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RESPONSE OF CAULIFLOWER ROOT-SHOOT GROWTH PARAMETERS, NUTRIENT UPTAKE AND PRODUCTIVITY TO VARYING DRIP IRRIGATION LEVELS AND FERTIGATION IN WET TEMPERATE ZONE OF WESTERN HIMALAYAS

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ABSTRACT

Experimentation was carried out at Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya, Palampur, India during 2010-11 and 2011-12 in cauliflower following factorial randomized block design, replicated thrice with 10 treatments comprising three drip irrigation levels viz., "$I_{1.2}$ - Drip at 120 % of cumulative pan evaporation (CPE)", "$I_{1.0}$ - Drip at 100 % CPE" and "$I_{0.8}$ - Drip at 80 % CPE", three fertigation levels viz., "F_{100} – 100 % of recommended dose of fertilizer (RDF)", "$F_{66.6}$ – 66.6 % RDF" and "$F_{33.3}$ – 33.3 % RDF" and "Control (I_{Rec}) - flood Irrigation of 4 cm at 8-10 days interval and 100 % RDF". During both the years of investigation the highest magnitude of increase in cauliflower curd yield was registered under treatment $I_{1.2}$ which gave significant respective increases of 8 and 15 % over $I_{1.0}$ and $I_{0.8}$ treatments. As regards fertigation treatments, highest magnitude of increase in above parameter under treatment F_{100} was to the tune of 11 and 16 % in comparison with $F_{66.6}$ and $F_{33.3}$, respectively. The highest magnitude of increase in water use efficiency was registered under drip irrigated treatments which gave significant respective increases of 27 % over control. The results indicated that plant height, number of leaves per plant, root growth parameters, relative leaf water content and nutrient uptake were significantly higher with less weed population in drip irrigation than the plants under surface irrigation.

Key words : *Drip irrigation, fertigation, marketable yield, water use efficiency, nutrient uptake.*

Western Himalayas have favorable soil and climatic conditions for cultivation of various vegetable crops, which are far more profitable than the traditional cereal based cropping systems. As such, it is worthwhile that the farmers should divert a portion of their land from conventional rice (or maize)-wheat sequence to a profitable and sustainable vegetable based cropping sequences. Cauliflower (*Brassica oleracea* var. *botrytis* L.) is one of the major vegetable crop grown under mid hill conditions (wet–temperate) of North–western (NW) Himalayas because of well suited agro-climatic conditions, fetching high premium prices to hill farmers in local and super vegetable markets. The soils of this region have low water retentivity and transmission characteristics due to silty loam/ silty clay loam texture.

In above background, it is very essential to bring the maximum area under irrigation with judicious and economic use of harvested rain water for increasing water productivity. Efficient utilization of "harvested rain-water" either in small or big farm ponds must be emphasized through micro-irrigation systems, especially flowing drip irrigation technology. Drip irrigation is the system for precise application of water to synchronize with the plant needs. It is an eco-friendly irrigation system that saves more than 60 % water and increases the yield by 30-40 % over conventional methods (6). Drip irrigation along with fertilizer (fertigation) reduces the wastage of water and chemical fertilizers and subsequently optimizes the nutrient and water use by applying them at critical stages at proper place and time, which finally increases the water and nutrient use efficiency. Fertigation technology reduces the requirement of fertilizer by 40-60 % and enhances the yield (5). The availability of N, P and K nutrient was found to be higher in root zone area of drip fertigated plots (10). The right combination of water and nutrients is the key for increasing the yield and quality of produce.

Currently, information role of drip irrigation and fertigation is lacking in Himalayan acid Alfisol and need to generate urgently, so that necessary recommendation can be made to the farmers' of above region. Hence, an initiative was taken to enhance yield, water productivity and nutrient uptake of above crop to harvest more produce using less quantity of water applied. The experiment was planned to study the "Effect of varying drip irrigation levels and NPK fertigation on soil water dynamics and productivity of cauliflower (*Brassica oleracea* var. *botrytis* L.)" with following objectives as :

To evaluate the effects of drip irrigation levels applied at 0.8 CPE, 1.0 CPE and 1.2 CPE on plant growth parameters, WUE and productivity.

To evaluate the effects of NPK fertigation on nutrient uptake and productivity at varying drip irrigation levels.

Table-1 : Soil test based fertilizer doses.

