



Influence of Foliar Boron Application and Sowing Dates on the Vegetative Development and Yield of Fennel (*Foeniculum vulgare* Mill.)

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Abstract

A field experiment was conducted during the 2021-22 winter season at the Agriculture Research Station, belong to the college of Agriculture, University of Anbar, Iraq, to study the growth and flowering characteristics of fennel plants *Foeniculum Vulgare* Mill. using different concentrations of boron and planting dates. Three planting dates (15 Nov, 1 Dec, and 15 Dec) and three boron concentrations (0, 50, and 100 mg L⁻¹) were examined. The experiment was done by the split-plot arranged by (RCBD) design and replicated three time. The results indicated significant differences for planting dates when the second date recorded the highest averages for vegetative growth characteristics; plant height, number of branches per plant, leaf chlorophyll content, and plant dry weight, and flowering characteristics (number of primary and secondary inflorescences of the fennel plants. Spraying with boron at a high concentration also improved plant height, number of branches per plant, leaf chlorophyll, plant dry weight, and flowering characteristics (main and secondary inflorescences). The interaction between the studied factors showing the behavior individually or together on all the studied traits and it can be most reliable results for improving fennel cultivation in Iraq.

Keywords: Planting date, Boron, Chlorophyll content of leaves, Main inflorescences.

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Introduction

The global trend in recent decades toward an interest in medicinal plants and a return to what was previously known as folk or traditional medicine has several causes. These include viewing medicinal plants as a laboratory for producing natural pharmaceutical substances, while the same substances and manufactured drugs can cause side effects that harm human health unless used on a sound scientific basis. Scientific progress has played an important role by providing effective methods and techniques for the rapid production of active compounds from plants, developing effective methods and

techniques for increasing medicinal compounds, and facilitating the circulation of medicinal plants and their products. Furthermore, scientific experiments have proven that laboratory-made active ingredients do not have the physiological effect of the same active ingredients extracted from medicinal plants (4 and 9). The Fennel plant (*Foeniculum vulgare* Mill.), belonging to the Umbeliferae family, is an important aromatic annual herbaceous plant worldwide, particularly in Iraq, due to its combination of medicinal, aromatic, and nutritional uses. It also contains up to 6% volatile oils, composed of Anethole, limonene, and α -pinen. The reason for its distinctive smell is due to its

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content of Fenchone. It also contains many vitamins such as (A, B, C) and salts (5 and 14).

The climate changes witnessed by countries around the world, particularly in developing countries, have had a clear impact on plant cultivation and its impact on growth and flowering characteristics. The problem of heat and other environmental changes has led to the deterioration of a third of agricultural land, affecting plant growth and development. According to astronomical statistics, further changes in temperature are expected, which have become evident in arid and semi-arid regions, including Iraq. Therefore, it must consider these changes an important warning to find factors that increase plant adaptation to changing environmental conditions (3). Among these factors are planting dates, which are important in determining thermal requirements, photoperiod, and radiation intensity, which directly affect all the major developmental transformations of the plant and are necessary for its growth, such as germination and the formation of vegetative and flower buds. The planting date determines the length of time a plant needs to reach its successive growth stages. Its suitability means achieving good vegetative growth with the ability to intercept solar radiation efficiently, thus enabling greater nutrient synthesis and accumulation (12 and 16). Plant growth is not limited to the appropriate planting date alone; instead, it must be provided with stimulants during growth stages affected by changing environmental conditions, which work together to increase plant growth (13).

In recent decades, micronutrients have attracted the attention of researchers as one of the most important stimulants for plant growth. Among these elements is boron, which has a direct effect on cell division, increasing cell number, and its ability to draw nutrients from the soil to the leaves and growing tips (11). This increases plant growth, encourages the formation and preservation of chlorophyll, prevents its decomposition, maintains leaf greenness for the longest possible period, and increases the number of leaves and branches (6, 15, and 16). It also plays a regulatory role in the function of nitrate-reducing and sugar-

transporting enzymes, which enhance photosynthesis and improve plant growth characteristics (8 and 14). However, Boron is a double-edged sword when used as a plant nutrient because the difference between safe and toxic amounts is very small. A deficiency causes deformities and stunted growth, while an excess leads to plant poisoning, scorching of the edges, and tissue death. So, extreme caution is necessary regarding its concentration, especially since excess is more dangerous than deficiency. Therefore, this research was carried out to promote the cultivation of this plant, there is a need to seriously consider conducting research and studies related to its cultivation techniques under different environmental conditions, due to its importance in future agricultural investment as an important medicinal plant, and due to the effect of planting dates and spraying with boron on the formation of green space (photosynthetic area) and the accumulation of dry matter, which is reflected in the increase in the number of flower inflorescences.

