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Influence of drip fertigation levels and scheduling on root characters of broccoli (*Brassica oleracea* L var. *italica*)

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Abstract
Efficient use of water and fertilizer is highly critical to sustain the agricultural production in the context of declining per capita land and water availability, pollution and increasing cost of fertilizers. Field experiments were conducted during *Rabi* season for two consecutive years (2016-17 and 2017-18) to study the effect of drip fertigation levels and scheduling on root growth of broccoli under *tarai* conditions of Uttarakhand. The experiment was laid out in two factorial randomized block design with one additional treatment replicated thrice. The treatment consists of five fertigation levels and two scheduling along with one control as additional treatment. Root length, root spread, fresh root weight and root dry mass were increased under drip fertigation practices as compared to conventional method of fertilizer application along with surface irrigation. Fertigation promotes the production of intensely branched roots that facilitates nutrient acquisition as well as foraging capacity. On the other hand, conventional method of irrigation and fertilizer application has exhibited limited root spread and rooting depth in the rhizosphere.

Keywords: Drip fertigation, broccoli, root length, root spread, fresh root weight, dry root weight

Introduction

Sprouting broccoli (*Brassica oleracea* L. var. *italica*), which derives its name from the Latin word 'brachium' meaning arm/branch belongs to the family Brassicaceae (Boswell, 1949; Gomez-compo, 1999) [4, 5]. It is an Italian vegetable and native to Mediterranean region. The edible part of broccoli is its inflorescence and is harvested before the flower buds to begin to open along with 10 cm of crisp fleshy stem. It is a very delicious, nutritious and exotic vegetable. It is rich in vitamins and minerals. It contains 2500 IU vitamin A in a 100 g edible part. It also contains 103 mg calcium, 78 mg phosphorous, 382 mg potassium and 113 mg vitamin C (Kohli *et al*., 2006) [7]. Now-a-days, broccoli attracted more attention due to its multifarious use and high nutritional value (Rangkadilok *et al*., 2004) [11]. Consumption of broccoli in daily diet minimizes the incidence of various types of cancers in human beings. It has cancer fighting substances like phytochemicals, ß-carotenes, indoles and isothiocynates. Besides this, it also contains Sulforaphane which checks the growth of tumours and reduces the risk of cancer.

Water is one of the most important inputs for a successful crop production. In present situation due to change in climate, rapid industrialization, population growth and urbanization, water has become a scarce natural resource. So today there is urgent need to reduce the consumption of water in irrigation. This could be possible by developing new irrigation efficient technologies and methods that could help to utilize precious input in an effective way. Drip irrigation is one of the latest and efficient method of irrigation having about 90 per cent water use efficiency. It is a type of micro-irrigation that has the potential to save water and nutrients by allowing water to drip slowly to the roots of plants minimize evaporation.

Efficient use of water and fertilizer is highly critical to sustain the agricultural production in the context of declining per capita land and water availability, pollution and increasing cost of fertilizers. Under this circumstances, fertigation could play a significant role in crop production. It is a efficient method of applying fertilizer through irrigation system as a carrier and distributor of crop nutrients holds key (Bachchhav, 2005) [3]. In the conventional practice of fertilizer application, a considerable portion of the applied fertilizer may not be available to the crop as majority of nutrients are lost or fixed in the soil as they come in contact with a large mass of soil and thereby reducing the nutrient availability to crop.

Improved efficiency of nutrient in crop may be possible if the fertilizer are applied at the right time of its requirement. Split fertilizer applications also play an important role in a nutrient management strategy, dividing total fertilizer applications in split doses according to crop demand. This technique enhances nutrient efficiency, promote optimum yields and mitigate the losses (Shock *et al*., 2003) [12].

Emphasis on the fertilizer application rate, source, timing and nutrient balance is critical for achieving good productivity of crop. Most of the work on nutrient management has been carried out using conventional methods fertilizer application. The information, however, on use of water soluble fertilizers, which has recently been introduced in the country especially for fertigation, is scanty. Furthermore, nutrient status is expected to vary markedly under fertigation and soil fertilization levels, hence there is a need to standardize nutrient elements applied through drip irrigation system. A retrospective analysis of work done on the above mentioned problems showed very limited information on vegetable crops especially on broccoli. With this background, this experiment was planned under *tarai* conditions of Uttarakhand to study the effect of fertigation involving the source and rate of fertilizers, scheduling of fertigation and methods of irrigation and fertilizer application on root characters of broccoli.

