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Effect of varying drip irrigation levels and NPK fertigation on nutrient uptake, root characteristics, physiological behaviour and head quality of broccoli (*Brassica oleracea* var. *italica*) in warm humid climatic condition of Assam

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Abstract
This field trail aimed at evaluating the nutrient uptake, root characteristics, physiological behaviour and quality response of broccoli (*Brassica oleracea* var. *italica*) to applied water and fertilizer under drip fertigation method during *Rabi* season of 2019–20 and 2020–21. The experiment consisted of 4 drip irrigation levels *viz.*, 120, 100, 80 and 60% ETc and 4 drip fertigation levels *viz.*, 100, 75, 50% recommended dose (RD) of NPK and control and was laid out in Factorial Randomized Block Design (FRBD) at Instructional-cum-Research Farm, Assam Agricultural University, Jorhat with three replications. Application of irrigation level at 100% ETc recorded higher nutrient uptake by the plant. Root parameters (root volume and root dry weight), fruit quality (protein content), chlorophyll content, photosynthesis rate and conductance also followed the same trend in response to the aforesaid treatment. However, root length and ascorbic acid content was recorded highest with irrigation level at 60% ETc. Among the fertility levels, drip fertigation with 75% RD of NPK showed superior results in terms of nutrient uptake, root parameters and protein content. The photosynthesis rate and stomatal conductance was more influenced by water than fertilizer. The chlorophyll content, photosynthesis and conductance were recorded highest with 75% RD. Therefore, broccoli can be grown better under drip fertigation at 100% ETc in combination with 75% RD of NPK in Assam for better yield, quality, profitability and resource saving.

Keywords: Broccoli, drip fertigation, FRBD, fruit quality, nutrient uptake, resource saving

Introduction
Crop production is considered one of the biggest stresses in the sphere. Over the years, the research focus has shifted towards producing high value healthy crop and broccoli is one such befitting substitute loaded with vitamins, minerals, fiber and antioxidants. However, it is also a water and nutrient demanding crop. Water is an important resource for broccoli production. Considering the current Indian scenario, water will soon become insufficient to feed the burgeoning population. Therefore, efficient water and nutrient management are most critical for profitable cultivation of broccoli in the context of alarming water stress and nutrient loss by conventional method of fertilizer application. Under such situation, drip fertigation plays a significant role in broccoli production. Although, consolidated efforts were made to review the work done by various workers on different aspects of drip irrigation in specific vegetable crops, little is known about the dynamic behavior of root systems and fruit quality in response to drip supply of nutrients and water. Being a newly introduced crop with high economic potential and low available information on different aspects of fertigation of broccoli under Assam conditions demands appropriate understanding. On that account, an experiment was undertaken to study the nutrient uptake, root characteristics, physiological behaviour and quality of broccoli under drip fertigation.

Materials and Methods
Growth conditions: Field trial was conducted during *Rabi* season of 2019–20 and 2020–21 at Instructional-cum-Research Farm, Assam Agricultural University at 24°47'N latitude, 94°12'E longitude. The research field is situated in subtropical humid climatic region of Upper Brahmaputra Valley Zone (UBVZ). The climatic parameters for the period of experimentation were recorded in the meteorological observatory of the department of Agricultural Meteorology, Assam Agricultural University. The soil consists of sand, silt and clay and could be classified under textural class sandy loam (Table 1).

Table 1: Initial properties of soil

Soil property	Value	
	2019-20	2020-21
A) Soil reaction (pH)	5.89	5.90
B) Available N (kg/ha)	240.59	241.39
C) Available P (kg/ha)	21.01	22.33
D) Available K (kg/ha)	125.30	125.40

