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Growth and yield response of broccoli (*Brassica oleracea* var. *italica*) to varying drip irrigation and fertigation levels

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ABSTRACT

The study was conducted during 2013–14 and 2014–15 at experimental farm of Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya, Palampur with the objective to evaluate the effect of drip irrigation and NPK fertigation levels on crop growth, nutrient uptake, nutrient use efficiency and productivity of broccoli (*Brassica oleracea* var. *italica*) The treatment combinations comprised two irrigation levels (0.4 and 0.8 CPE), four fertigation levels (50, 100, 150 and 200% RDF), one farmer's practice (FYM @ 1 kg/m^2 + 10 g/m^2 IFFCO (basal) + 2 g/L of 19:19:19 at 15 days intervals and drip irrigation applied @ 2 L/m^2 daily), and one recommended practice (100% RDF by conventional method + drip irrigation at 100% CPE). The results revealed that plants grown under fertigation had more number of leaves and plant height as compared to those grown under conventional method. Study on drip fertigation revealed that root length, volume and mass were significantly higher with F200 over F100 and F50 leading to higher marketable yield. However, fertigation treatment F50 resulted in high nutrient use efficiency and saving of 50% and 20–60% fertilizers and water, respectively, as compared to conventional fertilization with drip irrigation at I1.0 to maintain the same yield levels in broccoli.

Key words: Broccoli, Drip Irrigation, Fertigation, Growth, Nutrient Use Efficiency, Yield

Broccoli (*Brassica oleracea* var. *italica*) belonging to family Brassicaceae is a vitamin rich winter vegetable. It is a nutritious vegetable which has green inflorescence (head) rich in chlorophyll, ascorbic acid, vitamins and minerals (Fabek *et al.* 2012). It is a member of cole crops, popular in the state due to high market price and palatable taste compared to cauliflower. Broccoli is grown in winter season when there is low precipitation and high evapo-transpiration. Broccoli being a shallow rooted crop requires frequent irrigation to keep the plant vigorous, and to get higher yield (Gomes *et al.* 2000). However, availability of irrigation water in drier months is the main limiting factor to enhance crop productivity in several parts of the state. Further, the unscientific water management practices coupled with lack of proper water saving technologies can also lead to reduction in crop yield. Scientific management of irrigation water assumes significance in view of the fact that water as a resource in agriculture has become a limiting factor. Hence, judicious use of the available water resources through more efficient methods of water application like drip irrigation becomes necessary to enhance the yield.

Drip irrigation provides an efficient method of water/ fertilizer delivery and allows precise timing and uniform distribution of water and applied nutrients (Pandey *et al.* 2013). By employing fertigation it is possible to adjust doses and times of fertilizer application to the actual requirements of plants, thereby increasing yield and decreasing fertilizer consumption as there are less fertilizer losses due to leaching. To obtain high yield and maximum profits in broccoli production, the optimal management of both fertilizer and water is required. Therefore, it is important to develop irrigation and fertigation scheduling techniques under prevailing climatic conditions in order to utilize scarce water, and fertilizer resources effectively for crop production. Keeping in view the above concern, the study was undertaken to investigate the response of broccoli to different irrigation and fertigation levels to predict an effective drip fertigation schedule for broccoli production.

MATERIALS AND METHODS

The field experiments were conducted during the years 2013–14 and 2014–15 at the experimental farm of CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur. The experimental farm is located in Palampur Valley (32.6°N latitude and 76.3°E longitude, elevation 1290 m amsl) and represents the mid hills agro-climatic zone of Himachal

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Pradesh in North Western Himalayas. Research farm lies in Wet Temperature Zone according to Thornwaite's classification (Aggarwal *et al.* 1978). The average annual rainfall of the place is about 2500 mm. Monsoon starts from June end and ceases in mid- September with more than 70% annual rainfall received during this period. Winter rains are meager and erratic. The mean air temperature varies from 2°C in January to around 33°C during May-June. Soil temperature drops as low as 2°C and frost incidences are common. The relative humidity in the region varies from 46–84%.