Materials and Methods

The field trial was conducted at Vegetable Research Centre of Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Udham Singh Nagar, Uttarakhand, India during *Rabi* season for two consecutive years (2016-17 and 2017-18). Pantnagar is situated in the *tarai* foothills of Shivalik range of the great Himalayas. It is geographically situated at an altitude of 243.84 m above mean sea level with a latitude of 29^0 N and longitude of 79.3^0 E. The climate of this area is humid sub-tropical with maximum temperature ranging from 32^0 C to 43^0 C in summer (May-June) and minimum temperature ranging from 0^0C to 9^0 C during winter (January). The monsoon starts in month of June and often remains active up to the month of September. The physicochemical and chemical properties of the surface soil (0-0.15 m were determined before transplanting of seedlings. The soil had a pH value of 7.23, available N of 160.22 kg/ha, available P of 46.86 kg/ and available K of 323.90 kg/ha.

The experiment was laid out in two factorial randomized block design with one additional treatment replicated thrice. The treatment details are given in the table below. The quantity of water applied through drip was calculated based on the following formula given by Allen *et al*. (1998) [1]. V= Ep × Kp × Kc × Sp × Sr × Wp Where, V= Water requirement of plant per day (l), Ep= PAN evaporation, Kp=Pan Coefficient, Kc= Crop coefficient varies according to growth, Sp= Plant to plant spacing (m), Sr=Row to Row spacing (m), Wp= Fraction wetted area. Treatment details are as follows:

A) Fertigation levels (NPK): 5

F_1: 120 per cent of RDF
F_2: 100 per cent of RDF
F_3: 80 per cent of RDF
F_4: 60 per cent of RDF
F_5: 40 per cent of RDF

B) Scheduling of NPK fertigation throughout the growth period: 3

1. S_1

Crop growth stage	No of splits	Total nutrients supplied		
		N	P	K
Stage I (1-15 DAT)	4	25 percent of fertigation levels	15 percent of fertigation levels	20 percent of fertigation levels
Stage II (15-30 DAT)	4	40 percent of fertigation levels	15 percent of fertigation levels	25 percent of fertigation levels
Stage III (30-45 DAT)	4	20 percent of fertigation levels	50 percent of fertigation levels	40 percent of fertigation levels
Stage IV (45-60 DAT)	4	15 percent of fertigation levels	20 percent of fertigation levels	15 ercent of fertigation levels

2. S_2

Crop growth stage	No of splits	Total nutrients supplied		
		N	P	K
Stage I (1-15 DAT)	4	25 percent of fertigation levels	25 percent of fertigation levels	25 percent of fertigation levels
Stage II (15-30 DAT)	4	25 percent of fertigation levels	25 percent of fertigation levels	25 percent of fertigation levels
Stage III (30-45 DAT)	4	25 percent of fertigation levels	25 percent of fertigation levels	25 percent of fertigation levels
Stage IV (45-60 DAT)	4	25 percent of fertigation levels	25 percent of fertigation levels	25 ercent of fertigation levels

3. S_3

Crop growth stage	No of splits	Total nutrients supplied		
		N	P	K
Stage I (1-15 DAT)	4	20 percent of fertigation levels	20 percent of fertigation levels	20 percent of fertigation levels
Stage II (15-30 DAT)	4	40 percent of fertigation levels	30 percent of fertigation levels	20 percent of fertigation levels
Stage III (30-45 DAT)	4	30 percent of fertigation levels	30 percent of fertigation levels	30 percent of fertigation levels
Stage IV (45-60 DAT)	4	10 percent of fertigation levels	20 percent of fertigation levels	30 percent of fertigation levels

Treatment combinations: 15

T_1: F_1S_1 **T_8**: F_3S_2
T_2: F_1S_2 **T_9**: F_3S_3
T_3: F_1S_3 **T_{10}**: F_4S_1
T_4: F_2S_1 **T_{11}**: F_4S_2
T_5: F_2S_2 **T_{12}**: F_4S_3
T_6: F_2S_3 **T_{13}**: F_5S_1
T_7: F_3S_1 **T_{14}**: F_5S_2
T_{15}: F_5S_3

Additional treatment: 1 (one)

T_{16}: Soil application of RDF with surface irrigation

The field was well prepared by one deep ploughing followed by use of rotavator. After levelling, the field was divided into plot each of size 18 m^2. Four weeks old seedlings of broccoli cv *Paraiso* were transplanted in second week of October in both of the experimental seasons. Transplanting was done in the evening hours. Broccoli was transplanted in paired row i.e. one drip line in between the two rows of plants. Light irrigation was applied just after transplanting and the gap filling was done after seven days of transplanting.

