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Shoot-root traits of broccoli (*Brassica oleracea* var. *italica* L.) as influenced by different irrigation schedules

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Abstract
Frequency of irrigation to the crops is the key factor for proper growth and economic yield. Therefore, in the current study growth of broccoli plants was investigated under different irrigation levels in pot culture condition. Five levels of irrigation schedules were applied including I_0 [Non-irrigation control], I_1 [Irrigation up to 15 days after transplanting (DAT)], I_2 [Irrigation up to 30 DAT], I_3 [Irrigation up to 45 DAT] and I_4 [Irrigation up to 60 DAT] with three replications. Maximum plant height, shortest days to curd initiation, fresh mass of curd, curd diameter, shoot fresh mass and moisture content of roots per plant were obtained from irrigation up to 60 DAT. Moreover, maximum number of leaves, leaf fresh mass, moisture content, root length, root fresh and dry mass per plant were obtained from irrigation up to 45 DAT while the lowest results were obtained from non-irrigated control treatment. Higher dry weight (3.37 g plant^{-1}) and dry matter content of leaves (11.76%) and roots (18.94%) and root to shoot ratio (0.077) were observed from non-irrigated control treatment. Results suggested that irrigation up to 60 DAT might be optimum schedule for broccoli, but in terms of economic profitability, irrigation up to 45 DAT would be sufficient.

Keywords: dry matter content, water stress, root traits, root to shoot ratio, shoot traits.

Introduction

Proper irrigation scheduling for profitable crop production is very critical. Irrigation scheduling is complicated in vegetable production because scheduling depends on crop variety, growing season, planting time, planting method and water source. In Bangladesh, very limited natural precipitation occurs during the October to March broccoli production period (Edris et al., 1979). Therefore, artificial irrigation is the common practice for crop production. In addition, climate change issues became a sever threat for crop production in the dry season. Since broccoli is shallow rooted crop it requires frequent water supply during growth and development. Therefore, proper irrigation scheduling with required water supply is urgently necessary for broccoli production in Bangladesh.

Broccoli (*Brassica oleracea* var. *italica* L.) is a biennial, herbaceous vegetable crop belonging to the family Brassicaceae (Crucifereaceae). It is a fast-growing, upright, branched, 60-90 cm tall plant that is prized for its top crowns of tender, edible, green flower buds. Its thick, green stalks are also edible. Broccoli is also called as crown of jewel nutrition because it is rich in vitamins and minerals (Vasanthi et al., 2009). It contains 33% protein and it is a good source of vitamin A, B complex and ascorbic acid and also contains appreciable amounts of Ca, Fe, P, riboflavin, thiamin, niacin and

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fiber (Thompson and Kelly, 1985). It is an important source of vitamin K, which helps to resist malignant diseases of the stomach and colon. Broccoli also contains important photochemical such as beta-carotene, indoles and isothiocyanate that help prevent carcinogens (Shanmugasundaram, 2003).

Although broccoli originated from temperate regions, it has been distributed to the tropical and subtropical countries including Bangladesh. It has been introduced in Bangladesh from several years before, but it is not widely grown. There is a good scope for its large scale cultivation in Bangladesh for increasing vegetable diversification and to meet vegetable demand of the country's people. However, the cultivation of broccoli in Bangladesh is low compared to other countries due to lack of appropriate methods of production technology. For broccoli, irrigation is essential and proper irrigation system is required to reach high yields, under a management that supplies the exact amount of water required by plants, keeping soil moisture (Ayas et al., 2011; Kumar and Senseba, 2008). When the crop water requirements cannot be met with natural rainfall, irrigation is major input.

Irrigation scheduling is a critical management input to ensure optimum soil moisture status for proper plant growth and development as well as for optimum yield, water use efficiency and economic benefits (Himanshu et al., 2013). Different levels of irrigation vary with crop growth, development and yield. Regular or abundant irrigation according to crops requirement results in better plant growth and yield while scarce or limited irrigation results in poor plant growth and yield. Therefore, this study was carried out to find out the response of different irrigation cycles on vegetative growth of broccoli and also to explore a suitable irrigation cycle for successful broccoli production in Bangladesh.