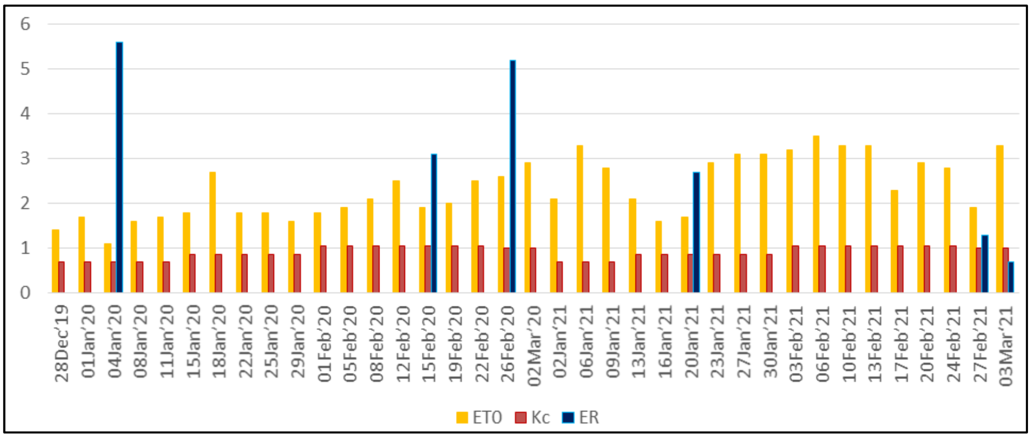

Fig 1: Evaporative demand of broccoli during crop growth period based on meteorological data and effective rainfall (ER) for 2019-20 and 2020-21

Experimental design

The experiment consisted of three replications in factorial randomized block design with drip irrigation levels (120, 100, 80 and 60% ETc) and drip fertigation levels (100, 75, 50% RD of NPK and control). The amount of irrigation water applied through drip system was calculated using a computer programme (ET_0 calculator) with reference evapotranspiration (Fig 1). This software is developed by the land and water division of FAO, and it assesses reference evapotranspiration from meteorological data by the means of Penman-Monteith method (Allen *et al.*, 1998) [1].

ET crop (ETc) = ET_0 x Kc

Where, ETc: Crop evapotranspiration
ET_0: Reference evapotranspiration
Kc: Crop coefficient

Volume of water required is calculated by multiplying emitter discharge (per ha) with number of emitters per plot. Crop coefficient values for calculating actual crop evapotranspiration vary with the development stage of the crop (Table 2).

Table 2: Crop coefficients for broccoli

Growth stage	Crop coefficient factor
2-3 weeks (Initial stage)	0.70
4-6 weeks (Crop development stage)	0.87
7-9 weeks (Maturity stage)	1.05
10 weeks onwards (Late season stage)	1.00

The individual plot size was 4m×3m. An entire drip irrigation system for the experiment was installed. The discharge rate of drippers was 2 lph and as a total of 30-line drippers were installed in the system. Irrigation schedule was started one week after transplanting. In NPK fertigation treatments, fertilizers were applied in split at weekly intervals in the form of Urea, Diammonium phosphate (DAP) and Muriate of Potash (MOP) as per the state level recommendation of broccoli (100kg N+80kg P+60 kg K/ha). 25% of the RDF was applied as basal at the time of final land preparation and remaining 75% was applied in split at weekly interval on crop growth basis through drip (Fig 2).

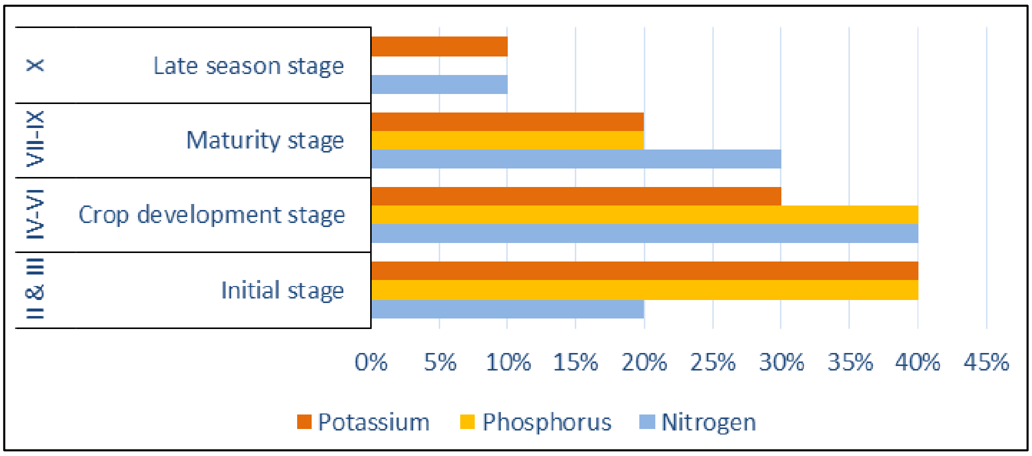

Fig 2: Growth stage based weekly fertilizer split schedule for broccoli

Treatment details

- **Drip irrigation level (I)**

I_1: 1.2 ETc (Drip at 120% ETc)
I_2: 1.0 ETc (Drip at 100%ETc)
I_3: 0.8 ETc (Drip at 80%ETc)
I_4: 0.6 ETc(Drip at 60% ETc)

- **Fertilizer level (F)**

F_1: 100% RD of NPK through drip
F_2: 75% RD of NPK through drip
F_3: 50% RD of NPK through drip
F_4: No fertilizer

Variety

The broccoli 'Green Magic' (F_1 hybrid) was used to assess its potential under drip fertigation. Broccoli seedlings at 4 to 5 leave stage were transplanted on 18 December and 21 December during 2019 and 2020, respectively with a spacing of 50cm×50cm. The crop was harvested from 09–21 March 2020 and 15–24 March 2021, respectively.