Materials and Methods

Field operation

A field experiment was conducted during the winter season (2021-2022) at the Agriculture Research Station, belong to the college of Agriculture, University of Anbar, Iraq. Field operations included plowing, leveling, and smoothing the experimental field was divided into experimental units measuring 2.5 x 3 m, resulting in an area of 7.5 m². Seeds were planted in rows, 75 cm apart, and 25 cm apart. The experimental unit contained four rows.

Study factors

1. The first factor: Three planting dates (15/11, 1/12, and 15/12).
2. The second factor: Boron at three concentrations (0, 50, and 100) mg L⁻¹.

Experimental design: A randomized complete block design (R.C.B.D.) arranged based on a split-plot design with three replicates. Planting dates occupied the main plots, while boron concentrations occupied the

secondary plots, resulting in a total of 27 experimental units.

Traits studied

1. Plant height (cm): Ten plants were randomly selected from the two median lines of each experimental unit during the fruiting stage. Plant height was measured from the soil level to the highest main inflorescence on the plant.

2. Number of branches (plant^{-1}): The average number of branches for the ten plants mentioned above was calculated.

3. Dry weight (g plant^{-1}): Ten plants were randomly selected from the two median lines of each experimental unit when fully ripe. They were placed in perforated paper bags and dried in an electric oven at 68°C for two consecutive days until the weight stabilized. After complete drying, the average weight of the dried samples was calculated.

4. Chlorophyll Estimation: Total chlorophyll content in fresh leaves was estimated using the method of Ranganna (1977).

5. Number of primary inflorescences per plant^{-1} : Calculated as the average of 10 plants randomly selected from the two median lines of each experimental unit at maturity.

6. Number of secondary inflorescences per primary inflorescence: The average number of secondary inflorescences per primary inflorescence was calculated for each of the ten plants mentioned above.

7. Weight of 1000 fruit (g): after harvesting, three samples including 1000 fruit from each treatment were taken and weighted by electric balance and then the average was taken.

8. Fruit yield (kg ha^{-1}): when fennel plants were reached to the maturity stage, the plant were harvested and weighted by gram and then the weight of each treatments converted to kg ha^{-1}

Statistical Analysis

After collecting and tabulating the data, they were statistically analyzed using the GenStat program. The least significant

difference (LSD) test was used to compare means at a probability level of 0.05 according to the split-plot arrangement with R.C.B.D design (7).

Results and Discussion

Plant height (cm)

The results in Table 1 indicate a significant increase in plant height for both study factors. Fennel plants planted on the second date gave the highest average plant height of 94.84 cm, while plants planted late on gave the lowest average height, reaching 82.76 cm. The reason for this increase is that planting comes as a result of suitable temperature and other environmental conditions, especially at the germination stage, which leads to an increase in the efficiency of carbon metabolism and provided ideal vegetative growth, thus increasing its height. These results were consistent with what was stated by (10), who indicated that planting Fennel at a suitable date led to an increase in plant height. Plants sprayed with a high concentration of boron (100 mg L^{-1}) gave the highest average plant height, which was 92.75 cm, compared to control plants sprayed with water only, which gave the lowest average of 84.64 cm. The superiority of high boron concentration in the plant height trait is attributable to its positive effect on meristematic tissue division and on cytokinin production, which is important for cell division and elongation, as evidenced by stem cell proliferation and elongation. This result was consistent with the findings of (11), who reported that using boron at acceptable concentrations led to significant increases in plant height. The interaction between planting dates and boron concentrations was also gave significant response, and fennel plants planted on the second date and sprayed with 100 mg L^{-1} of boron recorded the highest average for plant height trait, 99.30 cm, while plants planted on 12/15 with control treatments (only water) recorded the lowest average, 80.09 cm.

Table 1 The effect of boron spraying, planting dates, and their interaction on the plant height of Fennel plants (cm).