The soil of the experiment field was silty clay loam and rich in clay content with accumulation of sesquioxides. Taxonomically, the soils are classified as Alfisols – Typic Hapludalf (Verma 1979). The soil was tilled twice up to 15–20 cm depth before transplanting. Crop was transplanted on October 17, 2013 and October 22, 2014, respectively at 45×45 cm spacing in 12 m^2 plot size. The variety of broccoli used was PalamSamridhi.The treatments comprised two drip irrigation levels, viz. I0.4– Drip at 40% Cumulative pan evaporation (CPE) and I0.8– Drip at 80% CPE; four fertigation levels, viz. F50 – 50% recommended dose of fertilizer (RDF), F100– 100% RDF, F150– 150% RDF and F200– 200% RDF; farmers' practice— FYM @ 1 kg/m^2 + 10 g/m^2 IFFCO (basal) + 2 g/L of 19:19:19 at 15 days intervals and drip irrigation applied @2 L/m^2 daily; and Recommended Practice (RP)— 100% RDF (by conventional method) + drip irrigation at 100% CPE (Table 1). Ten treatment combinations were imposed in a factorial randomized block design which was replicated thrice. The drip lines spaced at 45cm (laterals) × 45cm (drippers) were laid with control valves provided on each lateral. A total number of 48 on line drippers were available for irrigation in 12 m^2 plot. A poly-lined farm pond located near the experimental site served as water source from where water was applied through gravity with hydraulic head of about 8–10 m. The average discharge rate from each dripper was 4.05 L/h. In drip irrigation treatments, drip system was operated daily for 30 min for initial 15 days. The scheduling of irrigation was done according to treatments, commencing 20 days after transplanting. The daily evaporation data was obtained from the University meteorological observatory for last 5 years, viz. 2008 to 2012 for the specific crop period and it was averaged to calculate irrigation requirement by multiplying the averaged values with corresponding CPE ratios. Irrigation was applied daily, except when rainfall or cool weather made irrigation unnecessary.

Table 1 Details of treatments

Treatment	Detail applied
Drip Irrigation levels (I)	
I0.4	Drip irrigation at 40% Cumulative pan evaporation (0.4 CPE)
I0.8	Drip irrigation at 80% Cumulative pan evaporation (0.8 CPE)
Fertigation levels (F)	
F50	50% RDF* applied in 5 splits at 15 days interval
F100	100% RDF applied in 7 splits at 10 days interval
F150	150% RDF applied in 10 splits at 7 days interval
F200	200% RDF applied in 20 splits at 3 to 4 days interval
Farmers' practice (FP)	FYM @ 1 kg/m^2 + 10 g/m^2 IFFCO (basal) + 2 g/L of 19:19:19 at 15 days intervals and drip irrigation applied at the rate 2 L/m^2 daily
Recommended practice (RP)	100% RDF(by conventional method) + drip irrigation at 100% CPE
Total number of treatment combination = 4×2+1+1 = 10	

*Recommended Dose of Fertilizer

Use of 100 % NPK (kg/ha) corresponds to the state level recommendations for respective crop which is 150:100:55. In all fertigation treatments, 25% of the recommended dose of fertilizer (RDF) was applied as basal through conventional fertilizers, viz. urea, SSP and MOP and remaining 75% was applied through drip line using water soluble fertilizers, viz. 19:19:19, 12:61:0 and urea in different splits. In farmer's practice, FYM @1 kg/m^2 + 10 g/m^2 12:32:16 (IFFCO) was applied as basal and 2 g/L of 19:19:19 at 15 days intervals with drip irrigation operated @2 L/m^2 daily. In Recommended Practice, 50% N and full P and K were applied as basal and remaining 25% N was applied after one month of transplanting and 25% N at head initiation stage.

For analyzing the growth pattern of the crop, five plants were selected randomly from the net plot area in each treatment. Root growth parameters, viz. root volume, root length and root mass per plant were determined. Root length was computed using formula by Tenant (1975):

Root length = 11/14 × number of intersections (N) ×grid unit

The volume of roots was determined by volume displacement method. The roots were then oven dried at 65°C to a constant weight and finally the dried weight was taken.The fresh marketable head yield of broccoli along with fresh haulm weight was recorded at harvest and expressed in kg/m^2. For chemical analysis, plant samples were collected from all the plots at harvest. These samples were oven dried at 60 to 70°C till constant weight was recorded. The uptake of nitrogen, phosphorus and potassium in head and haulm were calculated using the following formula by Pomares and Pratt (1987):

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

The nutrient use efficiency (N, P and K) was calculated by the formula (Pomares and Pratt 1987) given as:

NUE= (Total uptake in treated plot-Total uptake in absolute control)/(Total amount of nutrient applied)

The data generated from the field and laboratory studies was subjected to statistical analysis using analysis of variance for factorial randomized block design for the interpretation of results as described by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Effect of different levels of drip irrigation and fertigation on plant growth parameters

