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ASSESSMENT OF BEST FERTILIZER COMBINATION AND PLANTING DISTANCE FOR GROWTH AND PRODUCTIVITY OF BROCCOLI (*BRASSICA OLERACEA*)

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SUMMARY

The pertinent study investigated during autumn 2022 the effects of different fertilizer combinations and plant spacing on broccoli at the University of Mosul, Mosul, Iraq, to improve the broccoli plant's growth and productivity. The first factor comprised two planting distances (35 and 45 cm), and the second factor consisted of six levels of five different mineral fertilizer combinations obtained from $N_{15}P_{15}K_{15}S_{15}$ (rate of 400 kg/ha) and $N_{10}P_5K_7S_{10}Mgo_{2.5}Fe_{0.5}Zn_{0.019}$ (rate of 400 kg/ha), with a control (no fertilizer) as the check. Thus, the experiment used 12 treatments in a randomized complete block design with factorial arrangement and three replications. Results revealed that the broccoli plants cultivated at a 45 cm distance showed a considerable rise in the number of leaves compared with those planted at a 35 cm distance. The significant effects of different plant spacing also have varied impacts on the yield characteristics of broccoli. The varying fertilizer applications also enhanced substantially some broccoli's growth and yield characteristics. Considerably, the interaction of fertilizer combinations and plant spacing also significantly influenced positively the broccoli's growth and yield traits.

Keywords*:* Broccoli (*Brassica oleracea* L.), plant spacing, fertilizer combinations, macro- and micro-elements, growth and yield traits

Key findings: Results revealed that broccoli plants cultivated at a 45 cm distance showed a considerable improvement in growth traits compared with a plant spacing of 35 cm. The fertilizer combinations also significantly enhanced the growth and yield traits. The fertilizer combinations substantially interacting with plant spacing were consistent with the influence obtained through the single factor..

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INTRODUCTION

Broccoli (*Brassica oleracea*) belongs to the family Brassicaceae, containing numerous winter vegetable crops. The broccoli crop is of high economic value in all the Governorates of Iraq and costs five times more than cabbage and cauliflower. Broccoli also has limited productivity locally, with 90% produced through imports from neighboring countries. Despite a lack of farmers' know-how, the complexity of its cultivation and care of this crop might be the reasons for farmers' less interest in cultivating said vegetable (Ibraheem, 2015; AL-Taey *et al*., 2019; Ahmed *et al*., 2023).

Aside from being an economically valuable crop, broccoli is most nutritious in the Brassicaceae family, composed of various nutrients widely used for medicines in different countries, such as vitamins (A, B1, B2, B5, B6, B17, E) and elements, such as calcium, manganese, zinc, iron, and carotene, which turns into vitamin A in the human body (Thapa and Rair, 2012; Hamza and AL-Taey, 2020). By medical importance, broccoli contains antioxidants, which reduce the incidence of cancer diseases by 60% because it has glucoraphanin, which enhances the body's immunity against cancer. It helps the body prevent a carcinogen from causing the likelihood of stomach cancer. Broccoli also contains the indole-3-carbinol compound, an antioxidant that resists carcinogens, prevents breast and colon cancer, and boosts liver function (Griffin, 2021).

Several factors affecting broccoli's growth and productivity, including mineral fertilization with compound fertilizers and plant spacing, have become the main determinants of commercial production to enhance farm income. Mahadeen *et al*. (2008) suggested applying a compound fertilizer to broccoli plants, i.e., N20P20K20 + trace elements amounting to 0, 30, and 60 kg ha^{-1}, significantly increased plant height, dry weight, number of leaves, chlorophyll in leaves, average weight and diameter of the main curd, average number and weight of lateral curds. In addition, it gives a notable rise in the overall productivity per unit area for both the primary central head and the plants' lateral heads.

Broccoli plants resulted in a notable improvement in growth and yield parameters, with the best significant measured values obtained using a 300 kg ha^{-1} level of the compound fertilizer $N_{46}K_{42}$ (Dizayee and Saleh, 2017). Lodhi *et al*. (2017) revealed that broccoli yield indicators regarding the circumference of the main curd and the plant's typical weight significantly increased with compound fertilizer use at the rate of 120-80-80 NPK kg ha^{-1}. Considerable rise in plant height, leaf count, area, main curd diameter, average main curd weight, and unit area yield for broccoli plants have emerged using the NPK compound fertilizer (70:45:50 kg ha^{-1}) (Henawy *et al*., 2006).

