3	6.36	217484	6.43
I_4	32.05	76.64	106.73	29.55	428.1	7.49	207563	6.33
I_5	33.50	79.16	110.67	29.75	432.1	7.75	218438	6.66
I_6	26.52	63.16	89.68	29.59	334.4	7.93	167125	5.26
I_7	29.04	68.09	97.13	29.88	337.4	8.61	186025	5.85
I_8	20.06	49.13	69.19	28.97	243.0	8.26	119709	3.89
I_9	24.13	58.86	82.99	29.08	245.2	9.84	150234	4.89
Sem (±)	1.29	3.23	4.38	1.47	8.32	0.16	9656	0.30
CD (P=0.05)	3.85	10.02	13.10	NS	24.86	0.49	28862	0.89

Table 3: Effect of drip irrigation scheduling on nutrient content and uptake of fennel

Treatments	N content (%)		Total N uptake (kg ha^{-1})	P content (%)		Total P uptake (kg ha^{-1})
	Seed	Straw		Seed	Straw	
I_1	3.470	0.701	80.71	0.438	0.165	13.17
I_2	3.929	0.813	192.74	0.494	0.177	30.04
I_3	3.938	0.821	196.61	0.496	0.179	30.72
I_4	3.881	0.798	185.54	0.492	0.175	29.18
I_5	3.922	0.810	195.51	0.493	0.176	30.45
I_6	3.781	0.784	149.79	0.486	0.169	23.56
I_7	3.820	0.786	164.45	0.488	0.171	25.81
I_8	3.471	0.705	104.26	0.442	0.168	17.12
I_9	3.479	0.711	125.80	0.445	0.169	20.69
Sem (±)	0.093	0.022	6.86	0.011	0.005	0.86
CD (P=0.05)	0.278	0.067	20.51	0.033	NS	2.57

ratio in normal row planting (I_4) and 1.0 IW/CPE ratio in normal and paired row planting (I_2 to I_3), recorded significantly higher total uptake of nitrogen and phosphorus over 0.4 and 0.6 IW/CPE ratios with normal and paired row planting (I_6 to I_9). Further, the drip irrigation at IW/CPE ratio 0.6 with paired row planting (I_7), being at par with 0.6 IW/CPE ratio in normal row planting (I_6), also bring significant improvement in total uptake of nitrogen and phosphorus over 0.4 IW/CPE ratio (I_8 to I_9). The percent increase in total uptake of nitrogen with drip irrigation at IW/CPE ratio 0.8 in paired row planting was 142.2, 87.5, 55.4, 30.5 and 18.89 and total uptake of phosphorus was also 131.2, 77.8, 47.2, 29.2 and 17.9 over surface irrigation in normal row planting at IW/CPE ratio 1.0, drip irrigation at 0.4 IW/CPE ratio in normal and paired row planting and 0.6 IW/CPE ratio in normal and paired row planting, respectively. The paired row planting at 0.4 IW/CPE ratio (I_9) also significantly increased the total uptake of nitrogen and phosphorus over normal row planting at the same level of irrigation. This might be due to improved nutritional environment in the rhizosphere as well as in the plant system leading to enhanced translocation of nutrients in plant parts along with irrigation water. Since the nutrient uptake is a function of its content in crop plant and seed and straw yield of the crop. The increased N and P content in fennel might be ascribed to more availability of moisture in rhizosphere which solubilised the nutrients and ultimately the plants exploited more N and P from soil through their root proliferation. Under adequacy of soil moisture, the transpiration flow gets increased owing to full stomata opening which intends to higher content of nitrogen and phosphorus. The increase in N and P uptake by the crop might be ascribed to the cumulative effect of enhanced seed and straw yield as well as their increased concentration. Similar, findings have been reported by Bhunia *et al.*, (5) in fennel.