Number of leaves per plant: The results pertaining to number of leaves per plant recorded during both years under drip irrigation treatments were not significant (Table 2). However, under fertigation treatments, the higher numbers of leaves per plant were recorded with F200 (20.33) followed by F150 and F100, which were statistically at par with each other. The number of leaves per plant recorded in F200 was significantly higher over F50. The number of leaves per plant under 'FP' vs 'fertigation' was not significant. The number of leaves per plant under 'RP' vs 'others' was significantly superior under 'others' (fertigation including farmers' practice) over 'RP'. During second year also, higher number of leaves per plant were recorded with F200 followed by F150, both of them were statistically at par and significantly superior over F100 and F50. Drip fulfillment at 100% evaporation replenishment with cent % supplementation of recommended dose of nitrogen (200 kg/ha) through fertigation was found to be significantly superior in terms of growth, yield and economics of broccoli in comparison to the conventional fertilization with recommended dose of nitrogen (Sanchita *et al.* 2010).

Plant height: The results pertaining to plant height indicated that drip irrigation treatments I0.8 and I0.4 were statistically at par with each other (Table 2). However, under fertigation treatments, the highest plant height was recorded with F200 (28.73) which was significantly higher over other fertigation treatments. The plant height under 'RP' vs 'others' was significantly superior under 'others' (fertigation including farmer's practice) over 'RP'. During second year, the drip irrigation treatments were not significant. In case of fertigation treatments, the higher plant height was recorded with F200 followed by F150, both of them were statistically at par. However, plant height recorded in F200 (27.68) was significantly higher over F100 and F50.The plant height under 'FP' vs 'fertigation' was not significant. Plant height under 'RP' vs 'others' was found significantly superior under 'others' (fertigation including farmer's practice) over 'RP'.The treatment in which 100% fertilizer was applied through drip recorded maximum plant height (99.36 cm) as compared to 100% RDF through soil and drip irrigation (Sadarunnisa *et al.* 2010).

Table 2 Effect of drip based irrigation and fertigation scheduling on plant growth

Treatment	2013-14		2014-15	
	No. of leaves	Plant height (cm)	No. of leaves	Plant height (cm)
Drip irrigation level				
I0.4	19.18	26.03	17.11	25.38
I0.8	18.80	27.05	18.00	26.32
CD (P=0.05)	NS	1.02	NS	NS
Fertigation level				
F50	17.25	23.90	14.08	23.07
F100	18.13	26.30	16.47	25.67
F150	20.25	27.23	19.00	26.99
F200	20.33	28.73	20.67	27.68
CD (P=0.05)	2.27	1.44	2.17	1.43
Farmer's practice (FP) vs Fertigation levels				
FP	17.33	27.43	15.33	25.43
Fertigation	18.99	26.54	17.55	25.85
CD (P=0.05)	NS	NS	NS	NS
RP vs Others				
RP	14.67	24.28	14.00	24.28
Others	18.81	26.64	17.31	25.80
CD (P=0.05)	2.39	1.52	2.28	1.51

Root parameters: The data indicated that during first year, root length, volume and mass were significantly superior under I0.8over I0.4 (Table 3). Among the fertigation treatments, the highest root length, volume and mass were recorded with F200 which was significantly superior over other fertigation treatments. The root length and root mass were higher under fertigation treatments in comparison to farmer's practice, whereas root volume was found to be insignificant.The root length under 'RP' vs 'others' were significantly at par with each other. However, root volume and mass were significantly higher in 'others' in comparison to 'RP'.

During second year also, similar trend was observed. In case of fertigation treatments, the highest root length, volume and mass were recorded with F200 which were significantly superior over F150, F100 and F50. The root length, root volume and root mass were significantly higher under fertigation treatments in comparison to farmers' practice. The root length, volume and mass were significantly higher in 'others' in comparison to 'RP'. There was greater root concentration in the vicinity of the irrigation and fertigation drip lines for all irrigation treatments (Zotarelli *et al.* 2009). These results may be due to regular and efficient supply of irrigation and nutrition directly into root zone which gives better availability of nutrients through drip contributing to better expression of shoot and root growth. Crop showed a positive response to an increase of NPK concentration solution (Veeranna *et al.* 2001).