Fertigation was done through venturi starting 7 DAT and the doses were changed after every 15 days interval as per the treatments. The water soluble fertilizer (WSF-18:18:18) was used for fertigation. To meet the NPK requirement of different treatments, WSF (18:18; 18) was supplemented with urea, SSP and murate of potash (MOP). After each fertigation, drip system was thoroughly flushed for 5 minutes to prevent chocking. The RDF (recommended dose of fertilizer) was kept as 150:60:60 kg of NPK per ha in all the treatments. In case of conventional method of fertilizer application the entire quantity of P and K and half dose of N was applied as basal. The remaining dose of nitrogen was applied in two splits at 15 and 45 DAT.

The four tagged plants under each treatment were uprooted at the end of cropping period. Root length was measured with the help of measuring scale from the collar region to tip of the deepest root and expressed in cm. Root spread was also measured in centimetres with the help of measuring scale. After removal of roots these were washed thoroughly with tap water and fresh weight of roots were recorded. These roots were further kept in muslin cloth bags and dried in sun for one day and then kept into the electric oven at 60°C till their weights became constant to get mean dry weight per plant. The data were statistically analysed applying the two stage method of control vs rest analysis suggested by Rangaswamy (2015) [10].

Results and Discussion

Root length (cm)

The data pertaining to root length of plant measured at the final harvest has been presented in Table 1. The results clearly revealed that increasing the fertigation level increases the root length of broccoli at final stage of growth. During 2016-2017, among the different fertigation levels, significantly maximum root length of 33.87 cm was recorded under treatment F_1 (fertigation with 120 percent of RDF) which was statistically at *par* with F_2 (fertigation with 100 percent of RDF). During 2017-18, the maximum root length of 35.81 cm was recorded in F_1 (fertigation with 120 percent of RDF) which was statistically at *par* with F_2 (fertigation with 100 percent of RDF). Pooled analysis of data was also revealed the maximum root length (34.84 cm) of plant in F_1 which was statistically at par with F_2 (34.24 cm). Among the fertigation levels minimum root length (28.29, 27.39 and 27.84 cm) was measured in F_5 (fertigation with 40 percent of RDF). The effect of scheduling of the fertigation levels on root length was non-significant for both the years of study.

The difference in root length between the fertigation treatments and control (Soil application of RDF with surface irrigation) was also found significant for both the years. During 2016- 17, the root length recorded in control was 26.00 cm whereas in fertigation treatments it was 31.63 cm. In 2017-18, under the control treatment minimum root length of 24.83 cm was observed as compared to 32.27 cm in fertigation treatments. Pooled data revealed the minimum root length of 25.42 cm under control treatment as compared to 31.95 cm in fertigation treatments.

Interaction between fertigation levels and scheduling for plant root length was not found significant for both the years of study.

The higher root length under 120 percent of fertigation level may be due to the adequate quantity of nutrients coupled with adequate moisture which resulted in higher root proliferation. Besides it may be attributed to the split fertigation of phosphorus in at regular interval so the crop was able to absorb more P throughout the crop growth period with very minimum loss of nutrients. Whereas under conventional fertilized plots the entire quantity of P was applied as basal where the P gets fixed up in the soil profile and when the roots emerge and grows, it utilizes only the available P which are very low due to fixation in the soil (Raj *et al.*, 2013) [9]. Jeelani *et al.* (2017) [6] also recorded the higher root length in broccoli and minimum root length under conventional fertilization.

Table 1: Effect of fertigation levels and scheduling on root length (cm) of broccoli

Treatments	Root length (cm)		
	2016-17	2017-18	Pooled
Fertigation levels			
F_1	33.87	35.81	34.84
F_2	33.25	35.24	34.24
F_3	32.64	33.46	33.05
F_4	30.08	29.46	29.77
F_5	28.29	27.39	27.84
S.Em ±	0.35	0.43	0.33
CD (5%)	1.01	1.24	0.95
Scheduling			
S_1	31.79	32.53	32.16
S_2	31.52	32.05	31.78
S_3	31.58	32.24	31.91
S.Em ±	0.35	0.43	0.33
CD (5%)	NS	NS	NS
Control vs Rest			
Control	26.00	24.83	25.42
Rest	31.63	32.27	31.95
S.Em ±	0.44	0.54	0.42
CD (5%)	1.28	1.57	1.20
Interaction (F×S)			
S.Em ±	0.35	0.43	0.33
CD (5%)	NS	NS	NS

Fig 1: Difference in root growth between fertigation treatment combinations and control (Soil application of RDF with surface irrigation)

Root spread (cm)