Determination of different parameters

Plant samples (head, stem and leaf) were collected from each treatment after harvesting, dried and powdered. Nitrogen was estimated with microkjeldhal method, phosphorus was estimated with vando-molybdate phosphoric yellow colour method and potassium was estimated by flame photometry.
Uptake of macro nutrients (NPK) was computed using the data of N, P and K content in head, stem and leaf as follows.

$$\text{Nutrient uptake by head (kg/ha)} = \frac{\text{Nutrient content (\%)} \times \text{Dry weight of the head (kg/ ha)}}{100}$$

$$\text{Nutrient uptake by stem (kg/ha)} = \frac{\text{Nutrient content (\%)} \times \text{Dry weight of the stem} \left(\frac{\text{kg}}{\text{ha}}\right)}{100}$$

$$\text{Nutrient uptake by leaf (kg/ha)} = \frac{\text{Nutrient content (\%)} \times \text{Dry weight of the leaf (kg/ ha)}}{100}$$

Three plants were sampled per plot and plant roots were cleaned of soil with water. Root length was estimated by procedure suggested by Habib (1988) [7]. For the purpose of determining the dry matter amount, root samples were dried at 70 °C in an oven until the humidity was evaporated. Root volume was obtained by quantifying the volume of liquid a root displaces (Archimedes' principle, Birouste *et al*., 2014) [5]. The head samples were taken from the last harvest to analyze the ascorbic acid content. (A.O.A.C, 1984) [3]. The amount of protein present in the head was determined by lowry's method (Lowry, 1951) [9]. The chlorophyll content was estimated by the method given by Ranganna (1977) [10]. Photosynthesis reading was taken using LICOR 6200 at fruit formation stage (70 DAT). The stomatal conductance of the lower leaf surface was measured at midday using Li-Cor Model Li-1600. The diameter of head was determined by measuring the circumference of the head and dividing the circumference by the factor 3.142. Yield was recorded in tonnes per ha.

Soil analysis

A composite soil sample from 0 to 30 cm soil depth was collected prior to transplanting of seedlings before application of fertilizers as well as after harvesting of crop for estimation of initial and final soil available N, P and K.

Data analysis

All the data obtained from 2 years of study were subjected to statistical analysis using the F test for factorial randomized block design and standard error of means (SEm±). Critical differences (CD) at 5% probability level were calculated only when the F value was found significant.

Results and Discussion

Nitrogen uptake by head, stem and leaf

Effect of irrigation and fertilizer level

Nutrient content in this study was studied in terms of per cent N, P and K content against the effects of irrigation and fertilizer levels. Application of different irrigation levels significantly influenced the N uptake by head, stem, leaf and total uptake (head + stem + leaf) as shown in Fig 3. The highest data was recorded with irrigation level I_2 in first year and showed no change in trend in second year of experiment.
Across the two years (2019-20 and 2020-21), fertigation treatments significantly increased nitrogen uptake as a whole compared with control (Fig 3). Lowest values of individual uptake of nitrogen by different plant parts and as a total were obtained from the controlled treatment. Fertilizer level F_2 showed significantly highest N uptake by head, stem, leaf and total N uptake during both the year of study.
The higher uptake may be credited to drip application of irrigation below the soil's infiltration capacity throughout the crop growth period causing preferential uptake of nutrients.
The increased nutrient content in the fertilizer treatment with 75% RD might be due to split and balanced ratio of fertigation with drip resulting in high root growth and physiological activities of root that enabled the crop to offer better nutrient uptake from soil with minimal losses.

