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Effects of Organic and Inorganic Fertilizers and Their Combination on Growth, Yield and Quality of Broccoli (*Brassica oleracea* L. var. 'Italica')

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ABSTRACT

The application of balanced fertilizers is essential to produce high-quality broccoli. A field experiment was conducted to find an appropriate fertilizer management practice for broccoli (*Brassica oleracea* L. var. *'I*talica') that can generate higher yield and quality. The experiment comprised 24 treatment combinations with six fertilizer management practices, i.e., T1: control. T2: cow dung at 10 t ha^{-1}. T3: chicken manure at 10 t ha^{-1}. T4: recommended NPK dose. T5: cow dung at 5 t ha^{-1} + 50% of the recommended NPK dose. T6: chicken manure at 5 t ha^{-1} + 50% of the recommended NPK dose. The highest plant height (60.00 cm) occurred in response to T6, the highest stem length (22.25 cm) in T4, and the maximum number of leaves per plant (22.00) in T4 and T6 treatments. Maximum fresh leaf weight per plant (609 g), stem diameter (3.98 cm), curd diameter (16.63 cm), and individual curd weight (494.50 g) occurred in response to the T5 treatment. The optimum yield (25.78 t ha^{-1}) of broccoli can be obtained by application of cow dung (5 t ha^{-1}) with a recommended dose of 50% inorganic fertilizer NPK (T5). Maximum TSS value (10.54%) occurred in response to T3, which was statistically similar to the effect of T6 (10.52%). Vitamin C content (80.77 mg 100 g^{-1}) became significantly high in response to the T4 treatment (100% recommended dose of NPK). Minimum vitamin C content (53.84 mg 100 g^{-1}) occurred in the control treatment (T1). Applying cow dung at 5 t ha^{-1} in addition to the 50% recommended dose of NPK fertilizers (T5) led to superior yield values in broccoli.

Introduction

Broccoli (*Brassica oleracea* L. var. *italica*) is a prominent Cruciferae crop and is native to Italy (Regar et al., 2018). It is low in fat and calories but high in vitamin C and is a good source of vitamin A, vitamin B2, and calcium (Decoteau, 2000). Global broccoli production was 27 million tons in 2019. Of this amount, China and India produced 73%. The USA, Mexico, Spain, Italy, Turkey, Poland, France, and Bangladesh were major producers (FAOSTAT, 2020). Winter climates and soil in Bangladesh are suitable for the luxuriant growth of broccoli. However, the broccoli yield in Bangladesh is poor compared to other countries (Mahmud et al., 2007).

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Broccoli has attracted more attention due to its multifarious uses and high nutritional value (Salunkhe and Kadam, 1998; Talalay and Fahey, 2001; Rangkadilok et al., 2002, 2004). In Bangladesh, it is considered a promising vegetable that can prevail in local vegetable markets and reach the export stage. However, organic farming is small in scale in Bangladesh. Broccoli has a reputation as a supplementary vegetable in salads and in supper food. It is known to be a healthy and delectable vegetable that is rich in many nutrients. Broccoli is rich in vitamins, minerals, fibers, and antioxidants, supporting many dimensions of human health (Cartea et al., 2008; Faller and Fialho, 2009; Yvette, 2012). It contains carbohydrates, protein, vitamin A, vitamin C, vitamin B1, vitamin B2, calcium, and phosphorus. Broccoli has 4.0, 2.5, and 2.0 times more riboflavin, calcium, and ascorbic acid content than cauliflower, respectively (Hazra and Som, 1999). Broccoli effectively protects against several types of cancer (Yoldas and Esiyok, 2004). It has a low Glycemic Index (GI= 10) that can be safe for diabetic patients (Nagraj et al., 2020). Farmers in Bangladesh are very interested in producing broccoli for its high value. Applications of balanced portions of fertilizers can be essential to produce high-quality vegetables, including broccoli, and for achieving maximum returns (Ahirwar and Nath, 2020). Most farmers in Bangladesh are unaware of the benefits of balanced fertilizers, and they produce different vegetables without maintaining proper doses of fertilizers to test the soil. Generally, to get higher yields, the farmers indiscriminately use chemical fertilizers without adding sufficient quantities of organic manure. The irresponsible use of fertilizers can lead to the deterioration of soil health and reduce product quality and shelf life (Mal et al., 2014). Only chemical fertilizers may accelerate the crop yield initially, but they eventually have adverse effects (Gupta et al., 2019). Organic manure can meet demands for plant nutrients in maintaining quality attributes and improving the qualities of soil profile (Alam et al., 2019). Using mineral fertilizers (N, P, and K) increases broccoli vegetative growth, yield, and quality (Nonnecke, 2002). The ongoing use of chemical fertilizers affects soil structure. Organic manures can be an alternative to synthetic fertilizers (Hossain et al., 2020). Utilization of locally produced manures like cow dung and chicken manure by vegetable production operations may increase crop yields with less use of chemical fertilizer. Consumers demand higher quality and safer foods and are highly interested in organic products. This study aimed to determine the effects of different doses of organic and inorganic fertilizers on the yield and quality of broccoli.