Effect of different levels of drip irrigation and fertigation on biological yield

The data revealed that during first year (Fig 1), highest head and haulm yield was recorded under I0.8 (0.95 and 2.97) which was significantly superior over I0.4 and % increase was 7.95 and 6.83, respectively. The higher biological yield in I0.8 was due to more quantity of water application, thereby improving the plant shoot and root growth parameters in comparison to I0.4. Different fertigation levels significantly affected the head and haulm yield of broccoli. The highest head yield was recorded with treatment F200 (1.01) which was at par with F150and

Table 3 Effect of drip based irrigation and fertigation scheduling on root parameters

Treatment	2013–14			2014–15		
	Root length (m)	Root volume ($\times 10^{-6}$ m^3)	Root mass (g)	Root length (m)	Root volume ($\times 10^{-6}$ m^3)	Root mass (g)
Drip irrigation level						
I0.4	2.46	23.73	5.49	2.53	23.89	5.59
I0.8	2.68	25.78	6.26	2.79	26.21	6.27
CP (P=0.05)	0.18	1.81	0.29	0.16	1.72	0.34
Fertigation level						
F50	1.96	18.83	4.02	2.00	17.87	3.99
F100	2.36	22.42	5.20	2.38	22.59	5.04
F150	2.77	25.75	6.49	2.94	26.79	6.41
F200	3.18	32.00	7.79	3.33	32.97	8.29
CP (P=0.05)	0.26	2.56	0.42	0.23	2.43	0.48
Farmer's practice (FP) vs Fertigation levels						
FP	2.29	23.20	5.40	2.39	22.47	5.27
Fertigation	2.57	24.75	5.88	2.66	25.05	5.93
CP (P=0.05)	0.27	NS	0.44	0.24	2.57	0.51
RP vs Others						
RP	2.27	20.50	5.06	2.33	18.80	5.06
Others	2.54	24.58	5.82	2.63	24.76	5.86
CP (P=0.05)	0.27	2.70	0.44	0.24	2.56	0.50

significantly superior over F100 and F50 by 18.82% and 23.17%. The higher biological yield under F200 and F150 may be attributed to application of more amount of fertilizer with more number of fertigation splits as per the requirement of plant. The head and haulm yield obtained under 'FP' vs 'fertigation' was found significantly higher under fertigation treatments. In 'RP' vs 'others', the highest head and haulm yield was obtained under 'others' (fertigation including farmers' practice) which was significantly superior (34.85 and 10.35 %) over 'RP'.Results also revealed that the yield recorded under RP (0.66) was very low even less than the treatments F50 and I0.4 (0.82 and 0.88). Thus, these treatments resulted in saving of 50% fertilizers and 60% water compared to RP where 100% of water and fertilizer dose was applied.

During second year also, similar trend was obtained. The significant increase by 12.5% and 7.79% was recorded in drip irrigation treatment I0.8 (0.72 and 2.49) over I0.4 in head and haulm. In fertigation treatments, the highest head and haulm yield was recorded with treatment F200 (0.87 and 2.79) which was significantly higher over other fertigation treatments. In 'RP' vs 'others', the highest head and haulm yield was

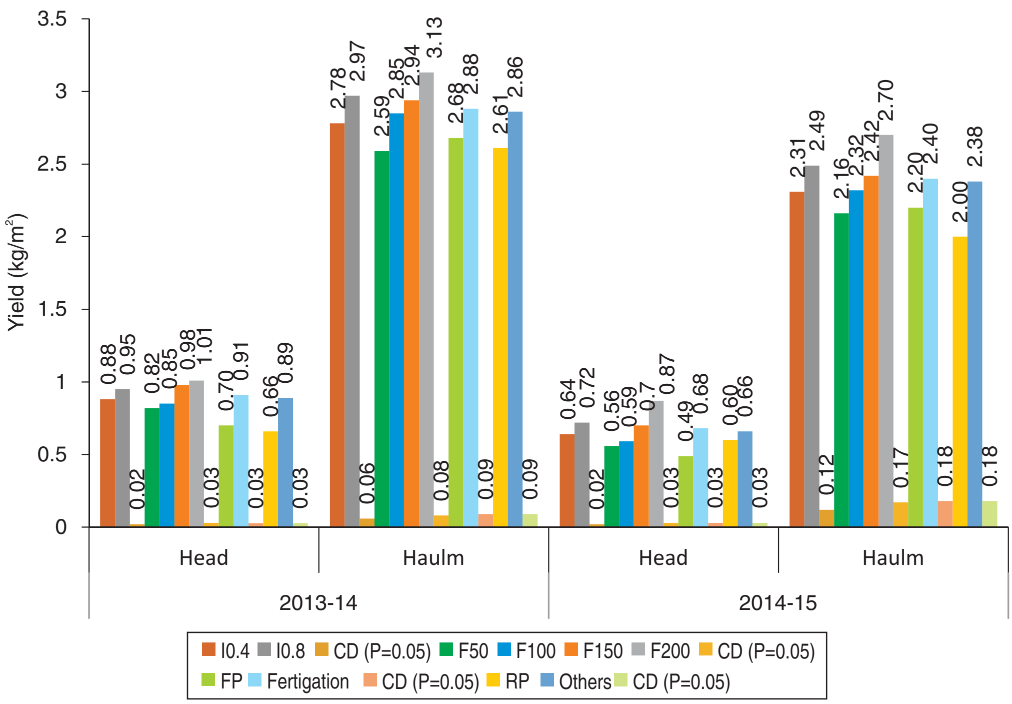

Fig 1 Effect of drip based irrigation and fertigation scheduling on yield (kg/m^2).