Materials and Methods

The experiment was conducted at the Horticulture Farm, Bangladesh Agricultural University, Mymensingh during October, 2015 to February, 2016 to investigate the growth performance of broccoli with different irrigation cycles. The experimental site was located at 24º75' North Latitude and 90°50' East Longitude at a height of 18 meter above the sea level. Broccoli variety 'Premium Crop' a hybrid produced by Takii and Co. Ltd., Kyoto, Japan was used as planting material for this study.

A pot experiment was conducted following completely randomized design with three replications of four pots with five irrigation cycles including I_0 [Non-irrigation, control], I_1 (Irrigation up to 15 DAT), I_2 (Irrigation up to 30 DAT), I_3 (Irrigation up to 45 DAT) and I_4 (Irrigation up to 60 DAT). In case of I_1 to I_4 treatments, 250 ml of tap water was applied to the pot mixture at 2-day intervals up to the stipulated DAT.

Pot soil was collected from the farm land, weeds and other stubbles were removed and sundried well decomposed cow dung was mixed with soil at a 1:1 ratio. Pots (10 kg size) were filled with similar volume of soil mixture to which urea, triple superphosphate and muriate of potash were applied at 17, 17 and 14 g pot^{-1}, respectively.

Thirty-day old uniform, disease, insect-free broccoli seedlings were transplanted in the pot. Equal amount of tap water was applied to all pots for one week after transplanting and thereafter irrigation cycles were imposed according to the experimental design. Pots were kept under a plastic shade to protect from rain water. Weeding, control of insects and diseases were done as when required. Data on number of leaves, plant height, fresh weight of leaves plant^{-1}, dry weight of leaves plant^{-1}, moisture content of leaves, percent dry matter content of leaves, days to curd initiation, curd fresh weight plant^{-1}, curd diameter, root length, root fresh and dry weight plant^{-1}, root dry matter and root to shoot ratio were recorded after harvesting of plants. Days to curd initiation was recorded when curd just appeared in the plants.

Statistical analysis

Data on shoot and root traits were recorded from selected plants of each irrigation treatment after harvesting. The collected data were analyzed by MSTAT-C computer package program. The analysis of variance was performed by F-variance test and the mean differences were adjusted by least significant difference test at 5% and 1% level of probability (Gomez and Gomez, 1984).

Results

Effects irrigation cycles on broccoli shoot traits

Irrigation cycles significantly influenced shoot traits of broccoli. It was noticed that increasing irrigation duration resulted in leaf growth thus increased number of leaves per plant. The maximum number of leaves (50 plant^{-1}) was found from plants those were received irrigation up to 60 DAT and irrigation up to 45 DAT. As irrigation duration reduced number of leaves reduced thus irrigation up to 30 DAT and 15 DAT produced 40 leaves plant^{-1} and 29 leaves plant^{-1}, respectively while non-irrigated control plants produced the minimum number of leaves (12 plant^{-1}) (Fig. 1A).

Plant height decreased significantly as irrigation cycles decreased. The maximum plant height (35.5 cm plant^{-1}) was obtained from irrigation up to 60 DAT followed by 45 DAT (34.6 cm plant^{-1}), 30 DAT (30.9 cm plant^{-1}) and 15 DAT (26.3 cm plant^{-1}) and minimum plant height (16.7 cm plant^{-1}) attained from non-irrigated control treatment (Fig. 1B).

In case of fresh mass of leaves, the highest results (48.25 g plant^{-1}) were obtained from the plants received irrigation up to 45 DAT followed by irrigation up to 60 DAT (44.67 g plant^{-1}), irrigation up to 30 DAT (41.83 g plant^{-1}), irrigation up to 15 DAT (35.42 g plant^{-1}) and the lowest fresh mass of leaves (29.33 g plant^{-1}) was recorded from non-irrigated control plants (Table 1).