Nutrient (kg/ha)	F_{100}	$F_{66.6}$	$F_{33.3}$
N	125	83	42
P_2O_5	55	37	18
K_2O	70	47	23

Table-2 : Effect of drip irrigation and fertigation on marketable yield and water use efficiency (pooled data of 2 years)

Treatment	Curd yield (Mg/ha)	Consumptive water use (mm)	Water use efficiency (kg/ha/mm)
Drip irrigation levels			
$I_{0.8}$	10.08	551.80	18.27
$I_{1.0}$	10.77	599.30	17.97
$I_{1.2}$	11.64	646.26	18.01
CD (P=0.05)	0.59		
Fertigation levels			
F_{100}	12.09	599.12	20.18
$F_{66.6}$	10.94	599.12	18.26
$F_{33.3}$	9.45	599.12	15.77
CD (P=0.05)	0.59		
Control vs Others			
Control	11.14	779.45	14.29
intblOthers	10.83	599.12	18.07
CD (P=0.05)	0.75		

MATERIALS AND METHODS

Study area : Field study was conducted on cauliflower (*Brassica oleracea* var. *botrytis* L.) during 2010-11 and 2011-12 at Experimental Farm of Soil Physics and Water Management, CSK HP KV Palampur, India (32º 6’ N latitude and 76º3’ E longitude, 1250 m above mean sea level) with wet–temperate climate in an acidic silty–clay loam soil. Taxonomically, the soils are classified as Alfisols – Typic Hapludalf (Verma 1979). The initial properties of experimental soil were: Silty clay loam texture, soil reaction (pH) 5.1, organic carbon 12.68 g kg^{-1}, available N (290.2 kg ha^{-1}), available P (48.1 kg ha^{-1}) and available K (270.2 kg ha^{-1}). At 33 and 1500 kPa tensions, soil retained around 0.31 and 0.16 m^3 m^{-3} moisture.

Experimental details : The field experiment on cauliflower was replicated thrice in a factorial randomized block design comprising 10 treatments viz. three drip irrigation levels viz.,” $I_{1.2}$ - Drip at 120 % of cumulative pan evaporation (CPE)”, “$I_{1.0}$ - Drip at 100 % CPE” and “$I_{0.8}$ - Drip at 80 % CPE”, three fertigation levels viz., “F_{100} – 100 % of recommended dose of fertilizer”, “$F_{66.6}$ – 66.6 % RDF” and “$F_{33.3}$ – 33.3 % RDF” and “Control (I_{Rec}) - flood Irrigation of 4 cm at 8-10 days interval and 100 % of recommended dose of fertilizer”.

The averaged pan evaporation data (2004-05 to 2010-11) was used to determine the amount of water to be given in the ratio of 0.8, 1.0 and 1.2 cumulative pan evaporation (CPE). The drip irrigation was applied at 2 days interval. The fertigation involving treatments, soil test based NPK fertilizer doses (125:55:70::N:P_2O_5:K_2O) were applied as per treatment in ten equal splits at 8-10 days interval (Table-1). The water soluble fertilizers viz., urea, 19:19:19 and 0:0:50 were used for fertigation. In control half of N and whole of P and K were given basal and the remaining N was given in two equal splits, at 30 and 75 DAT.

The fresh marketable curd yield of cauliflower was recorded at harvest expressed in Mg/ha. Water use efficiency (kg/ha/mm) was computed from curd yield production per unit consumptive water use. The consumptive water use was calculated by using following equation.

Consumptive Water Use = I + ER ± S

Where, ‘I’ is the amount of irrigation water applied, ‘ER’ is the effective rainfall during the crop period and ‘ÄS’ is the profile water depletion. RLWC was computed from the fresh weight, turgid weight and oven dry weight according to the method given by (16) as

$$\text{RLWC}(\%) = \frac{\text{Fresh weight} - \text{Oven dry weight}}{\text{Fully turgid weight} - \text{Oven dry weight}} \quad 100$$

Root length was computed using the modified version given by (8), as

$$\text{Root Length} = \frac{11}{14} \quad \text{number of intersections (N)}$$

grid unit

The volume of roots was determined by volume displacement method. Roots were then transferred to a filter paper and pressed gently in its folds to remove imbibed water. The roots then dried in an oven at 65 ^{0}C to a constant weight and finally the dried weight was taken. The uptake of nitrogen, phosphorus and potassium in curd and plant without curd were calculated using the following formula (9).