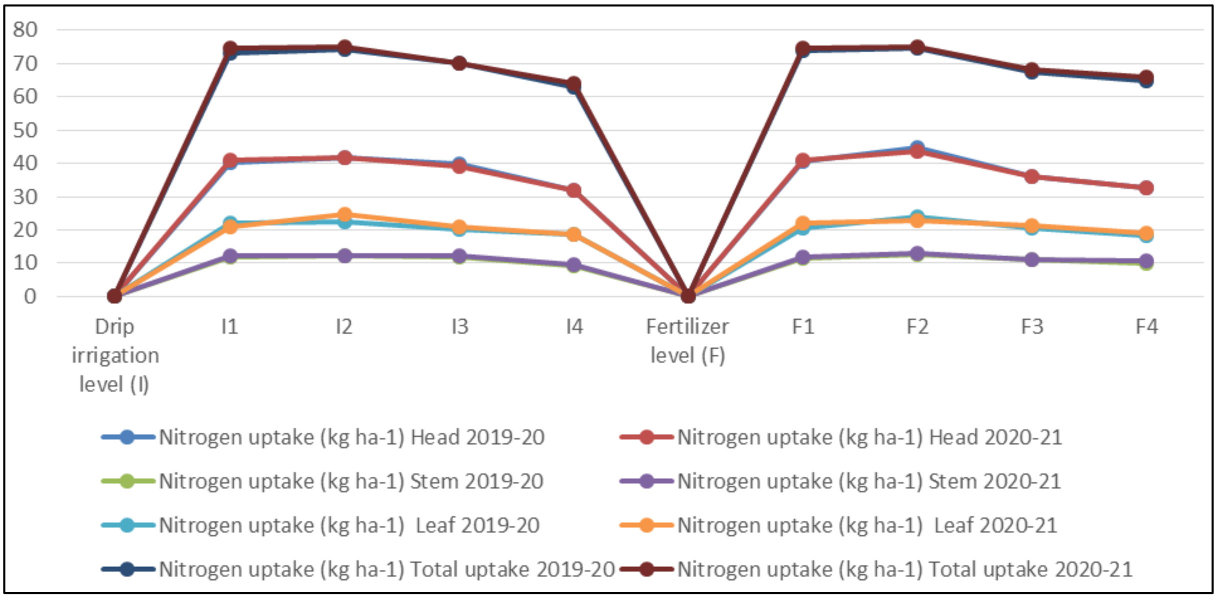

Fig 3: Effect of irrigation and fertilizer levels on nitrogen uptake (N) by head, stem, leaf and total uptake of broccoli

Phosphorus uptake by head, stem and leaf

Effect of irrigation and fertilizer level

It is evident from the data shown in Fig 4. That application of different irrigation levels significantly influenced the P uptake by head, stem, leaf and total uptake during both the years. Treatment I_2 showed superiority over other treatment while being at par with I_1 in all cases which might be due to mitigating effect of the water demand by the crop from the treatments with high water level *i.e.*, 100% ET_c might be the justification in obtaining such results.

As far as the effect of fertilizer level on P uptake is concerned, fertilizer level F_2 showed significantly highest P uptake (Fig 4). The per cent increase might be due to balanced need-based fertigation. Higher nitrogen increases the cation exchange capacity of plant roots and thereby increased uptake of nutrient ions like phosphorus.