Planting Dates	Boron concentration (mg L ⁻¹)			Mean
	0	50	100	
First - 15/11	83.55	92.27	95.85	90.56
Second - 1/12	90.29	94.94	99.30	94.84
Third - 15/12	80.09	85.08	83.10	82.76
Mean	84.64	90.76	92.75	
LSD	Planting Dates	Boron	Planting Dates * Boron	
	2.187	2.087	3.363	

Number of branches (branch per plant⁻¹)

Table 2 shows a significant effect of planting dates, boron concentrations, and their interaction on the number of plant branches. The second date produced the highest average number of plant branches, 8.23 branches per plant, compared to the other dates, where the third date produced the lowest average, 6.58 branches per plant. Suitable environmental conditions, such as temperature and light, positively affected plant tissue development in the early stages of plant growth, which was reflected in an increase in the number of plant branches. This result is consistent with the findings of (2), who indicated an increase in the number of plant branches when planting

fennel early. Increasing boron concentrations was accompanied by a significant increase in the average number of branches per plant, as the highest boron concentration (100 mg L⁻¹) gave the highest average of plant branches 7.73 compared to the control treatment, which gave the lowest average of 6.78 branch per plant⁻¹. The number of branches per plant also increased when the two study factors were interacted, as the plants planted at the second date and sprayed with a concentration of 75 mg L⁻¹ gave the highest average of 8.57 branch per plant⁻¹, compared to the plants planted at the third date and sprayed with water only, which gave the lowest average of 6.78 branch per plant⁻¹.

Table 2. The effect of boron spraying, planting dates, and their interaction on the number of branches of Fennel plants(branch/plant⁻¹).

Planting Dates	Boron concentration (mg L ⁻¹)			Mean
	0	50	100	
First - 15/11	6.74	6.89	7.81	7.15
Second - 1/12	7.63	8.57	8.50	8.23
Third - 15/12	5.96	6.90	6.88	6.58
Mean	6.78	7.45	7.73	
LSD	Planting Dates	Boron	Planting Dates * Boron	
	0.3185	0.2378	0.4147	

Leaf Chlorophyll Content (µg cm⁻²)

Table 3 shows the significant effect of planting dates in terms of leaf chlorophyll content. The second date significantly superior to the other two dates with the highest average of 2.90 µg cm⁻², while the third date yielding the lowest average of 1.50 µg cm⁻². This is attributed to the variation in environmental conditions during the vegetative growth stage

of the plant, particularly light, which influences the synthesis of compounds, including chlorophyll, through its role in photosynthesis. Boron also showed a significant effect on increasing leaf chlorophyll content. The concentration of 100 mg L⁻¹ recorded the highest average for this trait, 2.23 µg cm⁻², and differed significantly from the control treatment. The increased leaf

chlorophyll content with increasing boron comes in line with the results of (16) which obtained that boron stimulating enzymes involved in photosynthesis, increasing photosynthetic activity, and protecting chlorophyll from decomposition. the lowest average of $2.04 \mu\text{g cm}^{-2}$. Regarding The

interaction between the study factors, the second date with 100 mg L^{-1} concentration recorded the highest rate of chlorophyll content $3.09 \mu\text{g cm}^{-2}$, while plants planted at the third date and sprayed by 50 mg L^{-1} recorded the lowest rate of $1.34 \mu\text{g cm}^{-2}$.

Table 3. Effect of boron spraying, planting dates, and their interaction on leaf of Fennel plants chlorophyll content ($\mu\text{g cm}^{-2}$)

Planting Dates	Boron concentration (mg L^{-1})			Mean
	0	50	100	
First - 15/11	1.86	2.12	2.02	2.00
Second - 1/12	2.72	2.90	3.07	2.90
Third - 15/12	1.54	1.34	1.61	1.50
Mean	2.04	2.12	2.23	
LSD	Planting Dates	Boron	Planting Dates * Boron	
	0.1822	0.1098	0.1822	

Dry Weight (g)