Materials and Methods

A field experiment was conducted at the Field Research Centre of Bangladesh Open University Gazipur campus during the winter of 2022-2023 to evaluate vegetative growth, curd yield, and curd quality performance of broccoli plants under different fertilizer management practices. Broccoli was cultivated in six plots using five fertilizer management practices and one without fertilizer treatment. The basic physical and chemical properties of the soil of the experimental site, using cow dung and chicken manure, were analyzed by following a standard procedure. The experimental site was in Madhupur Tract (AEZ-28). The experimental field soil contained a pH of 6.95 and organic matter of 1.21%. Other major soil elements were 0.054% N, 26.541% P, 0.132% K, 10.718% S, 0.891% Zn, and 0.244% B at the initial stage. Cow dung contained 34.88% OM, 1.44% N, and 0.561% K. On the other hand, chicken manure contained 50.98% OM, 1.757% N, and 0.592% K (BRAC-Lab, 2022). We added the fertilizers to each plot as per treatments, namely, T1 (control), T2 (cow dung at 10 t ha^{-1}), T3 (chicken manure at 10 t ha^{-1}), T4 (100% of recommended dose of NPK), T5 (cow dung at 5 t ha^{-1} + 50% of the recommended NPK dose) and T6 (chicken manure at 5 t ha^{-1} + 50% of the recommended NPK dose). Concerning the plots under the T4 treatment, we added N, P, and K as urea, TSP, and MoP at 210, 120, and 100 kg ha^{-1}, respectively (Rahman et al., 2022). We used broccoli seeds of the F1 Hybrid Green Crown produced by SAKATA Seed Company (Japan). We purchased the seeds in September 2022 from a local seed store. Broccoli seeds were sown in a nursery bed on 1 October 2022 in winter. Thirty-day-old seedlings were transplanted in the open field on 31 October 2022. Each plot area was 2 m × 2 m, consisting of four rows. Four plants in each row (50 cm apart) were planted under an irrigation system. Weeding was done three times, i.e., 15/11/2023, 30/11/2023, and 15/12/2022, to keep the plots free from weeds, and soil mulching involved breaking the soil crust for easy aeration and conservation of soil moisture. Plots were irrigated regularly during the growing season to keep the field moist for better growth and development of plants. Morphological data were measured at the Agricultural Laboratory of Bangladesh Open University. Five plants per plot were selected for data collection on plant height, number of leaves per plant, fresh leaf weight per

plant, stem length, stem diameter, days required for primary curd initiation, days to plant maturity, curd diameter, individual curd weight, and curd yield. Plant height was measured at the marketable harvesting stage from the soil level to the tip of the shoot and expressed in cm. The curd weight of each plant appeared in grams (g), and the total yield per hectare in tons (t ha^{-1}). Quality parameters, i.e., pH, TSS (%), and vitamin C, were determined according to a method described by AOAC (1980). Statistical analysis of the obtained data was subjected to standard analysis of variance procedure. Broccoli was cultivated under six fertilizer treatments. The 24 experimental plots were in a randomized complete block design (RCBD) with four replications. Data pertaining to yield, yield-contributing characteristics, and quality parameters were analyzed using MSTAT-C software to compare mean values following Duncan's Multiple Range Test (Gomez and Gomez, 1984).

Results

The obtained results showed that all organic and inorganic fertilizers and their combined application led to a significant synergistic effect on broccoli growth, yield, and quality, compared to the control (Tables 1-3).

Plant height, stem length (cm) and stem diameter (cm)

The results pertaining to the effect of fertilizers applied through different nutrients on plant height, stem length and stem diameter of broccoli at marketable stage (80-90 DAT) are presented in Table 1. Plant height peaked (60.00 cm) in response to T6 (chicken manure 5 t ha^{-1} + 50% of the recommended NPK dose) followed by T4, T3, and T5. The minimum plant height (42.66 cm) occurred in response to the T1 treatment (control).

Table 1. Effects of fertilizers on growth and yield attributes of broccoli.