Nutrient uptake (kg/ha) = Nutrient concentration x oven dried biomass (kg/ha)

RESULTS AND DISCUSSION

Crop productivity : The highest magnitude of increase in cauliflower curd yield was registered under treatment $I_{1.2}$. Above treatment gave significant respective increases of 8 and 15 % over $I_{1.0}$ and $I_{0.8}$ treatments (Table-2). However, curd yield obtained under $I_{1.0}$ and $I_{0.8}$ treatments did not differ statistically. Similar findings were also reported by (14), who evaluated the economic feasibility of drip irrigation and indicated that 100 % irrigation requirement met through drip irrigation along with black plastic mulch gave the highest yield (14.51 t/ha) with 72% increase in yield as compared to furrow irrigation.

Table-3 : Effect of drip based irrigation and fertigation on shoot growth and relative leaf water content during crop growth.

Treatment	Shoot growth				Relative Leaf Water Content (%)			
	45 DAT		90 DAT		45 DAT		90 DAT	
	Plant height (m)	No of leaves	Plant height (m)	No of leaves	0700 h	1400 h	0700 h	1400 h
Drip irrigation levels								
$I_{0.8}$	0.19	7	0.30	10	75.63	70.17	78.06	72.46
$I_{1.0}$	0.20	8	0.31	10	80.96	73.51	82.24	78.09
$I_{1.2}$	0.23	8	0.32	12	90.94	82.70	91.04	86.63
CD (P=0.05)	0.01	0.5	0.02	1.2	1.11	1.44	1.94	1.18
Fertigation levels								
F_{100}	0.21	8	0.33	13	83.57	77.23	85.39	80.02
$F_{66.6}$	0.20	8	0.29	11	82.57	75.25	83.88	79.13
$F_{33.3}$	0.20	8	0.30	11	81.38	73.89	82.06	78.03
CD (P=0.05)	0.01	NS	0.02	1.2	1.11	1.44	1.94	1.18
Control vs Others								
Control	0.21	8	0.33	13	84.24	83.14	80.97	75.08
Others	0.21	8	0.31	12	82.51	75.46	82.83	79.06
CD (P=0.05)	NS	NS	0.03	1.5	1.43	1.86	2.50	1.53

As regards fertigation treatments, highest curd yield was registered under treatment F_{100}. The magnitude of increase in above parameter was to the tune of 11 and 16 % under F_{100} in comparison with $F_{66.6}$ and $F_{33.3}$, respectively. Similarly, a significant increase of 16% was registered under $F_{66.6}$ over $F_{33.3}$. In 'control v_s other', treatment control gave overall high curd yield due to application of 100 % soil test based recommended doses of fertilizer and additional water application in comparison with 'others', where varied doses of fertilizer were applied (33.3 to 100 %) and limited water was applied. Further, plant root zone remains fairly constant because irrigation water can be supplied slowly and frequently at a predetermined rate. Here, soil water suction decreased with elimination of wide fluctuations in soil water content. Proven results revealed that the benefits of drip irrigation includes frequent irrigation to crop as far as practicable , free from irrigation induced soil aeration , less plant disease and restricted plant root growth. The present results are in conformity with the findings of (7), who reported highest yield of red hot pepper under 100% recommended dose of nitrogen supplied through drip irrigation.

Water use efficiency : The highest magnitude of increase in WUE was registered under $I_{1.2}F_{100}$ followed by $I_{0.8}F_{100}$ treatment in comparison with all other treatments (Table-2). Above treatments gave a significant respective increase of 48 and 45% over I_{Rec}, which in turn was recorded significantly inferior among all treatments. The highest WUE under above treatments was primarily because of higher yields under these treatments. Any input that enhance yield, also enhances water use efficiency. Moreover, under these treatments fertilizer were applied through fertigation involving drip irrigation. So the plants received the nutrients directly into the root zone without any wastage of nutrients following various factors. The findings of present experimentation are in accordance with (13), who find out 87% more WUE following fertigation in comparison with treatment received furrow irrigation and conventional application of fertilizer.