Irrigation up to 60 DAT resulted in healthy vegetative growth (increased leaf size and fresh mass). On the other hand, reduced irrigation resulted in leaf wilting and caused decrease in the fresh mass of leaves but led to the production of highest dry mass of leaves (3.37 g plant^{-1}) whereas the lowest dry mass (2.93 g plant^{-1}) was obtained from plants irrigated up to 45 DAT (Table 1). On the contrary, irrigation up to 45 DAT contained the highest moisture (93.68%) followed by irrigation up to 60 DAT (93.42%) while the lowest moisture content (88.22%) was obtained from non-irrigated control plants (Table 1). Percentage of dry matter content of leaves was the highest in non-irrigated control plants (11.76%) while irrigation up to 45 DAT and 60 DAT plants contained the lowest (6.32% and 6.58%, respectively) (Table 1).

The highest shoot fresh mass was achieved from irrigation up to 60 DAT (1134.74 g plant^{-1}) followed by 45 DAT (1027.50 g plant^{-1}), 30 DAT (783.80 g plant^{-1}), 15 DAT (547.34 g plant^{-1}) and the lowest shoot fresh weight (249.18 g plant^{-1}) was obtained from non-irrigated control plants (Fig. 1C).

The vital part of broccoli is curd. Days to curd initiation of broccoli were significantly influenced by irrigation cycles. It was observed that early curd initiation (48.60 DAT) occurred in case of irrigation up to 45 DAT while it was delayed (51.80 DAT) in non-irrigated control plants (Fig. 2A).

However, the highest individual curd fresh mass (418.80 g) and curd diameter (11.93 cm plant^{-1}) were achieved from irrigation up to 60 DAT treatment followed by irrigation up to 45 DAT (371.83 g, 11.60 cm plant $^{-1}$), irrigation up to 30 DAT (262.60 g, 10.30 cm plant^{-1}) and irrigation up to 15 DAT (102.20 g, 8.08 cm plant^{-1}), while the lowest curd fresh mass (56.00 g) and curd diameter (5.60 cm plant^{-1}) were recorded in non-irrigated control treatment (Fig. 2B, 2C).

Table 1. Effect of irrigation cycles on fresh weight, dry weight, moisture content and dry matter content of leaves of broccoli

Irrigation cycles	Fresh mass of leaves (g plant^{-1})	Dry mass of leaves (g plant^{-1})	Moisture content of leaves (%)	Dry matter content of leaves (%)
I_0 (Non-irrigation)	29.33	3.37	88.22	11.76
I_1 (Irrigation up to 15 DAT)	35.42	3.10	91.27	8.72
I_2 (Irrigation up to 30 DAT)	41.83	3.35	91.99	8.01
I_3 (Irrigation up to 45 DAT)	48.25	2.93	93.68	6.32
I_4 (Irrigation up to 60 DAT)	44.67	2.97	93.42	6.58
LSD (0.05)	2.91	0.26	0.36	0.36
LSD (0.01)	4.24	0.38	0.53	0.52
Level of significance	**	**	**	**