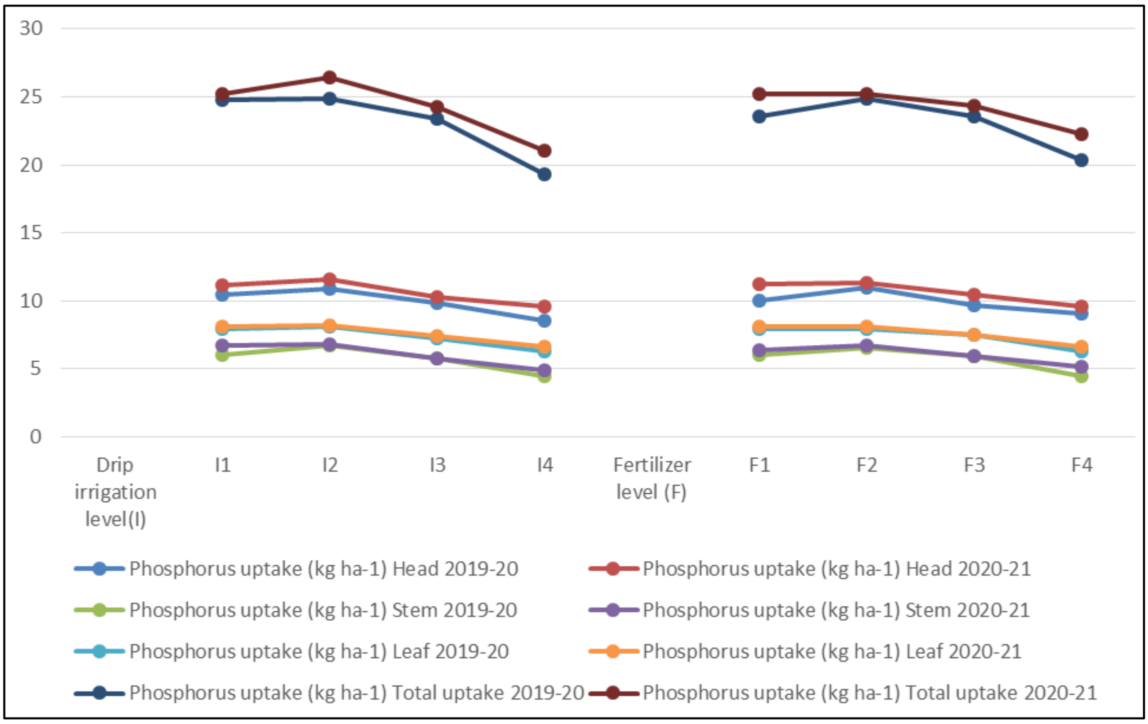

Fig 4: Effect of irrigation and fertilizer levels on phosphorus (P) uptake by head, stem, leaf and total uptake of broccoli

Potassium uptake by head, stem and leaf

Effect of irrigation and fertilizer level

During both the years of study, irrigation level I_2 showed superior results (Fig 5). The beneficial effect of irrigation level may be attributed to availability of optimum nutrients that increases photosynthetic and assimilation rate leading to higher uptake as suggested by Ugade *et al.* (2014) [11] in Brinjal.

The data from Fig 5. Revealed that the lowest and highest uptake of fertilizer potash was recorded under control and fertilizer level F_2 respectively. The increase of nutrient uptake with the increase in fertilizer levels from the control to 100% RD of NPK might be due to the higher crop response to applied fertilizer and reduce leaching and fixation losses of phosphorus in fertigation as compared to soil application of phosphorus.

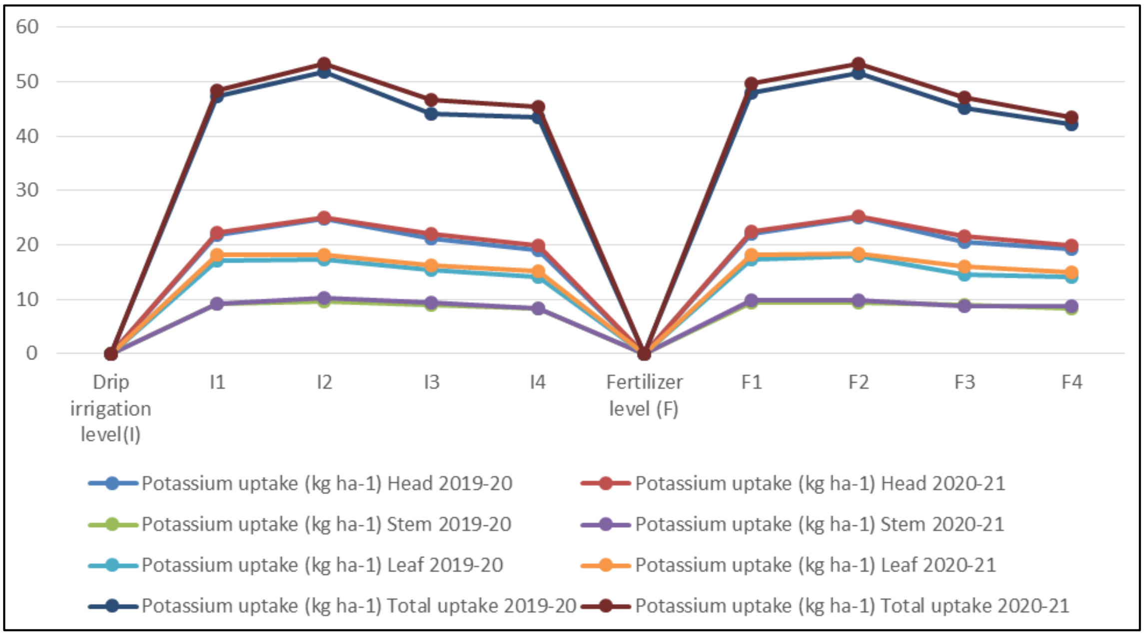

Fig 5: Effect of irrigation and fertilizer levels on potassium (K) uptake by head, stem, leaf and total uptake of broccoli

Effect of irrigation and fertilizer level

Data depicted in Fig 6. Showed gradual increment of root length at lower levels of irrigation. The highest root length was recorded by I_4 during both the year *viz*., 20.16 in 2019-20 and 20.55 in 2020-21. However, there was only a slight increase in root length at 120%, 100% and 80% drip irrigation. The superior root length in I_4 might be attributed to the water scarcity. Though the crop received water once in 2 days through drip irrigation, the amount of water applied was not sufficient to meet the evaporative demand resulting in increased length of roots to fetch more water.