Returns : Maximum net returns and B:C ratio of cauliflower was observed under I_{Rec} treatment due to lower cost of cultivation, whereas, drip fertigation treatments involved higher cost of production. The reason for higher cost of cultivation under fertigation treatments was because of higher cost of water soluble fertilizers and more cost involved in drip installation. Also, the interest and depreciation values of drip system were included which resulted in higher cost of cultivation. The cost involved in installation of drip irrigation units are one time investment. This cost increased the cost of cultivation in first season, which will be reduced in subsequent years and will provide more net returns and B:C ratio in coming years.

Plant/shoot growth parameters : The data pertaining to the effect of drip irrigation and fertigation on plant height and number of leaves at 45 and 90 DAT are given in table 3. The plant height recorded at 45 DAT indicated that the significantly higher plant height was recorded with $I_{1.2}$ (0.23 m) in comparison to $I_{1.0}$ (0.20 m) and $I_{0.8}$ (0.19 m). The higher plant height in $I_{1.2}$ may be attributed due to higher quantity of irrigation applied throughout the crop growth period. The fertigation treatments (F_{100}, $F_{66.6}$ and $F_{33.3}$) were statistically at par with each other. The plant height under 'control' vs 'others' was not significant. The plants grown under drip irrigation had more number of branches and plant heights compared to that of surface irrigated plants (1).

Table-4 : Effect of drip based irrigation and fertigation on root growth (0-0.30 m) of cauliflower.

Treatment	Root growth							
	45 DAT				90 DAT			
	Root length (m)		Root Volume ($x\ 10^{-6}\ m^3$)	Root weight (g)	Root length (m)		Root Volume ($x\ 10^{-6}\ m^3$)	Root weight (g)
	Primary	Secondary			Primary	Secondary		
Drip irrigation levels								
$I_{0.8}$	0.08	0.68	5.63	0.92	0.09	0.90	14.44	5.90
$I_{1.0}$	0.10	0.95	7.47	1.43	0.10	1.28	20.78	8.53
$I_{1.2}$	0.10	1.18	9.78	1.77	0.11	2.33	28.11	12.50
CD (P=0.05)	0.01	0.06	0.75	0.14	0.01	0.10	0.65	0.69
Fertigation levels								
F_{100}	0.10	1.05	8.56	1.68	0.11	1.78	23.11	10.28
$F_{66.6}$	0.10	0.90	7.77	1.28	0.10	1.48	21.33	9.06
$F_{33.3}$	0.08	0.86	6.56	1.16	0.09	1.25	18.89	7.60
CD (P=0.05)	0.01	0.06	0.75	0.14	0.01	0.10	0.65	0.69
Control vs Others								
Control	0.10	1.17	9.67	2.11	0.10	2.34	25.33	15.78
Others	0.09	0.94	7.63	1.37	0.10	1.50	21.11	8.98
CD (P=0.05)	NS	0.07	0.97	0.17	NS	0.12	0.84	0.89

Table-5 : Effect of drip based irrigation and fertigation on nutrient uptake (kg/ha).

Treatments	Nitrogen uptake (kg/ha)			Phosphorous uptake (kg/ha)			Potassium uptake (kg/ha)		
	Curd	Plant without curd	Total	Curd	Plant without curd	Total	Curd	Plant without curd	Total
Drip irrigation levels									
$I_{0.8}$	43.10	52.93	96.03	28.68	45.06	73.75	8.93	9.12	18.05
$I_{1.0}$	46.23	64.92	111.15	31.15	51.42	82.57	10.50	9.62	20.12
$I_{1.2}$	58.05	68.30	126.35	42.51	51.90	94.41	11.53	10.59	22.11
CD (P=0.05)	3.37	4.02	5.13	6.03	5.18	8.83	0.75	1.32	1.57
Fertigation levels									
F_{100}	56.86	67.77	124.63	39.93	54.35	94.28	11.84	11.09	22.94
$F_{66.6}$	51.05	60.61	111.66	36.05	52.12	88.17	10.24	9.57	19.80
$F_{33.3}$	39.47	57.77	97.24	26.35	41.92	68.27	8.87	8.67	17.54
CD (P=0.05)	3.37	4.02	5.13	6.03	5.18	8.83	0.75	1.32	1.57
Control vs Others									
Control	57.75	68.58	126.33	38.87	47.90	86.77	12.63	8.86	21.49
Others	49.13	62.05	111.18	34.11	49.46	83.58	10.32	9.78	20.09
CD (P=0.05)	4.35	5.19	6.63	NS	NS	NS	0.97	NS	2.02

The plant height recorded at 90 DAT indicated that the plant height in $I_{1.2}$ (0.32 m), $I_{1.0}$ (0.31 m) and $I_{0.8}$ (0.30 m) were statistically at par with each other. The plant height however, recorded in F_{100} (0.33 m) was significantly superior over $F_{66.6}$ and $F_{33.3}$. The higher plant height in F_{100} was due to application of recommended NPK dose in comparison to $F_{33.3}$, where only 33.3 % NPK dose was applied. The plant height recorded under 'control' vs 'others' was statistically at par. Fertigated plants had greater leaf area, dry matter production, and nitrate-N and total N contents than those given through broadcast N with or without drip irrigation (3).