Plant spacing is vital in strengthening the development of growth traits, crop quality, and yield for horticulture crops (AL-Taey and AL-Musawi, 2022). Marilyn and Garling (2010) confirmed that broccoli plants planted at 30 cm can significantly excel in the lateral and chief curds' yield for cultivation area compared with plants planted at 40 cm. Hossain *et al*. (2011) studied three planting distances, i.e., 40, 50, and 60 cm, for broccoli plants, and the planting distance of 60 provided the maximum leaf number per plant, amounting to 20.1 leaves, the broadest circumference and average weight of the main curd, and the number of lateral curds reaching 20 cm, 345 g, and three lateral curds per plant.

Esmot (2016) studied and compared e three cauliflower planting distances, viz., 30, 40, and 50 cm, and observed a significant increase in leaf count for plant and yield at 40 and 50 cm compared with the plant spacing at 30 cm. Tejaswini *et al*. (2018) observed a substantial increase and superiority in plant height, leaf count, area, and the typical major curd weight per plant with planting distance of 45 cm versus plant spacing of 30 cm. Given the greater importance of compound fertilizer and planting distance in the yield and quality of broccoli plants, the presented research planned to study the different planting distances and various types of compound fertilizers and their combinations, raise and improve broccoli

production quantity and quality, discover the most effective fertilizer combination and plant spacing broccoli plants respond well.

MATERIALS AND METHODS

The practical study commenced in the autumn of 2022 to investigate the effects of different fertilizer combinations and plants' spacing on broccoli at the University of Mosul, Mosul, Iraq. The first factor was two planting distances (35 and 45 cm), with the second factor comprising six levels of five different mineral fertilizer combinations obtained from $N_{15}P_{15}K_{15}S_{15}$ (rate of 400 kg/ha) and $N_{10}P_5K_7S_{10}Mgo_{2.5}Fe_{0.5}Zn_{0.019}$ (rate of 400 kg/ha) and the control (no fertilizer) as check. The control treatment (as the check) attained the label as T1, the mineral fertilizer ($N_{15}P_{15}K_{15}S_{15}$) marked as T2 and $N_{10}P_5K_7S_{10}MgO_{2.5}Fe_{0.5}Zn0_{0.19}$ as T3. The combination of the first half of the T2 and T3 incurred the tag as T4, the second quarter of the T2 with three-quarters of T3 marked as T5 and the third combination of three-quarters of T2 with a quarter of T3 as T6. Thus, 12 treatments in this experiment proceeded in a randomized complete block design with factorial arrangements using three replications.

Adding all the fertilizers at once during the land preparation ensued; however, applying nitrogen fertilizers (60 kg/ha) continued in two batches, with the first after four weeks of seedling and the second dose at the formation of curds. The broccoli 'Hot Bro' hybrid cultivar seeds' sowing in germination trays used the peat moss medium. After 34 days of seeding, the broccoli seedlings with 8–10 cm plant height and 4–5 true leaves obtained field planting with a planting distance of 35 and 45 cm. The field practices followed the guidelines used in the commercial cultivation of broccoli employing a drip irrigation system, paying close attention to the irrigation process following the plant's requirements.

Parameters studied

Vegetative growth traits

The plant's height measurement began from the base of the plant in the earth to its topmost leaf. Determining each plant's number of leaves attained counting, excluding the tiny ones. For the dry weight of vegetative growth (g/plant), randomly selected five plants in each unit bore uprooting with their roots intact, and after dusting off the dirt, weighing the plants while soft by an electric balance resulted in the rate of extraction. For the leaf area (cm^2/plant), randomly selected three plants in each experimental unit underwent leaf separation, taking 10 tablets with an area of 1 cm of two for each tablet of 10 leaves, computing the plant's leaf areas proportionally based on their wet weight.