In case of root volume and root dry weight, the highest was recorded with I_2 during both the years which might be due to optimum moisture availability in the root zone that allowed more accumulation in the same. The inverse relationship between root length with increasing quantities of applied water through drip might have been accompanied by an increase in thickness and more branching, thus maintaining the total weight and volume.

Root parameters were significantly influenced by different fertilizer levels (Fig 6). Progressive increase in level of fertigation from control to 100% RDF increased root length, volume and weight. The highest was however recorded by F_2. The combined effect of irrigation and fertilization, maintained optimum nutrients supply within the root zone causing increased root cell expansion thereby superior root characters. Findings were in conformity with Antony and Singandhupe (2004) [2].

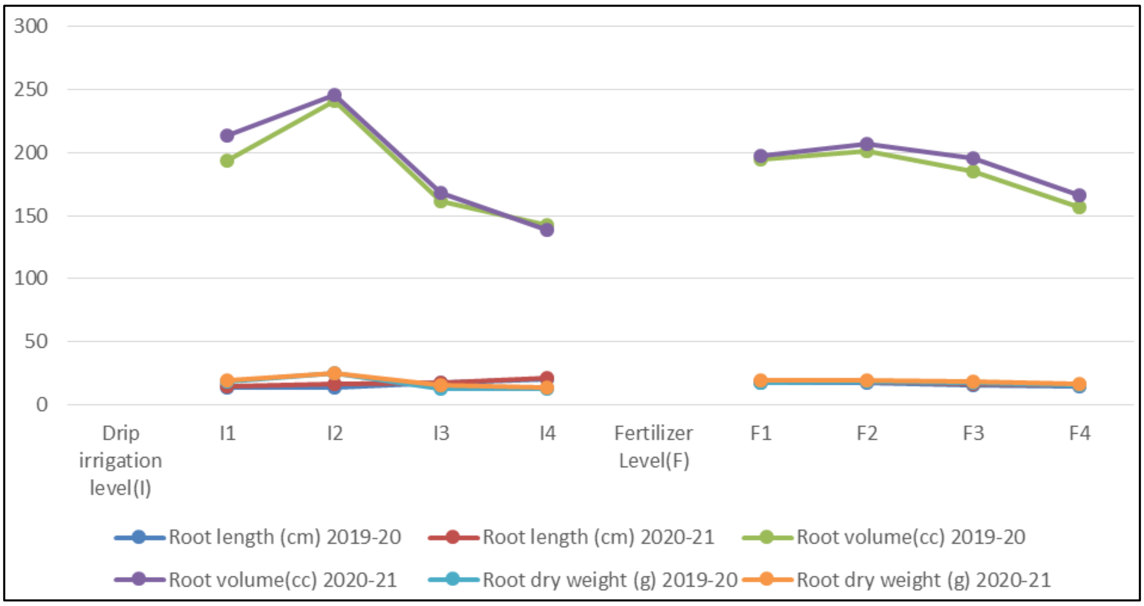

Fig 6: Effect of irrigation and fertilizer levels on root length, root volume and root dry weight of broccoli

Fruit quality parameters

Effect of irrigation and fertilizer level

Ascorbic acid has antioxidant properties. From the data shown in Fig 7. Ascorbic acid content in fruit was highest recorded under deficit irrigation *i.e.*, I_4 while lowest was recorded in I_1. Therefore, it can be concluded that ascorbic acid content is highly correlated with the amount of irrigation water and was lower when the full water requirement of broccoli was met. The high ascorbic acid content at moisture stress levels justifies its active role in helping the plants for better resistance by strengthening the walls of capillaries under the stress and decreased enzyme activity. Dolatabadian *et al.* (2009) [6] interpreted similar findings.

In case of protein content in fruit, the trend was reverse with superior results shown by I_2 and I_1. The reason behind this is the frequent application of water influencing better nutrient uptake.

Under high rates of fertilizer, regardless of irrigation, the content of ascorbic acid in the fruit was lowered as seen in Fig 7. During both the years, lowest value was recorded under F_1. This might be attributed to the fact that when the plant is supplied with high amounts of nitrogen, it increases protein production, and simultaneously decreases sugar production thereby ascorbic acid production. These findings are in agreement with those findings of Babik and Elkner (2002) [4].

Different fertilizer levels exerted significant influence on protein content, where highest values were recorded with F_2 and F_1. This may be attributed to positive effect of nitrogen, phosphorus and potassium on biosynthesis of hormones responsible for protein synthesis.