The information pertaining to root length depicted in Table 2 clearly shows that root spread increased gradually with increasing the fertigation level. In 2016-17, among the different fertigation levels significantly maximum root spread of 42.19 cm was observed in F_1 (fertigation with 120 percent of RDF) and it was statistically at *par* with F_2 (fertigation with 100 percent of RDF). In 2017-18, F_1 (fertigation with 120 percent of RDF) recorded the maximum root spread (41.40 cm) which was statistically at *par* with F_2 (fertigation with 100 percent of RDF). Pooled data was also revealed the maximum root spread of 41.80 cm in F_1 followed by F_2. Among the different fertigation levels minimum root length (33.24, 31.67, 32.46 cm) was measured in F_4.

In the present study the effect of scheduling of the fertigation levels on root spread was non-significant for both the years of study.

The difference in root spread between the control (Soil application of RDF with surface irrigation) and rest of the fertigation treatments was also found significant for both the years of study. In 2016-17, minimum root spread of 31.87 cm was recorded under control treatment as compared to 38.44 cm under rest of the fertigation treatments. In 2017-18, under control treatment the root spread observed was 30.67 cm whereas under fertigation treatments it was 38.05 cm. Pooled analysis of data clearly revealed that minimum root spread (31.27 cm) was recorded in control treatment as compared to 38.05 cm under various fertigation treatments.

Interaction between fertigation levels and scheduling for plant root length was not found significant for both the years of study.

Maximum root spread under drip fertigation might be attributed to the adequate quantity of nutrients coupled with adequate moisture which resulted in the production of highly fibrous root system and fertigation also promotes the production of intensely branched roots that facilitates nutrient acquisition and foraging capacity (Raj *et al.*, 2013) [9]. This result was in conformity with the findings of Jeelani *et al.* (2017) [6] in broccoli.

Table 2: Effect of fertigation levels and scheduling on root spread (cm) of broccoli

Treatments	Root Spread (cm)		
	2016-17	2017-18	Pooled
Fertigation levels			
F_1	42.19	41.40	41.80
F_2	41.10	40.61	40.86
F_3	39.55	38.51	39.03
F_4	36.15	36.06	36.11
F_5	33.24	31.67	32.46
S.Em ±	0.44	0.62	0.46
CD (5%)	1.27	1.79	1.32
Scheduling			
S_1	38.71	37.67	38.19
S_2	38.29	37.67	37.98
S_3	38.33	37.62	37.98
S.Em ±	0.44	0.62	0.46
CD (5%)	NS	NS	NS
Control vs Rest			
Control	31.87	30.67	31.27
Rest	38.44	37.65	38.05
S.Em ±	0.56	0.78	0.58
CD (5%)	1.61	2.27	1.67
Interaction (F×S)			
S.Em ±	0.44	0.62	0.46
CD (5%)	NS	NS	NS

Fresh weight of root at final stage

The data on effect of fertigation levels (F) and scheduling (S) along with the effect of control on plant root weight are presented in Table 3. The results shown in Table 3 clearly revealed that the dry root weight of broccoli at final harvest significantly affected by fertigation levels.

During first year of study, among the different fertigation levels tested significantly higher fresh weight of root at final stage was recorded in F_1 (165.89 g) and it was statistically at *par* with F_2 (163.89 g). During second year of study, higher fresh weight of root was recorded in F_1 (154.89 g) which was statistically at *par* with F_2 (152.23 g). Pooled analysis of data revealed that the maximum fresh weight of root was recorded in F_1 (160.39 g) and it was statistically at *par* with F_2 (158.04 g). Out of different fertigation levels, minimum fresh root weight was recorded in F_5 (142.82, 135.59 and 139.35 g).

The comparison between control and fertigation treatments revealed that they differ significantly with respect to fresh weight of root in both the years of study. In first year, fresh root weight in control was 127.45 g as compared to 156.45 g in fertigation treatments. In second year, in control the fresh root weight of 123.34 g was recorded as compared to 147.17 g under fertigation treatments. Pooled analysis of data registered root fresh weight of 125.40 g whereas under fertigation treatments it was 152.34 g.

The increased in root weight due to increasing the drip fertigation level might be attributed to the frequent and consistent application of water and nutrients in the vicinity of the roots which provide better soil moisture regime in the crop root zone throughout the crop growth and gives better root growth. The above result is also in support of the findings of Antony and Singandhupe (2003) [2]. Under surface application of fertilizer with surface irrigation most of the nutrients were either fixed in the soil or leached away from the root zone. So the fertilizer use efficiency and the uptake was low which might have resulted in lower root growth. Similar result were reported by Raj *et al.* (2013) [9].