Yield characteristics

The weight of the main curd (g/curd) calculation continued by dividing each repeater's experimental unit product by its curd yield. Dividing the number of lateral curds per plant produced by the number of plants in the experimental unit occurred. The average weight of the lateral curd (g/curd) incurred division by each repeater's trial unit product by the number of lateral curds produced. The total yield of the main curds (t/ha) in each experimental unit and the estimated major curd yield employed the following equation:

$$Total\ yield\ = \frac{Experiment\ yield\ \times\ 10000\ m2}{Experimental\ \ unit\ \ area}$$

Computing the lateral curd yield (t/ha) was the same way as the total yield of the main curds. The yield of main curds + yield of lateral curds (t/ha) also bore measuring and combining. The data recorded for all the parameters underwent processing and analysis

using a computer program called SAS (2020). The comparison and separation of the means used Duncan's polynomial test at a significance level of 0.05 (Al-Rawi and Khalaf-Allah, 2000).

RESULTS AND DISCUSSION

Growth traits

The studied impact of planting distances in broccoli, the type and combination of fertilizers, and their interactions on the vegetative growth characteristics appear in Tables 1 and 2. The planting spacing of 35 and 45 cm revealed no considerable differences for almost all the vegetative growth characteristics, except for the number of leaves where the planting distance of 45 cm outperformed the 35 cm distance (19.21 and 18.27 leaves/plant, respectively). The planting distance among the plants has resulted in a rise in the soil nutrients' absorption, as the ground area occupied by plants with a distance of 45 cm was broader than that occupied by plants with 35 cm. Thus, it increased the processing of nutrients absorbed by the plant roots, and the amount of light penetrating from the sun's rays was higher by increasing the distance between plants, effectively enhancing photosynthesis that reflected significantly in leaves per plant. Al-Hussainy and Manea (2019) reported that the increased planting distance among the broccoli plants resulted in a significant increase in the majority of the vegetative growth traits.

Regarding the influence of the type and combination of fertilizers, the fertilizer combinations showed significant differences in growth traits in broccoli (Table 2). For plant height, the fertilizer treatment T6 gave the highest value (66.96 cm) and excelled all other fertilizer combinations. The fertilization treatments also caused leaves to increase significantly in each plant (except for the fertilizer treatment T2). The highest average dry weight of the broccoli plant leaves and the plant leafy area was 262.97 g/plant and 5,081.8 cm^2/plant, respectively, with the fertilizer combination of treatment T5, which notably differed from T4 treatment in the dry weight trait, observing the pattern also for leaf area characteristic. The increase in vegetative characteristics can be due to the substantial impact fertilizers have on stimulating cellular proliferation and improving the efficacy of photosynthesis. Furthermore, fertilizers are crucial in the light reaction process by aiding in the synthesis of pigments (Al-Tamimi and Farhood, 2022; Ahmed *et al*., 2023). Mohammed *et al*. (2021) asserted that the augmentation of a plant's photosynthetic efficiency has the interplay of cellular division and elongation accomplishing it, along with the activation of physiological systems, leading to an elevation in chlorophyll content within the foliage.

All the fertilization treatments significantly affected the description of plant height and the number of leaves, with fertilizer treatment T5, leading to the dry weight of plant leaves and leaf area in broccoli compared with the control treatment. It might be due to the richness of these fertilizers with the basic macro- and micro-elements found in their composition. The fertilizers' composition also contains nitrogen, phosphorus, and potassium, directly influencing positively the physiological processes, such as respiration, photosynthesis, and protoplasmic building, and their inclusion in the creation of nucleic acids, DNA, and RNA necessary for cell elongation and division, which eventually enhance the biomass for the vegetative development of broccoli plants (AL-Taey *et al*., 2018; Ibraheem *et al*., 2019).

Regarding the interaction of broccoli planting distances and the fertilizer combinations, results showed the planting distance of 45 cm's interaction with fertilizer treatment T6 recorded the highest value in plant height (66.92 cm), and the same with fertilizer treatment T5 recorded a maximum value in plant leaf number (20.50 leaves/plant). The plant dry weight of 294.01 g/plant was evident in the interaction between the 35 cm planting distance and the T5 fertilization treatment. Likewise, the same interaction gave the highest value for leaf area in broccoli plants (5,420.4 cm^2/plant) and proved consequently varied from other interactions. This result agreed with the findings of Hill (1990).