Treatments	Plant height (cm)	Number of leaves $plant^{-1}$	Leaf fresh weight $plant^{-1}$ (g)	Stem length (cm)	Stem diameter (cm)
T1	44.66^{c*}	11.50^{d}	516.25^{c}	13.50^{c}	3.06^{c}
T2	51.78^{b}	16.25^{c}	543.00^{b}	20.00^{a}	3.53^{b}
T3	55.30^{a}	18.75^{b}	562.50^{b}	22.00^{a}	3.48^{b}
T4	57.05^{a}	22.00^{a}	516.50^{a}	22.25^{a}	3.65^{b}
T5	54.18^{a}	21.50^{a}	609.00^{a}	18.50^{b}	3.98^{a}
T6	60.00^{a}	22.00^{a}	585.00^{a}	21.00^{a}	3.63^{b}
CV (%)	8.0	8.4	4.6	8.1	6.6
LSD (0.05)	6.47	2.35	38.30	2.38	0.30

* in a column with similar letter(s) indicates values that are statistically similar, and those having dissimilar letter(s) differ significantly ($p \leq 0.05$). T1: control. T2: cow dung at 10 t ha^{-1}. T3: chicken manure at 10 t ha^{-1}. T4: recommended NPK dose. T5: cow dung at 5 t ha^{-1} + 50% of the recommended NPK dose. T6: chicken manure at 5 t ha^{-1} + 50% of the recommended NPK dose.

The highest stem length (22.25 cm) occurred in response to the T4 treatment, which was statistically similar to the effects of the T3, T6, and T2 treatments. The lowest stem length (13.50 cm) appeared in the control treatment (T1). The highest stem diameter (3.98 cm) occurred in response to the T5 treatment, and the lowest stem diameter (3.06 cm) in T1.

Number of leaves per plant and fresh leaf weight (g)

The data presented in Table 1 clearly showed that the fertilizers played a significant role in directly affecting the number of leaves per plant. The maximum number of leaves per plant (22.00) was recorded under T4 and T6 treatments, statistically similar to T5 (21.50). The minimum number of leaves per plant (11.50) was noticed with control (T1) treatment. The various treatment combinations significantly influenced the fresh leaf weight of plant (Table 1). In treatment T5 leaf fresh weight per plant was highest (609.00 g) that was statistically similar to T6 and T4 but the lowest leaf fresh weight per plant (516.25 g) was found in T1 (control) plot.

Primary curd initiation days

Primary curd initiation times were observed differently due to variations in fertilizer treatments (Table 2). Curd initiation time was delayed from the transplanting date in the T4 treatment and early in the T1 treatment. The results indicated that treatment T4 took maximum days (67.8) for primary curd initiation. The T1 treatment induced minimum days (55.00) (without fertilizer) for primary curd initiation.

Early flowering was observed in the T1 treatment due to the smaller nutritional effect of chemical fertilizers, especially nitrogen. T4 induced maximum days to primary curd initiation (recommended NPK dose) and was statistically similar to T6 (chicken manure at 5 t ha^{-1} + 50% of the recommended NPK dose), T3 (chicken manure at 10 t ha^{-1}), and T5 (cow dung at 5 t ha^{-1} + 50% of the recommended NPK dose) treatments for their primary curd initiation.

Table 2. Effects of fertilizers on growth and yield attributes of broccoli.

Treatments	Primary curd initiation time (days)	Curd length (cm)	Curd or head diameter (cm)	Curd weight (g plant^{-1})
T1	55.0^{c*}	13.00^{c}	9.48^{c}	202.00^{b}
T2	60.0^{b}	16.25^{b}	10.28^{c}	469.00^{a}
T3	65.0^{a}	18.50^{a}	15.95^{a}	451.00^{a}
T4	67.8^{a}	17.00^{a}	15.20^{a}	345.24^{a}
T5	65.0^{a}	19.50^{a}	16.63^{a}	494.50^{a}
T6	67.5^{a}	16.50^{b}	13.78^{b}	483.25^{a}
CV (%)	3.8	9.8	9.7	24.4
LSD (0.05)	3.63	2.48	1.98	149.97

* in a column with similar letter(s) indicates that values are statistically similar and those having dissimilar letter(s) differ significantly (p≤0.05). T1: control. T2: cow dung at 10 t ha^{-1}. T3: chicken manure at 10 t ha^{-1}. T4: recommended NPK dose. T5: cow dung at 5 t ha^{-1} + 50% of the recommended NPK dose. T6: chicken manure at 5 t ha^{-1} + 50% of the recommended NPK dose.