Table 4 indicates significant differences between planting dates in plant dry weight. Plants grown on the second date significantly outperformed those grown on the third date, with the highest average of 106.16 g , with an increase of 16.27% over plants grown on the third date, which yielded the lowest average of 88.88 g . This may be attributed to the superiority of this date in vegetative growth traits, including plant height, number of branches, and leaf chlorophyll content (Tables 1, 2, and 3). This, in turn, increases the efficiency of photosynthesis due to optimal exposure to sunlight, which is reflected in increased carbohydrates produced and stored within plant tissues, which are represented in the form of dry matter in the plant. Regarding boron, its concentrations significantly affected the dry weight of the plant. The concentration of 100 mg L^{-1} significantly exceeded the other concentrations, with the highest average of 96.81 g , while plants with the concentration of

50 mg L^{-1} recorded the lowest average of 94.98 g . The reason for the superiority of the high concentration of boron may be attributed to the acceleration of the transfer of manufactured nutrients from the source to the outlet, which caused significant increases in the vegetative growth traits represented by plant height, number of branches in the plant and chlorophyll content of the leaves (Tables 1, 2, and 3) which is positively reflected in the increase of dry matter of the plant. Regarding the interaction between planting dates and boron concentrations, the results indicated a significant interaction between the three planting dates and boron application concentrations on dry weight. The second treatment, with the second date and concentration, yielded the highest average dry weight of $109.42 \text{ g plant}^{-1}$, compared to the plants planted at the third date and sprayed by water, which yielded the lowest average of $87.78 \text{ g plant}^{-1}$.

Table 4: Effect of boron application, planting dates, and their interaction on of fennel plants dry weight (g) .

Planting Dates	Boron concentrations (mg L ⁻¹)			Mean
	0	50	100	
First - 15/11	95.42	90.31	92.30	92.68
Second - 1/12	104.60	104.47	109.42	106.16
Third - 15/12	87.78	90.15	88.72	88.88
Mean	95.93	94.98	96.81	
LSD	Planting Dates	Boron	Planting Dates * Boron	
	0.936	1.171	1.787	

Inflorescence per plant

Table 5 shows that the three planting dates differed significantly in the number of main inflorescences per plant. The second date recorded the highest number of 166.67 inflorescences per plant, significantly outperforming the two dates, which yielded averages of 162.96 and 119.78 inflorescences per plant respectively. The increased inflorescence number in plants grown with the second date is due to its positive effect on increasing the number of plant branches and the chlorophyll content of leaves (Tables 2 and 3).

As for boron concentrations, significant differences between boron concentrations in the number of inflorescences per plant were noticed. The highest concentration significantly outperformed the other concentrations, recording the highest rate of 157.30 inflorescences per plant, with an increase of 0.87 and 13.42% for concentrations 50 and 0 mg L⁻¹, respectively. The control treatment recorded the lowest rate of 136.19

inflorescences per plant. Adding Boron played a crucial role by their transporting photosynthetic products to new growth areas had a positive impact on increasing the number of primary inflorescences in the plant, in addition to the this, increasing the plant's vegetative characteristics resulted by plant height and number of branches, which directly contributed to increasing the transfer of nutrients from the production areas to the new growth centers, thus increasing the number of inflorescences per plant (16). Regarding interaction, the results in the same table indicated significant differences between planting dates and boron concentrations in the number of inflorescences per plant. Plants grown on the second date and sprayed with a high boron concentration produced the highest rate of 179.00 inflorescences per plant, compared to plants grown on the first date and sprayed with water only (the control treatment), which produced the lowest rate of 103.89 inflorescences per plant.

Table 5: Effect of boron spraying, planting dates, and interaction between them on the number of main inflorescences (inflorescence per plant) in fennel plants.

Planting Dates	Boron concentrations (mg L ⁻¹)			Mean
	0	50	100	
First - 15/11	152.56	169.89	166.44	162.96
Second - 1/12	152.11	168.89	179.00	166.67
Third - 15/12	103.89	129.00	126.44	119.78
Mean	136.19	155.92	157.30	
LSD	Planting Dates	Boron	Planting Dates * Boron	
	1.062	1.564	2.336	

Number of secondary inflorescences

Table 6 indicates significant differences between planting dates in the number of secondary inflorescences. The second date

recorded the highest average of 17.68 secondary inflorescences/main inflorescence⁻¹, which differed significantly with the first and third dates (15.35 and 13.11), respectively. The

increase in the number of secondary inflorescences with changing planting dates is due to the increased chlorophyll content in the leaves (Table 3), which positively reflects an increase in the products of photosynthesis and the transfer of these products to new sites of growth in the plant (reproductive parts), thus increasing the number of secondary inflorescences. Boron had a significant effect on this trait, with the highest average number of secondary inflorescences reaching 16.04 secondary inflorescences/main inflorescence at a concentration of 100 mg L⁻¹ which differed

significantly from the rest of the concentrations and the control treatments gave the lowest average of 14.35. The increasing Number of secondary inflorescences by adding boron may be coming due to increase the vegetative growth and flowering traits, as evidenced by the increase in the number of secondary inflorescences. As for the interaction between planting dates and boron, no significant differences were found between the averages for the trait of number of secondary inflorescences.