Table 1. Effect of planting distance, fertilizer combinations, and their interaction on the vegetative growth indicators of broccoli.

Planting distances	Type and combination of fertilizers	Plant height (cm)	Leaves plant^{-1}
35 cm	T1	56.89 e	17.32 d
	T2	62.33 d	18.33 b-d
	T3	65.55 a-c	17.75 cd
	T4	63.44 bc	19.50 a-c
	T5	62.66 d	18.43 a-d
	T6	67.00 a	18.28 b-d
45 cm	T1	54.50 f	17.67 cd
	T2	62.47 d	18.44 a-d
	T3	66.33 ab	20.39 ab
	T4	65.31 a-c	18.60 a-d
	T5	64.44 b-d	20.50 a
	T6	66.92 a	19.66 a-c
Average of planting distance effect	35 cm	62.98 a	18.27 b
	45 cm	63.33 a	19.21 a
Average of fertilizer effect	T1	55.69 d	17.49 b
	T2	62.40 c	18.39 ab
	T3	65.94 a	19.07 a
	T4	64.38 b	19.05 a
	T5	63.55 bc	19.46 a
	T6	66.96 a	18.97 a

Averages that share the same letter or letters of the alphabet according to the Duncan's test at the probability level of 5% indicate each factor and interaction do not substantially differ from one another.

Table 2. Effect of planting distance, fertilizer combinations, and their interactions on the vegetative growth indicators of broccoli.

Planting distances	Type and combination of fertilizers	Dry weight of vegetative growth (g/plant)	Leaf area (cm^2/plant)
35 cm	T1	172.74 d	2989.7 d
	T2	215.29 b-d	3956.0 b-d
	T3	225.63 a-d	4006.7 a-d
	T4	222.98 a-d	4330.1 a-d
	T5	294.01 a	5420.4 a
	T6	228.11 a-d	4163.1 a-d
45 cm	T1	268.06 ab	4736.4 a-c
	T2	258.05 a-c	4759.4 a-c
	T3	237.10 a-d	4800.1 a-c
	T4	187.89 cd	3489.9 cd
	T5	231.93 a-d	4743.2 a-c
	T6	262.20 a-c	5144.3 ab
Average of planting distance effect	35 cm	226.46 a	4144.3 a
	45 cm	240.87 a	4612.2 a
Average of fertilizer effect	T1	220.40 ab	3863.0 b
	T2	236.67 ab	4357.7 ab
	T3	231.36 ab	4403.4 ab
	T4	205.44 b	3910.0 b
	T5	262.97 a	5081.8 a
	T6	245.15 ab	4653.7 ab

Averages that share the same letter or letters of the alphabet according to the Duncan's test at the probability level of 5% indicate each factor and interaction do not substantially differ from one another.

Yield traits

The broccoli plant spacing demonstrated no substantial differences for yield traits, i.e., the number of lateral curds per plant, the yield of the lateral curds, and the yield of the main curds + lateral curds (Tables 3, 4, and 5). However, the planting distances significantly affected the rest of the yield characteristics. Broccoli planting 45 cm apart highly outperformed those closer at 35 cm for the yield feature, such as weight of the main curd (357.346 g/curd), lateral curd's average weight (34.4433 g/curd), and plant yield per lateral curd (220.89 t/ha). The planting distance of 45 cm showed a significant superiority and resulted in a considerable rise in leaves per plant compared with the plant spacing of 35 cm. This outcome aligned with the findings of Hossain *et al*. (2012).

With an increased broccoli plant biomass, the efficient photosynthesis process could result in more managed carbohydrates consumed in the plant and their transition from vegetative growth areas to the flower buds, which increases their storage, further encouraging the formation of more flower buds and enhanced yield-related traits. These results were analogous to the research conducted by Hossain *et al.* (2011), who reported that broccoli-cultivated plants with a 35 cm distance have significantly excelled in the main curds' yield compared with the planting distance of 45 cm, which might be due to an increased number of plants in the lower plant spacing. The presented results were also in better analogy with the findings of Ara (2016), which reported similar findings in cauliflower.