Number of leaves per plant : The highest numbers of leaves per plant were recorded with $I_{1.2}$ (8) followed by $I_{1.0}$ (8), both of them were statistically at par. However, number of leaves per plant recorded in $I_{1.2}$ was significantly higher over $I_{0.8}$ (7). The number of leaves per plant was higher under $I_{1.2}$ due to application of more quantity of water indicating higher soil moisture availability in comparison to $I_{0.8}$. The numbers of leaves under fertigation treatments was not significant. Also the number of leaves per plant under 'control' vs 'others' was not significant. The number of leaves recorded at 90 DAT indicated that the highest number of leaves per plant was recorded with $I_{1.2}$ (12) which was significantly superior over $I_{1.0}$ (10) and $I_{0.8}$ (10). The treatments $I_{1.0}$ and $I_{0.8}$ were however statistically at par with each other. The number of leaves recorded in F_{100} (13) was significantly superior over $F_{66.6}$ (11) and $F_{33.3}$ (11). The number of leaves in 'control' (13) and 'others' (12) were statistically at par with each other. The higher number of leaves per plant in F_{100} treatment was due to the application of recommended doses of fertilizer in comparison to $F_{66.6}$ and $F_{33.3}$ where 66.6 and 33.3 % fertilizer doses were applied.

Relative leaf water content (RLWC) : The relative leaf water content (RLWC) determined at 45 and 90 DAT, during cauliflower growth period at 0700 h and 1400 h are shown in table 3. A significant increase in RLWC was recorded with increasing quantity of irrigation. The RLWC at 45 and 90 DAT were significantly higher under $I_{1.2}$ compared to $I_{1.0}$ and $I_{0.8}$ at 0700 h and 1400 h, respectively. The RLWC decreased with decrease in irrigation amount from $I_{1.2}$ to $I_{0.8}$ leading to proportional decrease in quantity of available water in soil.

The RLWC however, in all the fertigation treatments were statistically at par with each other. The RLWC under 'others' treatment (82.83 and 79.06 %) was significantly higher over 'control' (80.97 and 75.08 %) during 0700 h and 1400 h at 90 DAT. The higher RLWC in 'others' treatments may be due to application of irrigation water at 2-3 days interval which might have maintained higher root zone moisture in comparison to 'control' where irrigations were applied at 8-10 days interval.

Root parameters : The effect of drip irrigation and fertigation on cauliflower root growth parameters at 45 and 90 DAT are presented in table 4. The data revealed that at both 45 and 90 DAT all root parameters like primary root length, secondary root length, root volume and root weight were recorded highest with $I_{1.2}$ followed by $I_{1.0}$ which were significantly superior over $I_{0.8}$. The reduced growth of primary roots in $I_{0.8}$ may be attributed due to lesser availability of soil moisture in the surface layers due to less quantity of irrigation in comparison to $I_{1.2}$ and $I_{1.0}$. More fibrous roots were developed towards the porous drip tubing which supplied moisture and nutrients (4). Among the fertigation treatments, the primary and secondary root length, root volume and root weight were recorded highest with F_{100} followed by $F_{66.6}$ and were significantly superior over $F_{33.3}$. The higher root length, volume and weight under F_{100} attributed due to application of 100 % recommended dose of NPK in comparison to $F_{66.6}$ and $F_{33.3}$ where 66.6 and 33.3 % recommended dose of fertilizer applied. Similar results were also reported by (2). The primary root length under 'control' vs 'others' was not significant. The secondary root length, volume and weight were significantly higher in 'control' in comparison to 'others'. The higher secondary root length, root volume and root weight in 'control' were due the application of recommended NPK doses with conventional fertilizer and recommended irrigation schedule in comparison to 'others' where varied doses of NPK fertilizers (100 to 33.3 % NPK) were applied.