Table 4 Effect of drip based irrigation and fertigation scheduling on NUE (%)

Treatment	2013-14			2014-2015		
	NUE	PUE	KUE	NUE	PUE	KUE
Drip irrigation level						
I0.4	52.91	18.79	63.73	54.65	15.32	62.02
I0.8	61.06	20.65	75.14	65.49	16.91	75.61
CP (P=0.05)	3.10	1.20	3.04	4.37	0.58	3.90
Fertigation level						
F50	79.70	28.32	80.05	78.68	23.41	96.32
F100	53.96	20.09	69.41	57.16	15.91	65.72
F150	55.48	15.95	65.99	56.66	12.61	56.63
F200	38.79	14.54	62.29	47.78	12.52	56.61
CP (P=0.05)	4.38	1.70	4.31	6.18	0.82	5.51
Farmer's practice (FP) vs Fertigation levels						
FP	91.25	17.49	61.09	97.91	14.03	61.68
Fertigation	56.98	19.72	69.44	60.07	16.11	68.82
CP (P=0.05)	4.64	1.80	4.57	6.55	0.87	5.85
RP vs Others						
RP	36.74	10.01	50.47	32.63	7.49	44.70
Others	60.79	19.47	68.51	64.28	15.88	68.03
CP (P=0.05)	4.61	1.79	4.45	6.51	0.87	5.81

obtained under 'others' (fertigation including farmers' practice) which was significantly higher (10% and 19%) over 'RP'. Drip fertigation gave significantly higher tomato yield (24% and 39%) in comparison to drip irrigation and furrow irrigation with conventional fertilizer application (Tanaskovik *et al.* 2011).

Effect of different levels of drip irrigation and fertigation on nutrient use efficiency

During both the years, the drip irrigation treatment I0.8 resulted in higher N, P and K use efficiency in comparison to the I0.4 (Table 4). The higher nutrient use efficiency with respect to N, P and K in I0.8 may be attributed to higher uptake of nutrients which in turn improved the yield and other growth parameters of the plants.

Among fertigation treatments, the highest N, P and K use efficiency was recorded in F50 which was significantly higher over other fertigation treatments. However, it is very difficult to obtain maximal nutrient use efficiency and maximal yield simultaneously because reduction in the amount of fertilizer results in higher nutrient use efficiency but at lower fertilizer rate higher yield can't be achieved. Thus, higher nutrient use efficiency is achieved at lower fertilizer rate. Application of 50% recommended dose of fertilizer improved fertilizer use efficiency (Singandhupe *et al.* 2007). In 'farmers' practice' vs 'fertigation' the N use efficiency was significantly higher under 'farmers' practice' over 'fertigation' treatments. Whereas, P and K use efficiency was recorded highest under fertigation treatment. Under 'RP' vs 'others', the N, P and K use efficiency was recorded highest in 'others' over 'RP' by 65.46, 94.5 and 35.74%, respectively. The reason for better response in fertigation where nutrients were applied through split doses to match the nutrients uptake by the crop as compared to RP where soil application of conventional fertilizers results in less nutrient use efficiency.

From the above mentioned results, the study concluded that increasing the drip irrigation quantity from 0.4 to 0.8 CPE and fertigation from 50 to 200% RDF significantly increased the plant growth parameters and marketable yield. However, it is very difficult to obtain maximal NUE and maximal yield simultaneously because reduction in the amount of fertilizer results in higher NUE; but at lower fertilizer rate higher yield can't be achieved. Thus, higher NUE is achieved at lower fertilizer rate. Study concluded that fertigation F50 with drip irrigation saved fertilizers and water to the tune of 50% and 20–60% as compared to conventional fertilization with drip irrigation at I1.0 to maintain the same yield levels in broccoli.

With the need to increase productivity while saving water, microirrigation will play a key role for the future of Indian agriculture.The balanced crop nutrition is also critical for high yield, and while most farmers are able to apply needed nutrients in the early stages of crop growth only. Further, the study will help farmers to adopt drip irrigation and fertigation, through which nutrients like N, P, K which are needed in high amounts can be added throughout the growth season to encourage optimum yield.

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