Considering the impact of fertilizer treatments on the yield-related traits of broccoli, the fertilizer combinations have resulted in a considerable rise in all the characteristics of the yield studied in contrast to the control plants, except for the number of lateral curds unaffected by most of the fertilizer treatments. However, the said trait incurred significant effects only from fertilizer treatment T3 with the most meaningful values, and the weight of the main curd, the lateral curd's average weight, and the yield of main curds amounted to 392.96 g/plant, 36.135 g/plant, and 9.660 t/ha, respectively. The fertilizer treatment T5 significantly outperformed the T3 fertilizer treatment for the number of lateral curds and plant yield per curd, amounting to 6.755 curds/plant and 220.96 g/curd. The fertilizer treatment T6 achieved the highest significant results for the qualities, i.e., lateral curd product and the proportion of the main curds + lateral curds (10.8095 and 19.6010 t/ha, respectively). Thus, the said treatment significantly differed from other treatments for these two qualities. This result agreed with the findings of AL-Taey *et al.* (2019).

The substantial influence of fertilizer applications in most of the yield's studied features, using each type of fertilizer alone or in different fertilizer combinations, may be due to the compound fertilizer's ability to physiological function the N-P-K on sulfur, magnesium, iron, and zinc with the amino acids, enzymes, nucleic acids, alkaloids, purine bases, phytin, and energy transitions. Their transfer also contributes to the transfer of sugars in the plant after manufacturing in the vegetative growth to flower buds, facilitating the conversion of carbohydrates into starch, making its presence essential for photosynthesis (Oloyede *et al*., 2013). The fertilizer combinations also may have led plants to reach an optimal nutritional balance, reflecting positively the studied yield traits in broccoli and other vegetables (AL-Taey *et al.*, 2019, 2022).

The interactions of different planting distances and fertilization treatments were significant for yield-related broccoli. The planting distance of 45 cm with fertilizer treatment T3 showed greater significance in the weight of the main curd (425.72 g/plant). The interaction between plant spacing of 45 cm with fertilizer treatment T4 recorded the highest remarkable average value for lateral curds (7.1667 curds/plant), only differing significantly with the fertilizer treatments T1, T2, T3, and T4 for planting distance of 35 cm. The observed rise in crop productivity can refer to the notable fertilizer impact on enhancing the chemical and physical characteristics of the soil. Consequently, enriching the soil's capacity

Table 3. Effect of planting distance, fertilizer combinations, and their interactions on the yield-related traits of broccoli.

Planting distances	Type and combination of fertilizers	Main curd weight (g/curd)	Lateral curds plant^{-1}
35 cm	T1	209.82 f	4.8333bc
	T2	292.77 e	4.6667 c
	T3	360.20 bc	4.9667 bc
	T4	286.00e	4.6100 c
	T5	301.73 de	6.9000 a
	T6	357.83 bc	6.8333 a
45 cm	T1	259.47 e	6.3333 a
	T2	338.67 cd	6.2500 a
	T3	425.72 a	6.0000 ab
	T4	391.28 ab	7.1667 a
	T5	386.53 ab	6.6100 a
	T6	342.40 cd	6.0533 ab
Average of planting distance effect	35 cm	301.392 b	5.4683 a
	45 cm	357.346 a	6.4022 a
Average of fertilizer effect	T1	234.64 d	5.5833 bc
	T2	315.72 c	5.4583 c
	T3	392.96 a	5.4833 c
	T4	338.64 bc	5.8883 a-c
	T5	344.13 bc	6.7550 a
	T6	350.12 b	6.4433 ab

Averages that share the same letter or letters of the alphabet according to the Duncan's test at the probability level of 5% indicate each factor and interaction do not substantially differ from one another.

Table 4. Effect of planting distance, fertilizer combinations, and their interactions on the yield-related traits of broccoli.