** =Significant at 1% level of probability, DAT= Days after transplanting

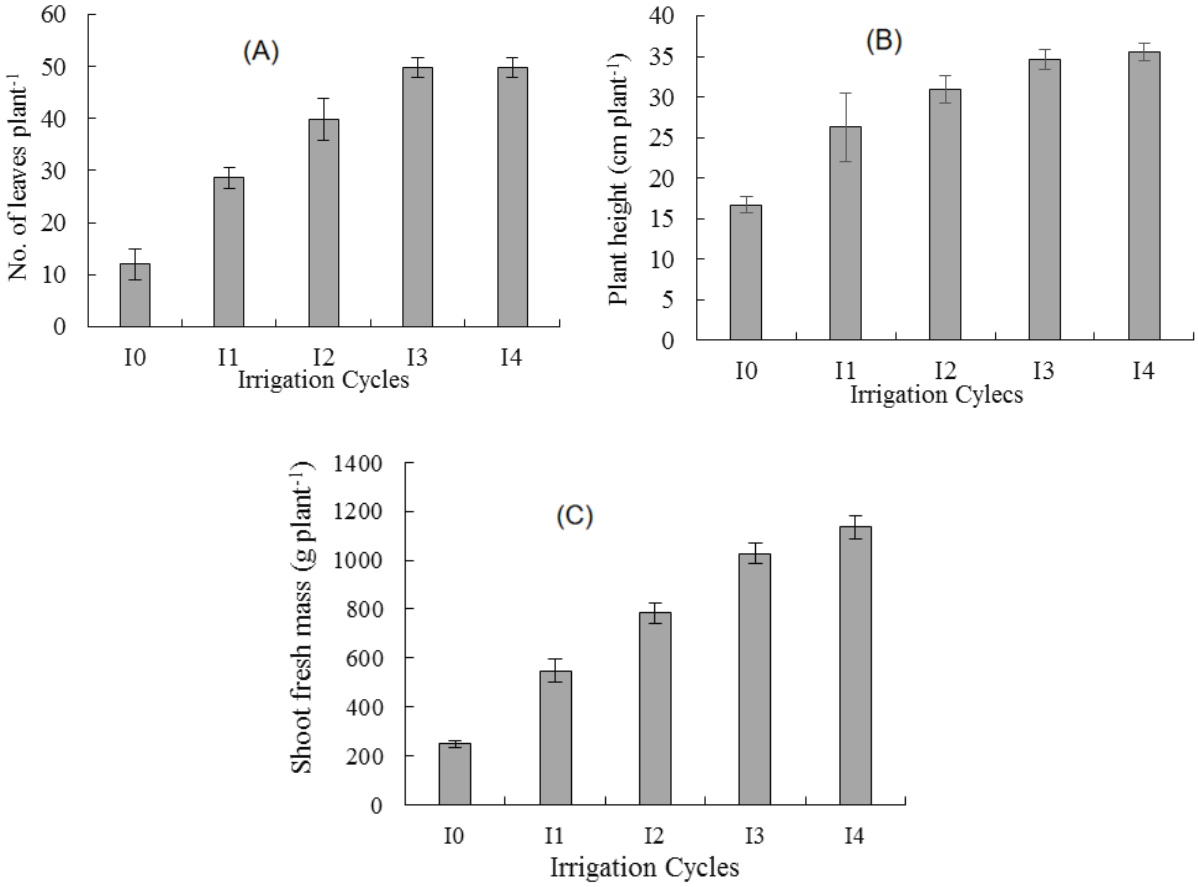

Fig. 1. Effect of irrigation cycles on number of leaves (A), plant height (B) and shoot fresh mass (C) of broccoli. Vertical bars indicates mean ± SD (standard deviation). I_0 [Non-irrigation control], I_1 [Irrigation up to 15 days after transplanting (DAT)], I_2 [Irrigation up to 30 DAT], I_3 [Irrigation up to 45 DAT] and I_4 [Irrigation up to 60 DAT].