Physiological characters

Effect of irrigation and fertilizer level

The maximum chlorophyll content was recorded with I_2 (Fig 7) which might be due to the compensation of daily water need through drip, enabling greater uptake of nitrogen and other nutrients.

As the level of drip irrigation decreased from 100% ETc to 60% ETc, the photosynthesis and conductance decreased which might be because of water stress that led to stomata closing, lowering conductance values.

Among the fertility levels, highest values were recorded with F_2 and F_1 being at par with each other in most of the parameters (Fig 7). This can be justified due to increased metabolic activity at root zone and thereby better uptake and accumulation of vegetative plant parts. The photosynthesis rate and stomatal conductance was more influenced by water than fertilizer. Water deficit reduced photosynthesis rate and stomatal conductance and it might have been intensified by nitrogen stress resulting such results. These findings are in accordance with Jawaharlal and Ganesh (2020) [8].

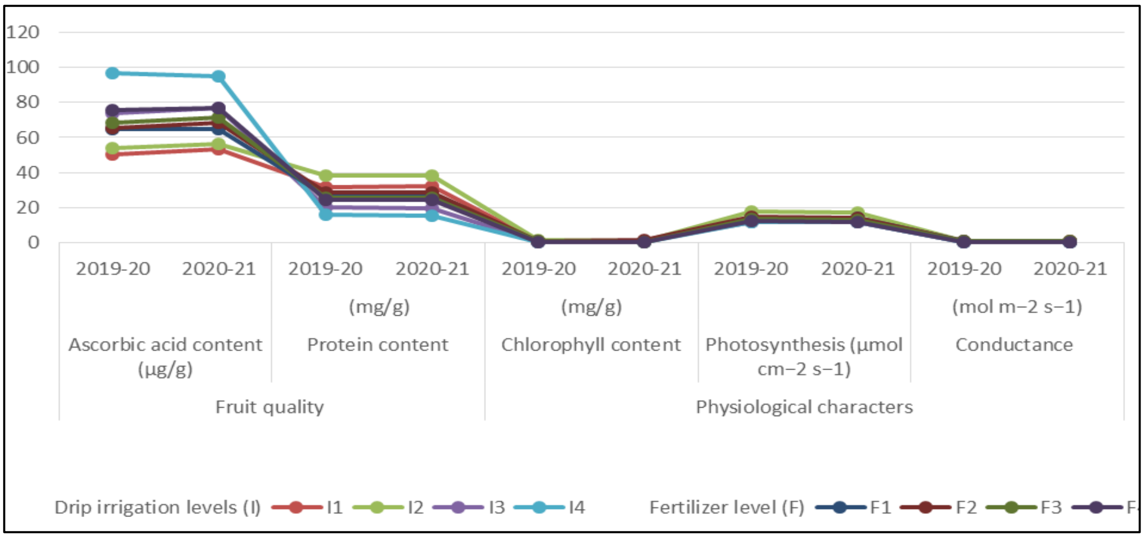

Fig 7: Effect of irrigation and fertilizer levels on fruit quality and physiological characters of broccoli

Head diameter and Yield

Effect of irrigation and fertilizer level

The data from Fig 8. Shows irrigation level at 100% ET_c recorded significantly the highest head diameter and head yield. Combined role of both drip irrigation and fertigation might be the justification in obtaining such results.

Among different fertigation treatments, the higher diameter and yield in 75% NPK treatment through drip during both the years indicated an efficiency of the drip system to save fertilizers while producing desirable yield and yield attributes. The superiority of results with 75% NPK treatment may be due to precise weekly split of fertilizers.