Table 6: The effect of boron spraying, planting dates, and their interaction on the number of secondary inflorescences (secondary inflorescence, primary inflorescence⁻¹) of the Fennel plant.

Planting Dates	Boron concentrations (mg L ⁻¹)			Mean
	0	50	100	
First - 15/11	14.44	15.39	16.20	15.35
Second - 1/12	16.31	18.35	18.37	17.68
Third - 15/12	12.28	14.36	12.69	13.11
Mean	14.35	16.04	15.75	
LSD	Planting Dates	Boron	Planting Dates * Boron	
0.4940		0.3808	N.S.	

Weight of 1000 fruits (g)

As can see from the data presented in table 7, Both planting dates and boron spray concentrations revealed significant effects on the weight of 1000 fruits. Regarding planting dates, the second planting date achieved the highest average weight of 1000 fruits (10.57 g), while the third planting date yielded the lowest average weight of 8.97 g. This difference may be attributed to the second planting date being optimal for increasing the number of primary and secondary inflorescences and their fertility, which positively impacted fruit weight.

As for boron spray concentrations, a variation was observed in its concentrations on the weight of 1000 fruits. The highest concentration resulted in the highest average weight of 10.22 g, while the control treatment with 0 mg L⁻¹ boron recorded the lowest

average weight of 9.43 g. The effect of boron in increasing this trait is attributed to its important role in facilitating the movement of synthesized compounds from the manufacturing site (leaves) to the final destination (fruits), which in turn increases their plumpness and weight. This occurs through the combination of borate with the hydroxyl group in sugars to form boric acid esters, which move more easily and rapidly across cell membranes than the passage of polarized sugar molecules alone.

The interaction between planting dates and boron foliar application concentrations was significant also. Plants planted at the second date with a high boron concentration achieved the highest average weight per 1000 fruits (11.38 g) compared to plants planted at the third date with a 0 mg/L boron concentration (7.77 g).

Table 7: The effect of boron spraying, planting dates, and their interaction on the Weight of 1000 fruits (g) of the Fennel plant.

Planting Dates	Boron concentrations (mg L ⁻¹)			Mean
	0	50	100	
First - 15/11	9.06	9.86	10.76	9.89
Second - 1/12	9.78	10.55	11.38	10.57
Third - 15/12	7.77	9.05	10.07	8.97
Mean	8.87	9.82	10.74	
LSD	Planting Dates	Boron	Planting Dates * Boron	
	0.9425	0/3445	0.9446	

C Fruit yield (kg ha⁻¹)

The results in Table 8) show significant differences in the two study factors and their interactions regarding the fruit yield trait. The average fruit yields varied significantly across the three planting dates. Plants planted at the second planting date exhibited the highest average yield of 3250 kg ha⁻¹, while plants planted at the third planting date recorded the lowest average yield (1469 kg ha⁻¹). This is attributed to the fact that plants planted at the second planting date were better adapted, leading to superior performance across all study indicators. They were able to utilize the products of photosynthesis in their early growth stages, which positively impacted plant productivity in later stages, including fruit yield.

The results from the same table show that fruit yield increased with increasing boron concentrations. The highest average yield for this trait was recorded at 3354 kg ha⁻¹ at a

concentration of 100 mg L⁻¹, while the control treatment (spraying with distilled water) recorded the lowest average yield at 1670 kg ha⁻¹. The increase in yield achieved with higher boron concentrations resulted from boron's role in increasing the weight of the main and sub inflorescences (Tables 5 and 6), as well as its effect on increasing the chlorophyll content in the leaves (Table 3). This chlorophyll content positively impacted photosynthetic activity, increasing the production of photosynthetic byproducts that are transferred to the fruits, thus increasing their weight and consequently the yield per unit area.