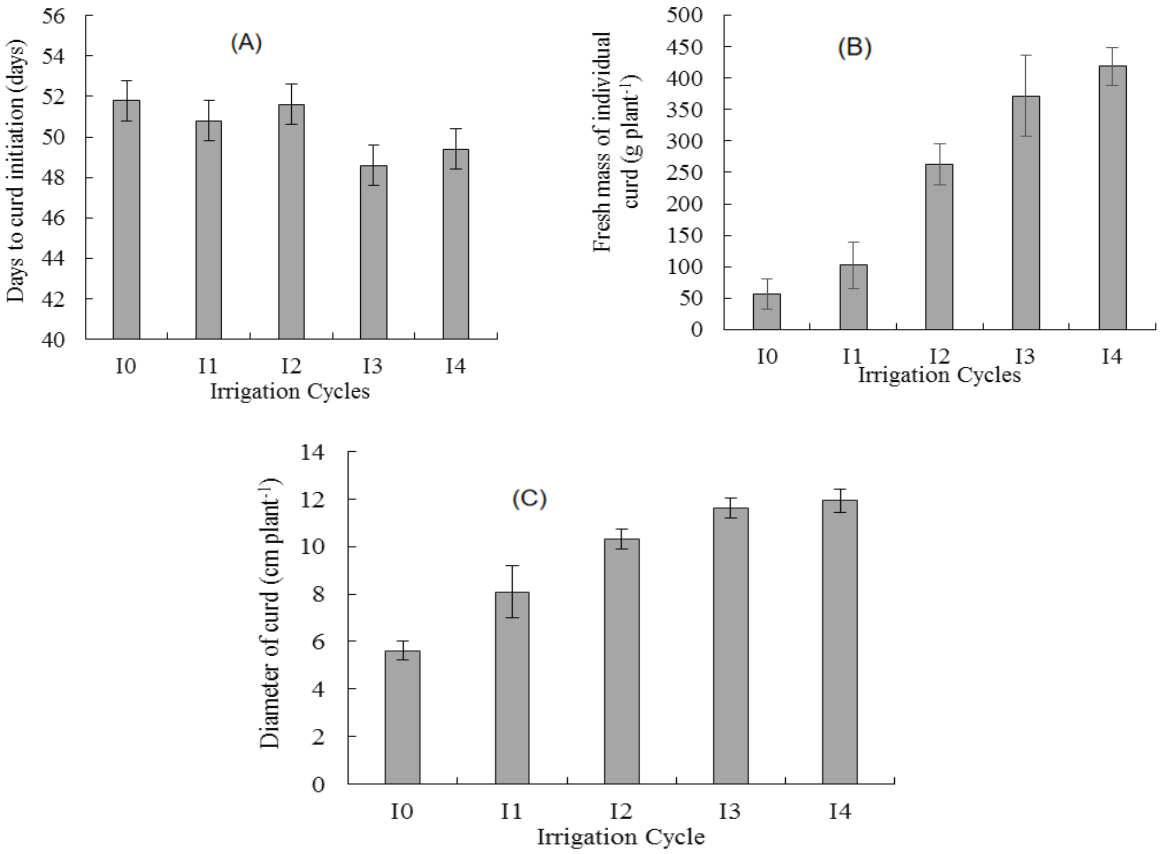

Fig. 2. Effect of irrigation cycles on days to curd initiation (A), fresh mass of individual curd (B) and diameter of curd (C) of broccoli. Vertical bars indicates mean ± SD (standard deviation). I_0 [Non-irrigation control], I_1 [Irrigation up to 15 days after transplanting (DAT)], I_2 [Irrigation up to 30 DAT], I_3 [Irrigation up to 45 DAT] and I_4 [Irrigation up to 60 DAT].

Effects of irrigation cycles on broccoli root traits

Root traits of broccoli were significantly affected by different irrigation cycles. The maximum root length (25.34 cm plant^{-1}) was obtained from irrigation up to 45 DAT followed by 30 DAT (24.92 cm plant^{-1}), irrigation up to 60 DAT (22.46 cm plant^{-1}) and non-irrigated control treatment (16.76 cm plant^{-1}), whereas the minimum root length (15.80 cm plant^{-1}) was recorded in irrigation up to 15 DAT (Fig. 3).

Root fresh and dry masses were maximum (40.67 and 6.68 g plant^{-1}, respectively) from irrigation up to 45 DAT followed by irrigation up to 60 DAT (37.17 and 6.63 g plant^{-1}), irrigation up to 30 DAT (33.67 and 5.99 g plant^{-1}), irrigation up to 15 DAT (27.67 and 4.95 g plant^{-1}), while the lowest (19.17 and 3.62 g plant^{-1}) was observed in non-irrigated control treatment (Table 2).