Planting distances	Type and combination of fertilizers	Lateral curd weight (g)	Plant yield curd^{-1} (g)
35 cm	T1	14.950 e	72.26 e
	T2	28.947 cd	135.09 d
	T3	31.267 c	155.87 cd
	T4	31.453 c	144.76 d
	T5	22.623 d	155.85 cd
	T6	31.883 c	216.01 bc
45 cm	T1	22.387 d	141.85 d
	T2	30.453 c	193.9 b-d
	T3	41.003 ab	245.05 ab
	T4	33.857 c	241.9 ab
	T5	43.243 a	286.06 a
	T6	35.717 bc	216.46 bc
Average of planting distance effect	35 cm	26.8539 b	146.64 b
	45 cm	34.4433 a	220.89 a
Average of fertilizer effect	T1	18.668 c	107.05 c
	T2	29.700 b	164.53 b
	T3	36.135 a	200.46 ab
	T4	32.655 ab	193.35 ab
	T5	32.933 ab	220.96 a
	T6	33.800 ab	216.23 a

Averages that share the same letter or letters of the alphabet according to the Duncan's test at the probability level of 5% indicate each factor and interaction do not substantially differ from one another.

Table 5. Effect of planting distance, fertilizer combinations, and their interactions on the yield-related traits of broccoli.

Planting distances	Type and combination of fertilizers	Main curds yield (t/ha)	Lateral curds yield (t/ha)	Main + lateral curds yield (t/ha)
35 cm	T1	6.295 f	4.336 e	10.631 f
	T2	8.783 bc	8.105 cd	16.888 cd
	T3	10.806 a	9.352 bc	20.158 b
	T4	8.580 b-d	8.686 c	17.266 cd
	T5	9.052 b	9.351 bc	18.403 bc
	T6	10.735 a	12.961 a	23.696 a
45 cm	T1	5.189 g	5.674 de	10.863 f
	T2	6.773 ef	7.759 cd	14.532 e
	T3	8.515 b-d	9.802 bc	18.316 bc
	T4	7.826 cd	9.678 bc	17.503 cd
	T5	7.731 de	11.44 ab	19.173 bc
	T6	6.848 ef	8.658 c	15.507 de
Average of planting distance effect	35 cm	9.042 a	8.7983 a	17.8401 a
	45 cm	7.147 b	8.8356 a	15.9825 a
Average of fertilizer effect	T1	5.742 d	5.01 c	10.746 d
	T2	7.778 c	7.93 b	15.710 c
	T3	9.660 a	9.57 ab	19.237 a
	T4	8.203 bc	9.18 ab	17.384 b
	T5	8.391bc	7.93 b	18.788 ab
	T6	8.792 b	10.80 a	19.601 a

Averages that share the same letter or letters of the alphabet according to the Duncan's test at the probability level of 5% indicate each factor and interaction do not substantially differ from one another.

to retain moisture leads to improved conditions for root system development and increased activity and population of microorganisms. It, in turn, promotes the breakdown of organic matter and enhances the availability of essential nutrients required for plant growth (Oloyede *et al*., 2013).

The interaction of broccoli planting distance of 45 cm and fertilizer treatment T5 achieved the highest weight of the lateral curd and plant yield per one of the lateral curds (43.243 g/plant and 286.06 g/plant, respectively). The interaction between the planting distance of 35 cm and fertilizer treatment T3 showed the highest main curds' yield (10.806 t/ha). For lateral curd yield and the main curd yield + lateral curds, the interaction between the planting distance of 35 cm and the fertilizer treatment T6 provided sizable values for these two traits (12.961 and 23.696 t/ha, respectively), which significantly outperformed most of the other interactions for the two mentioned characteristics. The observed increase in crop productivity can be due to the fertilizer's substantial influence in improving the chemical and physical properties of the soil. As a result, the soil's moisture retention capacity intensifies, creating favorable circumstances for the growth of root systems and the proliferation of microorganisms. According to Oloyede *et al*. (2013), this process facilitates the decomposition of organic materials, increasing the accessibility of vital nutrients necessary for plant growth.

CONCLUSIONS

The results revealed that broccoli plant spacing and fertilizer combinations had a less clear impact on vegetative growth traits than on most yield traits. However, the planting distances significantly affected the traits, i.e., the average main curd weight, the weight of the lateral curd, and the plant yield per one of the lateral curds. Fertilizer combination treatment T3 proved the best for the average weight of the main curd's traits, the weight of the lateral curd, and the primary curds' yield

for the unit area. Hence, the importance of T6 fertilizer treatment becomes clear in improving the characteristics of the side curd and the yield of the main curd and the side curd.

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