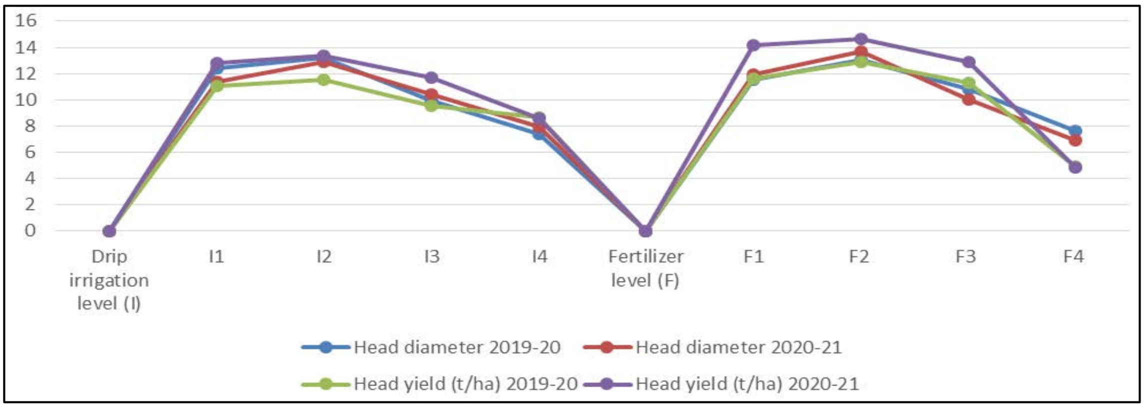

Fig 8: Effect of different levels of irrigation and fertilizer on head diameter and head yield of broccoli

Soil parameters

Effect of irrigation and fertilizer level

100% ET_c during both the year of experimentation recorded superior results (Fig 9). This may be due to more utilization of applied fertilizers and complete solubility due to split application of water with minimal losses.

The macro-nutritional status of soil studied under different parameters showed significant improvement of available N, P_2O_5 and K_2O in soil after harvest over their initial levels indicating the overall improvement of soil fertility (Fig 9). The reason may be attributed to high nutrient use efficiency under drip fertigation

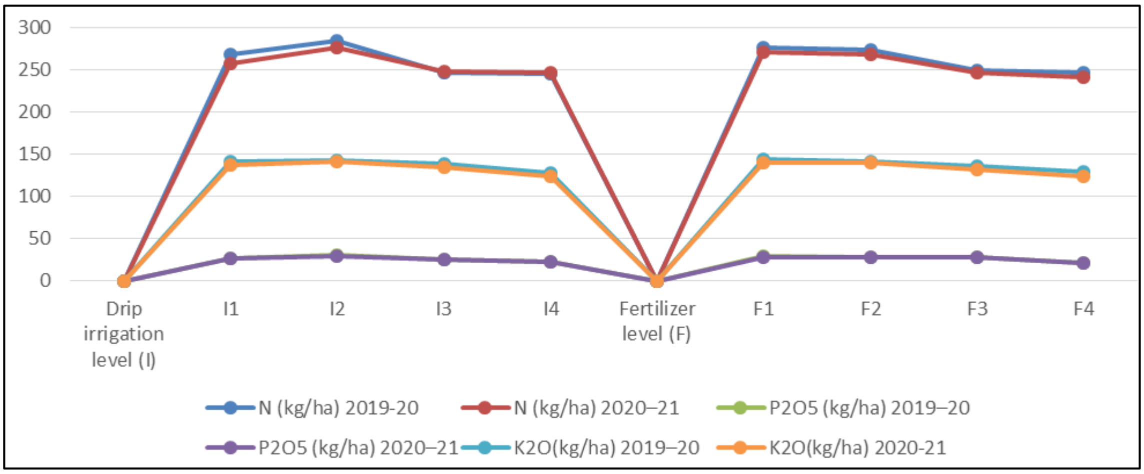

Fig 9: Effect of different levels of irrigation and fertilizer on available N, P2O5, K2O in soil after harvesting

Economic analysis

The economic analysis in terms of net return of different treatments presented in Table 3. Shows the highest net income from drip irrigation of 100% ET_c and fertigation with 75% RD of NPK through drip. Whereas, the lowest net returns were obtained with the irrigation level at 60% ET_c without any fertilizer application during both the years.

Conclusion

From the above-mentioned data, it can be assumed that the adoption of drip irrigation and fertigation system can efficiently reduce the water and fertilizer requirement with increased yields with better quality and net return in broccoli. Therefore, drip fertigation at 100% ET_c with 75%RD of NPK under Assam condition may be recommended for broccoli cultivation for better yield, quality, profitability and resource saving.

Table 3: Effect of different levels of irrigation and fertilizer on net return

Treatment	Net return (Rs/ha)	
	2019-20	2020-21
Drip irrigation level (I)		
I_1	2,34,408.00	2,86,383.00
I_2	2,49,030.17	3,04,580.00
I_3	1,89,842.00	2,54,242.00
I_4	1,63,833.33	1,61,033.00
S.EM±	14,955.55	24,616.18
CD (p = 0.05)	43,188.99	71,087.19
Fertilizer level (F)		
F_1	2,51,322.25	3,27,966.25
F_2	2,91,541.25	3,42,847.25
F_3	2,42,958.83	2,86,866.17
F_4	51,291.17	48,558.83
S.Em ±	14,955.55	24,616.18
CD (p = 0.05)	43,188.99	71,087.19
Interaction(I×F)	NS	NS

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