Curd head length, diameter, and weight

The highest curd length, diameter of head, and weight of head occurred in response to T5 (Table 2). Different fertilizer applications significantly influenced the head diameter compared to the control (T1). The maximum curd length (19.50 cm) and curd diameter (16.63 cm) were recorded in the T5 treatment, followed by T3 and T4 treatments. The lowest curd length (13 cm) and diameter (9.48 cm) were observed in T1 (control). The curd weight was significantly influenced by different treatment combinations. The highest curd weight (494.50 g) was observed under the T5 treatment that was statistically similar to T6, T4, and T3. The lowest curd weight (202.0 g) was observed in T1 (control).

Curd Yield

The results showed that treatment T5 led to a significantly higher curd yield per hectare than the other treatments (Fig. 1). The optimum broccoli yield (25.78 t ha^{-1}) was obtained by the application of cow dung at 5 t ha^{-1} plus 50% of the recommended NPK dose (T5). The yield of treatment T6 (23.60 t ha^{-1}) was statistically similar to T5. Treatment T1 (control) led to the lowest yield per hectare (7.5 t ha^{-1}).

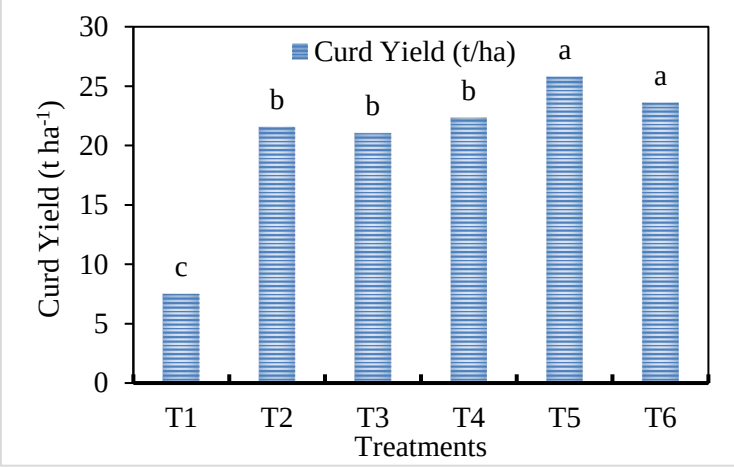

Fig. 1. Effect of fertilizer treatments on the curd yield of broccoli. T1: control. T2: cow dung at 10 t ha^{-1}. T3: chicken manure at 10 t ha^{-1}. T4: recommended NPK dose. T5: cow dung at 5 t ha^{-1} + 50% of the recommended NPK dose. T6: chicken manure at 5 t ha^{-1} + 50% of the recommended NPK dose. Similar letter(s) on the top of the bar are statistically similar and those having dissimilar letter(s) differ significantly (p≤0.05).

Effect of fertilizers on quality parameters

The application of fertilizers in different combinations significantly affected the TSS% and vitamin C content in broccoli curds (Table 3). The lowest pH value occurred in response to the T4 treatment that had 100% of the recommended NPK dose. Statistical similarity was observed among the effects of T1, T2, T3, T5 and T6 treatments. The maximum values for all these quality attributes were found significantly superior in the T2, T3, T4 and T5 treatments, compared to the T1 treatment (control). Treatment T3 (chicken manure at 10 t ha^{-1}) recorded the highest TSS value (10.54%) which was statistically similar to T6. The lowest TSS value was observed under T1 (control) treatment and was statistically similar to T2. The maximum vitamin C content in curd (80.77 mg 100 g^{-1}) was recorded in the T4 treatment (100% of the recommended NPK dose) and was significantly superior to the rest of the treatments. The lowest vitamin C content (53.84 mg 100 g^{-1}) was found in T1. The second highest vitamin C content (60.72 mg 100 g^{-1}) was observed in T3.

Table 3. Effect of fertilizers on the pH, TSS%, and vitamin C in broccoli curds.

Treatments	pH	TSS%	Vitamin C (mg 100 g^{-1})
T1	6.30[a*]	8.07[c]	53.84[c]
T2	6.40[a]	8.27[c]	60.85[c]
T3	6.20[a]	10.54[a]	70.70[b]
T4	6.00[b]	9.54[b]	80.77[a]
T5	6.30[a]	9.52[b]	56.99[c]
T6	6.30[a]	10.52[a]	60.72[c]
CV (%)	2.4	2.1	7.7
LSD (0.05)	0.27	0.36	9.42

[*] in a column with similar letter(s) indicates statistical similarity and those having dissimilar letter(s) differ significantly ($p \leq 0.05$). T1: control. T2: cow dung at 10 t ha^{-1}. T3: chicken manure at 10 t ha^{-1}. T4: recommended NPK dose. T5: cow dung at 5 t ha^{-1} + 50% of the recommended NPK dose. T6: chicken manure at 5 t ha^{-1} + 50% of the recommended NPK dose.