The roots of irrigated up to 60 DAT plants contained the highest moisture (84.17%) followed by irrigation up to 45 DAT (83.14%), 30 DAT (82.20%) and 15 DAT (82.06%) treatments, while the lowest moisture content (81.06%) was found from non-irrigated control plants (Table 2). On the other hand, non-irrigated control plants produced the highest root dry matter (18.94%) followed by irrigation up to 15 DAT (17.94 %), irrigation up to 60 DAT (17.84 %), irrigation up to 30 DAT (17.74%) and the lowest dry matter content (16.87%) was recorded from irrigation up to 45 DAT (Table 2). The maximum root to shoot ratio (0.077) was obtained from non-irrigated control treatment followed by irrigation up to 15 DAT (0.051), 30 DAT (0.043), 45 DAT (0.040), while the minimum root to shoot ratio (0.033) noticed from irrigation up to 60 DAT treatment (Table 2).

Table 2. Effect of irrigation cycles on different traits of broccoli roots

Irrigation cycles	Fresh mass of roots (g plant^{-1})	Dry mass of roots (g plant^{-1})	Moisture content of roots (%)	Dry matter content of roots (%)	Root: shoot ratio
I_0 (Non-irrigation)	19.17	3.62	81.06	18.94	0.077
I_1 (Irrigation up to 15 DAT)	27.67	4.95	82.06	17.94	0.051
I_2 (Irrigation up to 30 DAT)	33.67	5.99	82.20	17.74	0.043
I_3 (Irrigation up to 45 DAT)	40.67	6.68	83.14	16.87	0.040
I_4 (Irrigation up to 60 DAT)	37.17	6.63	84.17	17.84	0.033
LSD (0.05)	2.93	0.52	2.99	0.59	0.01
LSD (0.01)	4.27	0.76	4.35	0.72	0.02
Level of significance	**	**	*	**	**

* and ** =Significant at 5% and 1% level of probability, respectively, DAT= Days after transplanting,

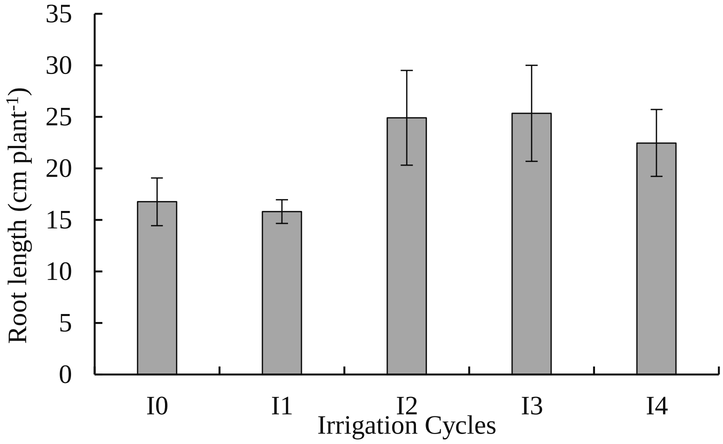

Fig. 3. Effect of irrigation cycles on root length of broccoli. Vertical bars indicates mean ± SD (standard deviation). I_0 [Non-irrigation control], I_1 [Irrigation up to 15 days after transplanting (DAT)], I_2 [Irrigation up to 30 DAT], I_3 [Irrigation up to 45 DAT] and I_4 [Irrigation up to 60 DAT].

Discussion

The shoot and root traits of broccoli were significantly influenced by different irrigation cycles.

In case of leaf number it is indicated that as plants received moisture stress the number of leaves become reduced. The results of our study are consistent with Ali et al. (2005) and Pervez et al. (2009) who noted that under water stress condition the number of leaves per plant decreased gradually. Wurr et al. (1982) showed that the differences in rate of leaf production and the final number of leaves in cauliflower were greatly irrespective of environmental treatments.