Regarding the combined effect of planting dates and boron spray concentrations, the second date, when sprayed with a concentration of 100 mg L⁻¹ of boron, showed the highest average yield of the trait (4559 kg ha⁻¹), while the third date, sprayed with distilled water, recorded the lowest average fruit yield of 992 kg ha⁻¹.

Table 8: The effect of boron spraying, planting dates, and their interaction on fruit yield (kg ha⁻¹) of the Fennel plant.

Planting Dates	Boron concentrations (mg L ⁻¹)			Mean
	0	50	100	
First - 15/11	1768	2473	3657	2633
Second - 1/12	2251	2939	4559	3250
Third - 15/12	992	1571	1844	1469
Mean	1670	2327	3354	
LSD	Planting Dates	Boron	Planting Dates * Boron	
	61.8	86.2	129.5	

Conclusion

Changing planting dates had a positive impact on the growth characteristics of fennel plants, which was reflected positively in flowering characteristics, as plants grew under favorable environmental conditions. The second planting time (early December) gave

them sufficient time to take advantage of the favorable environmental conditions for growth and flowering. Furthermore, foliar application of boron at a concentration of 100 mg L⁻¹ had a direct impact on vegetative growth and flowering characteristics, yielding superior results compared to other concentrations. The interaction acted as a single factor in its

positive impact on the growth and flowering characteristics of fennel plants. However, Boron is an essential micronutrient for plants, but it is highly toxic when used in excess; therefore, it is recommended to use it in low and balanced concentrations.

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Author Contributions:

Author 1: Methodology, writing—original draft preparation; Both authors: writing—review and editing. All authors have read and agreed to the published version of the manuscript.

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استجابة بعض صفات النمو الخضري وصفات الحاصل لنبات حبة الحلوة للرش بالبورون ومواعيد الزراعة

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الخلاصة

أجريت تجربة حقلية خلال الموسم الشتوي ٢٠٢١-٢٠٢٢ في الفلوجة - محافظة الأنبار الواقعة على خط طول ٤٣ شرقاً وخط عرض ٣٣ شمالاً، بهدف استجابة صفات النمو الخضري والتزهير لنباتات حبة الحلوة تحت تأثير تراكيز مختلفة من البورون ومواعيد الزراعة. حيث تم دراسة ثلاث مواعيد للزراعة (١١/١٥، ١٢/١ و ١٢/١٥)، وثلاث تراكيز للبورون (٠، ٥٠ و ١٠٠ ملغم لتر⁻¹) طبقت التجربة بحسب ترتيب الالواح المنشقة Split plot design وفق تصميم القطاعات العشوائية الكاملة RCBD وبثلاث مكررات، احتلت مواعيد الزراعة الالواح الرئيسية، في حين احتلت تراكيز البورون الالواح الثانوية. اشارت النتائج الى وجود اختلافات معنوية لمواعيد الزراعة حيث تفوق الموعد الثاني (١٢/١) بتسجيله أعلى المتوسطات لصفات النمو الخضري ارتفاع النبات، عدد التفرعات لكل نبات، محتوى الاوراق من الكلوروفيل، الوزن الجاف للنبات وصفات التزهير كعدد النورات الرئيسية والثانوية لنباتات حبة الحلوه. كما أدى الرش بالبورون بالتركيز العالي ١٠٠ ملغم لتر⁻¹ الى تحسين صفات ارتفاع النبات (٩٤.٨٤ سم) وعدد التفرعات بالنبات (٢٣ فرع نبات⁻¹) ومحتوى الاوراق من الكلوروفيل (٢.٩٠ مايكروغرام سم⁻²) والوزن الجاف للنبات (١٠٦.١٦ غم) وصفات التزهير (النورات الرئيسية والثانوية). سلك التداخل بين عوامل الدراسة سلوك العوامل الفردية في تأثيرها في جميع الصفات المدروسة حيث كان التأثير الايجابي في معاملة التداخل بين الموعد الثاني والتركيز ١٠٠ ملغم لتر⁻¹ بتسجيلها أعلى المتوسط لعدد النورات الرئيسية والثانوية

كلمات مفتاحية: موعد الزراعة، البورون، محتوى الورقة من الكلوروفيل، النورات الرئيسية.

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