Soil moisture studies

The consumptive use of water progressively increased with each increment of IW/CPE ratio (Table 2). The consumptive use (522.4 and 527.3 mm) with drip irrigation at IW/CPE ratio 1.0 in both the methods of planting (I_2 and I_3) was found significantly higher over surface irrigation at IW/CPE ratio 1.0 as well as drip irrigation at IW/CPE ratio 0.4, 0.6 and 0.8. Surface irrigation (I_1) at IW/CPE ratio 1.0 also recorded significantly higher consumptive use over drip irrigation at 0.4, 0.6 and 0.8 (I_9 to I_4). The drip irrigation at IW/CPE ratio 0.4 (I_8 and I_9) also recorded significantly minimum consumptive use of water over higher level of drip irrigation and surface irrigation (control). As compared to drip irrigation at 1.0 IW/CPE ratio with paired row planting the increase in consumptive use were 12.52 percent over surface irrigation at 1.0 IW/CPE ratio, 48.14 and 47.67 percent over drip irrigation at 0.4 IW/CPE ratio in normal and paired row planting, 28.63 and 27.99 percent over drip irrigation at 0.6 IW/CPE ratio in normal and paired row planting, 8.64 and 7.78 percent over drip irrigation at 0.8 IW/CPE ratio in normal and paired row planting, respectively. The higher consumptive use under higher drip irrigation levels as well as surface irrigation over lower drip irrigation levels might be due to the fact that under more soil moisture, evaporation was at potential rate due to availability of more soil water than the crop irrigated with less irrigation water. Similarly, higher irrigation water increased the availability of nutrients, and thus encouraged greater root development, which in turn extracted more soil moisture. It might also be due to more vegetative growth under adequate supply of water which in turn increased the evapotranspiration losses. The water use efficiency as measured by the quantity of water needed to produce unit quantity of fennel seed revealed that this ranged from 6.32 to 9.84 Kg/ha-mm for drip irrigation as against 3.29 Kg/ha-mm under conventional method of surface irrigation. It is further revealed that drip irrigation at different IW/CPE ratios significantly increased water use efficiency over surface irrigation at 1.0 IW/CPE ratio (I_1). Drip irrigation at 0.4 IW/CPE ratio in paired row planting (I_9) recorded statistically higher water use efficiency (9.84 kg/ha-mm) and it was progressively decreased with higher drip irrigation levels at IW/CPE ratio 0.6, 0.8 and 1.0. The enhanced water use efficiency in drip irrigation system is because of decreased surface evaporation, controlled deep percolation loss below the crop root zone, reduced irrigation runoff and irrigation of smaller portion of soil volume. The highest water use efficiency in drip irrigation at 0.4 IW/CPE ratio indicates most efficient utilization of water for growth and development of plants and ultimately yield of crop. The decrease in water use efficiency with increase in drip irrigation level from 0.4 to 1.0 IW/CPE ratio indicates that production of seed per mm of water utilized decrease with increase in irrigation water supply and the relative increase in seed yield of fennel has not been in proportional to the increase in consumptive use, thereby resulting in decrease in water use efficiency under higher levels of drip irrigation levels. Therefore, the water use efficiency clearly indicates that when water quantity limits irrigation, scheduling should be adjusted in accordance to maximize water productivity rather than maximum yield per unit area of land as opined by scientists working for efficient management of irrigation water. These results also substantiated by the findings of Bandyopadhyay *et al.*, (3) in wheat.

Economics

The results indicated that drip irrigation at different IW/CPE ratios significantly increased net returns and B:C ratio over surface irrigation (T_1) at 1.0 IW/CPE ratio (control). The drip irrigation at an IW/CPE ratio 0.8 with paired row planting (T_5), being at par with 0.8 IW/CPE ratio in normal row planting (T_4) and 1.0 IW/CPE ratio in normal (T_2) and paired row planting (T_3), recorded significantly higher net returns (₹ 2,18, 438 ha^{-1}) and B:C ratio (6.66) over 0.4 and 0.6 IW/CPE ratios with normal and paired row planting (T_9 to T_6). The drip irrigation at an IW/CPE ratio 0.6 with paired row planting (T_7) also significantly increased net returns and B:C ratio over 0.4 IW/CPE ratio with normal (T_8) as well as paired row planting (T_9) but remained statistically at par with 0.6 IW/CPE ratio in normal row planting (T_6). The paired row planting at 0.4 IW/CPE ratio also significantly increased the net returns and B:C ratio over normal row planting at the same drip irrigation level. The cost involved under this treatment was comparatively lower than its additional income, which led to more returns under this treatment. These results also substantiated by the findings of Kumar *et al.*, (8) in potato and Rao *et al.*, (12) in cumin. Tripathy and Bastia (17) at Bhubaneswar during summer seasons of 2010 and 2011 also reported that higher net returns of sesame was recorded at 1.0 IW/CPE ratio as compared to 0.6, 0.8 and 1.2 IW/CPE ratios.

Conclusion

From the study of this experiment, it may be concluded that drip irrigation at IW/CPE ratio 0.8 with paired row planting proved to be the most superior treatment as it give higher productivity, economics and water use efficiency from fennel. The study revealed that there is 17.80 to 53.45 per cent savings of irrigation water and yield increases from 30.12 to 177.53 per cent in drip irrigation at different IW/CPE ratios as compared to surface irrigation.

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