Table 3: Effect of fertigation levels and scheduling on fresh root weight (g) of broccoli

Treatments	Fresh root weight (g)		
	2016-17	2017-18	Pooled
Fertigation levels			
F_1	165.89	154.89	160.39
F_2	163.86	152.23	158.04
F_3	158.60	150.15	154.38
F_4	151.08	147.97	149.52
F_5	142.82	135.59	139.35
S.Em ±	1.71	0.99	0.97
CD (5%)	4.95	2.87	2.81
Scheduling			
S_1	156.96	148.70	152.83
S_2	156.25	147.64	151.95
S_3	156.13	148.16	152.23
S.Em ±	1.71	0.99	0.97
CD (5%)	NS	NS	NS
Control vs Rest			
Control	127.45	123.34	125.40
Rest	156.45	147.17	152.34
S.Em ±	2.17	1.26	1.23
CD (5%)	6.26	3.63	3.55
Interaction (F×S)			
S.Em ±	1.71	0.99	0.97
CD (5%)	NS	NS	NS

Dry root weight at final stage

Similar to fresh weight of root, the dry root weight of broccoli at final harvest was also significantly affected by fertigation levels (Table 4). In 2016-17, significantly higher dry weight (25.28 g) of root was observed in plants receiving 120 percent of RDF fertigation and it was statistically at *par* with F_2. In 2017-18, higher dry weight of root (22.79 g) was recorded in treatment F_1 (fertigation with 120 percent of RDF) which was statistically at *par* with F_2 (fertigation with 100 percent of RDF). Pooled data analysis also revealed the maximum dry root weight of 24.04 g in F_1 followed by 23.63 g in F_2.

The comparison between control and fertigation treatments revealed that they differ significantly with respect to plant dry root weight in both the years of study. Minimum dry root weight of 15.77, 12.33 and 14.05 g was recorded in control (Soil application of RDF with surface irrigation) treatment as compared to 22.32, 20.13 and 21.22 g in fertigation treatments.

In the present study the effect of scheduling of the fertigation levels and the interaction of fertigation levels and scheduling on root dry weight was non-significant for both the years of study.

The higher root weight may be due to the application of readily available form of fertilizer directly at the root zone particularly in frequent intervals thus the crops could able to utilize maximum quantity of nutrients reducing the leaching and volatilization loss and increasing the nutrient use efficiency which might have resulted in higher root growth This showed positive response of root characters to higher fertilizer dose producing higher root biomass under favourable moisture and nutrient status as observed by Parthasarathi *et al.* (1999) [8] in radish. Similar results were observed by Jeelani *et al.* (2017) [6] in broccoli. Under surface application of fertilizer nearly 75 per cent of total fertilizers were applied as basal, due to which the crop could not able to absorb all the nutrients at a single time and the unutilized nutrients were either fixed in the soil or leached away from the root zone. So the fertilizer use efficiency and uptake was low which might have resulted in lower root growth **(**Raj *et al.*, 2013) [9]

Table 4: Effect of fertigation levels and scheduling on dry root weight (g) of broccoli

Treatments	Dry root weight (g)		
	2016-17	2017-18	Pooled
Fertigation levels			
F_1	25.28	22.79	24.04
F_2	25.09	22.17	23.63
F_3	22.04	20.53	21.29
F_4	20.06	18.83	19.45
F_5	19.13	16.30	17.72
S.Em ±	0.35	0.30	0.23
CD (5%)	1.01	0.86	0.66
Scheduling			
S_1	22.43	20.29	21.36
S_2	22.25	19.99	21.12
S_3	22.28	20.10	21.19
S.Em ±	0.35	0.30	0.23
CD (5%)	NS	NS	NS
Control vs Rest			
Control	15.77	12.33	14.05
Rest	22.32	20.13	21.22
S.Em ±	0.44	0.38	0.29
CD (5%)	1.27	1.09	0.83
Interaction (F×S)			
S.Em ±	0.35	0.30	0.23
CD (5%)	NS	NS	NS

Conclusion

Fertigation had significant impact on root system of broccoli. Root spread, root length, fresh root weight and root dry mass were increased under drip fertigation practices as compared to conventional method of irrigation and fertilizer application. Fertigation with 120 percent of RDF registered maximum root length, root spread, fresh root weight and dry weight of root. Fertigation promotes the production of intensely branched roots that facilitates nutrient acquisition and foraging capacity. On the other hand, conventional method of irrigation and fertilizer application has exhibited limited root spread and rooting depth in the rhizosphere

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