Discussion

The organic fertilizer, inorganic fertilizer, and their combinations played a significant role in directly affecting the growth, yield, and quality parameters of broccoli. Stem length significantly varied due to fertilizer treatments in this experiment. The maximum number of leaves per plant was recorded under T4 and T6 treatments which was significantly different from T5. In treatment T5, leaf fresh weight per plant was highest. The lowest leaf fresh weight per plant was found in T1. A good foliage status indicates the vigor condition of plants. Plant vigor provides more growth, development, and productivity in plants (Hossain et al., 2020). This variation might be due to the availability of nutrients, especially nitrogen, and could be due to the improvement in the soil's water holding capacity as mentioned earlier by Roe and Cornforth (2000). Application of solely recommended NPK chemical fertilizers treatment increased vegetative growth and delayed the flowering stage in this experiment. It happened due to N effects on plants that increased vegetative growth and delayed reproductive stages. Positive effects of nutrients of cow dung with NPK fertilizers (T5) on curd or head diameter and individual curd weight may be due to the better availability of soil nutrients that produced healthy plants with large vegetative growth, which reflected head diameter, head weight, and improved soil chemical and physical properties. Head diameter was higher when a combination of organic and inorganic fertilizers was added compared with their individual use. Yoldas et al. (2008) reported that increasing N rates significantly increased head diameter compared to the control, but decreased with increasing doses. The optimum yield of broccoli can be obtained by application of cow dung at 5 t ha^{-1} with 50% of recommended dose of NPK (T5). These findings are in line with those reported by Soliman et al. (2006). They reported that cow dung (5 t ha^{-1}) in combination with half the recommended dose of inorganic nutrients appeared as the best combination of fertilizer, which provided maximum benefit to farmers.

In previous research, the effects of broccoli variety and N were significant on total curd yield, but their interaction effect was insignificant (Giri et al., 2013). The increase in vitamin C content in

broccoli under T4 treatment might be due to an increase in N, P, and K nutrients with an increase in microbial activity in the soil, which might have added growth regulators, vitamins, and hormones to the soil profile and ultimately led to more plant growth. Similar findings by Mohapatra et al. (2013) confirm these findings. Organic manure seemed less effective in increasing broccoli yield than inorganic fertilizer. Organic manure needs more time for nutrients to become available for plant absorption. However, the beneficial effect of organic manure on yield may be due to an increase in organic matter rate caused by the release of carbon dioxide during compost decomposition (Wilkinson, 1979) and improvement of the soil structure conditions, which encouraged plants to have good root development by improving the aeration of the soil (Arisha et al., 2003). Organic fertilizers enhance the availability of nitrogen and phosphorus to plants and give rise to better utilization of the nutrients by the plant, which might have promoted more root growth. The present findings are in close agreement with earlier work done by Sable and Bhamare (2007) on cauliflower. Nonnecke (2002) reported that mineral fertilizer (NPK) increased broccoli vegetative growth, yield, and quality. Broccoli plants can be grown better in soils amended with organic fertilizers. Organic and inorganic fertilizers together resulted in optimal values for all tested parameters. These findings corroborate the findings of Ouda and Mahadeen (2008), Blatt (1991), and Dufault et al. (2001) on broccoli.

Conclusion

The results showed that all organic and inorganic fertilizers and their combined application had a significant synergistic effect on broccoli growth, yield, and quality compared to the control. The use of manure in combination with chemical fertilizers enhanced all growth and yield parameters. Organic manure enhances soil aggregation, aeration, and water-holding capacity, which, in combination, creates favorable conditions for broccoli growth, yield, and quality. Using organic manure with inorganic fertilizers significantly affected plant growth, curd yield, and broccoli quality. Maximum broccoli yield occurred in the T5 treatment group (cow dung (5 t ha^{-1})) with 50% of the recommended dose of NPK fertilizers. Thus, from the current research, we can recommend that cow dung (5 t ha^{-1}) with 50% of the recommended dose of NPK fertilizers can maximize broccoli yield and quality in the Gazipur district of Bangladesh.

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Conflict of Interest

The authors indicate no conflict of interest in this work.

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