Khan et al. (2015) reported that relative growth rate declines as plants are subjected to increasing water stress condition. Plant height increased with the availability of water in the pot mixture then vegetative growth stopped and reproductive growth started. Increased plant height with the increasing irrigation level may be attributed to the favorable soil moisture and temperature for proper plant growth associated with rapid increment and expansion of plant cells as stated by Mannan and Haque (1999). Zaicovski et al. (2008) reported that low water content during growth of broccoli leads to leaf size reduction without affecting yield and contribute to maintenance of green color. However, severe stress leads to reduction of broccoli yield and morphology as observed by Wurr et al. (2002).

In this study, irrigated up to 60 DAT plants initiated curds earlier than non-irrigated control plants because of increased vegetative growth (leaf number, shoot fresh mass) as a result of receiving adequate water supply. Babik (2006) reported that the earliness of broccoli was related to soil type and irrigation. Early periods of water stress delayed curd initiation but did not affect other parameters. Low water levels after curd initiation advanced maturity and reduced leaf nitrogen levels (Bratsch, 1993).

Irrigation treatments exhibited a significant variation in fresh mass of individual curd. Insufficient supply of soil moisture in pot soil which forms small sized curd thus fresh mass of curd also reduced. The plants having adequate water supply produced larger curds and higher fresh mass. Frequent irrigation to the soil especially during the early growth stages of the crop prevented water stress and kept the soil in available moisture condition that helped to improve plant growth and ultimately increased the curd yield. Gomes et al. (2000) reported highest curd yield of broccoli from 12 days interval irrigation. Islam et al. (1996) also found similar results. Curd dimeter also influenced by irrigation cycles, it might be due to sufficient amount of soil moisture which subsequently contributed in the formation of larger and comparatively broader curd of broccoli. Bratsch (1993) postulated that higher water levels delayed maturity, improved head size and external quality, but decreased internal quality.

Among the irrigation levels, irrigation up to 45 DAT produced the longest length of roots followed by 30 DAT and irrigation up to 60 DAT and non-irrigated control plants produced the shortest length of roots. It is indicated that as water status in pots declined root length reduced. This result is in consistent with the findings of Atkin and Macherel (2009). Increased root length under irrigation up to 45 DAT was possibly due to the availability of sufficient moisture in pot mixture which initiated rapid cell elongation leading to longer root formation. Ahmed et al. (2005) reported that root length of carrot was higher with higher amount of water level. Van den Boogaard et al. (1996) noticed that the root growth rate decreased as drought imposed in plants.

Fresh mass of roots was higher in plants that received irrigation up to 45 DAT and lower root fresh mass was obtained from non-irrigated control plants. These results indicated that plants that received water produced longest roots having maximum diameter and that might have contributed to the maximum fresh mass of roots as stated by Ahmed et al. (2005).

It has been well-known that deficiencies of water increases root to shoot ratio and increasing water decreases root to shoot ratio. Mild drought stress generally affects root dry mass less than shoot dry mass, resulting in an increase in the root: shoot dry weight ratio (Watts et al., 1981).

Conclusion

Irrigation cycles significantly influenced vegetative and reproductive traits of broccoli. Among the irrigation cycles, irrigation up to 60 DAT and 45 DAT exhibited better performance on shoot and root traits of broccoli due to sufficient water supply in pot mixture. On the other hand, non-irrigated control plants experienced water stress which resulted in reduced vegetative and reproductive growth. In addition to this, deficiencies of water also reduced the leaf size, decreased photosynthesis rate thus reduced photosynthates and produced smaller curds with lower fresh mass. Delayed curd initiation, limiting root length, deceased roots fresh mass were also resulted due to non-irrigation condition. Based on the results of this study it may be concluded that irrigation up to 60 DAT and/or at least irrigation up to 45 DAT is effective to produce broccoli in pot culture system.

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