Plant nutrient uptake : The nutrient uptake in curd and plants without curd was determined separately at harvest and is given in table 5. The fresh curd and plant without curd had 91.45 and 85.36 % of water. Accordingly, the oven dried weight was calculated for determination of nutrient uptake.

Nitrogen uptake : The significantly higher N uptake in curd and total uptake (curd + plant without curd) was recorded in $I_{1.2}$ in comparison to $I_{1.0}$ and $I_{0.8}$. There was an increase of N uptake (20.36 and 12.03 %) in curd and total uptake (25.75 and 23.99 %) under $I_{1.2}$ in comparison to $I_{1.0}$ and $I_{0.8}$. The highest nitrogen uptake was observed in plants without curd in $I_{1.2}$ followed by $I_{1.0}$, both of them were statistically at par with each other. There was an increase of N uptake by 22.50 % in plants without curd under $I_{1.2}$ in comparison to $I_{0.8}$. The higher uptake in $I_{1.2}$ may be due to higher soil water content, better root and shoot growth and biological yield. Total nitrogen uptake in drip irrigation was 8–11 % higher than that of furrow irrigation (11).

Among fertigation treatments, significantly higher N uptake was recorded in curd and plants without curd in F_{100} in comparison to $F_{66.6}$ and $F_{33.3}$. The higher N uptake may be due to the application of 100 % recommended dose of fertilizer leading to better root and shoot growth in F_{100} in comparison to $F_{66.6}$ and $F_{33.3}$ where 66.6 and 33.3 % of recommended dose was applied. Similar results were also reported by (12). The N uptake was significantly highest under 'control' over 'others'.

Phosphorus uptake : Phosphorus uptake in curd and total uptake was significantly higher under $I_{1.2}$ in comparison to $I_{1.0}$ and $I_{0.8}$. In plants without curd, higher P uptake was observed in $I_{1.2}$ (10.59 kg/ha) followed by $I_{1.0}$ (9.62 kg/ha), both of them were statistically at par with each other. A significant increase of P uptake by 13.88 % in plants without curd was recorded with $I_{1.2}$ over $I_{0.8}$ (9.12 kg/ha). Among fertigation treatments, significantly higher P uptake was recorded in curd and plants without curd in F_{100} in comparison to $F_{66.6}$ and $F_{33.3}$. The P uptake under 'control' vs 'others' was not significant.

Potassium uptake : A significant increase of K uptake (26.72 and 32.53 %) in curd was recorded with $I_{1.2}$ over $I_{1.0}$ and $I_{0.8}$. However, K uptake in plants without curd was though highest under $I_{1.2}$ but was statistically at par with $I_{1.0}$. The highest K uptake in plants without curd under $I_{1.2}$ treatment may be due to better vegetative growth as a result of more volume of water applied in comparison to $I_{0.8}$. In case of fertigation, the highest K uptake in curd and total uptake was recorded with F_{100} followed by $F_{66.6}$ which was statistically at par with each other. There was an increase of K uptake by 34.00 and 27.58 % in curd and total uptake under F_{100} in comparison to $F_{33.3}$ (26.35 and 68.27 kg/ha). This may be due to the application of 100 % recommended dose of fertilizer in comparison to $F_{66.6}$ and $F_{33.3}$. The highest K uptake was recorded with plants without curd in F_{100} followed by $F_{66.6}$, both of them were statistically at par with each other. The K uptake in curd was significantly highest under 'control' over 'others' whereas K uptake in plants without curd was not significant. The NPK uptake was increased by WSF fertigation (2).

CONCLUSIONS

The highest magnitude of increase in cauliflower curd yield and water use efficiency was registered under fertigation treatment over conventional method of fertilization. The highest magnitude of increase in WUE was registered under drip irrigated treatments which gave significant respective increases of 27% over control. Moreover, irrigation water requirements can be reduced with drip irrigation over traditional one. Primary reasons for water savings include precision irrigation, decreased surface evaporation, reduced irrigation-runoff from the field and controlled deep percolation losses below the crop root zone. Moreover, continuous application of plant nutrients along with the irrigation water is feasible and appears to be beneficial for crop production. The contributing factors for increased efficiency of fertigation include decreased quantities of applied fertilizer, improved timing of fertigation and improved distribution of fertilizer with minimum leaching or runoff.

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