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Article

Interactive Effects of Gibberellic Acid and Nitrogen Fertilization on the Growth, Yield, and Quality of Sugar Beet

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Abstract: Two field trials were conducted during the 2014/2015 and 2015/2016 seasons at Aweesh Al-Hagar Village, center of Mansoura, Dakahlia Governorate, Egypt. A split-split-plot design with four replicates was used. The main plots were assigned three nitrogen fertilizer levels, i.e., 165, 220, and 275 kg/ha. The sub-plots were restricted to four gibberellic acid (GA_3) concentrations, i.e., 0, 80, 160, and 240 mg/L, and the sub-sub plots received GA_3 application twice, i.e., 60 and 120 days after planting (DAP). The results showed that both root length and diameter, root and foliage fresh weights/plant, and root and foliage yields/ha increased with the incremental level of nitrogen and/or GA_3 concentration. Foliar application of GA_3 and N-fertilizers also significantly decreased quality parameters including sucrose and total soluble solid (TSS) percentages. Early application of GA_3 (60 DAP) had an active role on sugar beet growth, yield, and quality compared with spraying at 120 DAP. Generally, fertilizing sugar beet with 275 kg N/ha or spraying GA_3 with a concentration of 160 mg/L at 60 DAP is the recommended treatment for raising sugar yield under the ecological circumstances of this research.

Keywords: sugar beet; nitrogen fertilizer; gibberellic acid; TSS; sugar yield

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1. Introduction

Sugar beet (*Beta vulgaris* L.) is one of the main raw materials for sugar production in many countries. It is considered to be the second most important crop in the world, after sugarcane, for the production of sucrose. The total area cultivated with sugar beet in Egypt during the 2018/2019 season was about 255,725.6 hectare (with an increase of 23.5% over the 2017/2018 season), producing about 12,247,170 tons (62.2% of national sugar production), with an average root yield of 47.89 t/ha [1]. Despite the importance of sugar beet as an industrial cash crop, some farmers still do not have great experience in its production; therefore, it is necessary to pay great attention to this and search for safe stimulating growth and untraditional natural substances that have a marked influence on plant growth parameters [2] that can increase plant growth and maximize productivity [3].

Generally, one of the most important questions for sugar beet growers is how much nitrogen fertilizer is needed to achieve maximum net profit. Consequently, the effects of nitrogen fertilization on the quality and production of sugar beets is one of the main concerns in the management of sugar beet production. Many studies have been conducted where it was concluded that fertilizing sugar beet with too little nitrogen resulted in the reduction of root tonnage and, conversely, the application of too much resulted in reduced sucrose concentrations and purity percentage [4–7]. Although deficient nitrogen content in the soil can reduce sugar beet root yield, excess amounts of N can decrease sucrose content while lowering sucrose recovery due to higher nitrate impurities [8,9]. In England, sugar beets are fertilized using 100–110 kg N/ha as an equilibrating rate between fertilizer prices and beet value [10]. In Germany, a maximum yield of sugar beet was achieved by adding an amount in the range of 100–125 kg N/ha [11], while, in Greece, maximum yield was expected from using 252.5 kg N/ha because it showed a quadratic response to nitrogen levels [12]. Moreover, Hosseinpour et al. [13], in Iran, showed that fertilizing sugar beet using zero N significantly increased sugar percentage in the first season, while it was not influenced by N levels in the second season. Application of nitrogen fertilization is considered as an important practice that determines sugar beet growth and production [14]. In this regard, El-Sarag and Moselhy [15] in Egypt concluded that all sugar beet yields of root, top, and gross sugar were significantly affected by the addition of nitrogen, where each increase in nitrogen level caused a significant increase in these yields. Moreover, Abdelaal and Tawfik [16] reported that fertilizing sugar beet plants with 105 kg N/fad produced the highest values of root diameter and length, root and foliage fresh weights, and root yield/fed. Meanwhile, the highest means of sucrose and apparent purity percentages resulted from 0 kg N/fed (control treatment). Mekdad [17] stated that increasing the nitrogen level to 140 kg N/fad significantly increased root length and root diameter as well as root and top fresh weight. Additionally, it whas been stated by Mekdad and Rady [18] that, except for purity percentage and harvest index, all parameters, including root length and diameter, root and top fresh weights, and root and biological yield, were significantly increased by the application of 350 kg N/ha compared to 200 kg N/ha. Moreover, it was reported that raising nitrogen levels from 69 to 92 and 115 kg N/fad significantly increased root diameter, root length, root weight, and foliage fresh weight/plant, while it significantly decreased total soluble solid (TSS), sucrose, and purity percentages [19]. Tarkalson et al. [20] reported that nitrogen rates did not affect sugar beet yields compared to manure application treatments, where manured treatments increased root yields by 12 and 36% compared to nitrogen treatments in both seasons, respectively. Increasing the rate of nitrogen fertilizer from 56 to 224 kg/ha led to a linear increase in sugar beet root yield; however, sucrose concentration and purity percentage decreased [21]. Later, Zarski et al. [22] recorded a greater yield of sugar and roots in the fertilized sugar beet plants with a high nitrogen rate.

Optimal use of plant growth regulators with appropriate concentrations is considered one of the most effective practices for increasing sugar beet yields. It can improve growth regulation and the development of plants [23], and it may also be a solution for achieving a balance between growth and sucrose content in roots. Gibberellic acid (GA_3) is one of the most important plant growth regulators used for agronomic and scientific research [24,25]. Previously, El-Taweel et al. [26] reported that the application of GA_3 at a concentration of 300 mg/L significantly increased root length, root diameter, root weight, total soluble solids, and sucrose percentages. Root weight/plant and root length as well as root and sugar yields/fad were significantly increased with the increase of gibberellic acid concentrations from zero to 100, 200, and 300 mg/L. Conversely, it decreased TSS, sucrose, and purity percentages in both seasons [27]. In addition, Selim et al. [28] reported that foliar application of GA_3 at 200 mg/L led to a significant increase in root length in the first season, root diameter, root weight, and purity percentage in the second season, and sucrose percentage and root and sugar yields in both seasons. Ibrahim et al. [29] stated that increasing the GA_3 concentration from 50 to 100 or 150 mg/L significantly increased root and sugar yields. Recently, it has been revealed that foliar application of GA_3 at 300 mg/L achieved 819.8 and 853.8 g root weigh/plant, 26.5 and 26.5 cm root length/plant, 20.0 and 19.7 tons root yield/fad, 4.8 and 4.6 tons top yield/fad, 23.1 and 22.3% TSS percentage, and a 3.6 and 3.5 ton sugar yield/fad in the first and second seasons, respectively [30]. Foliar spraying with GA_3 was found to be more effective in enhancing root yield, sugar content, and leaf area index by increasing the activities/levels of non-enzymatic and enzymatic antioxidants [31].

Agricultural practices applied at specific times can enhance sugar beet growth, final root yield, and quality attributes. Several studies have been conducted to determine the effect of growth regulator types and concentrations on growth and productivity, while there have only been a few studies concerning their application time. Earlier, it was noted that foliar application of growth regulators 3 to 6 weeks before harvest time is more effective for enhancing sugar content in sugar beet roots [32]. However, Nelson and Wood [33] reported that applying gibberellic acid at 100 mg/L on the same dates (3 to 6 weeks before harvest time) decreased sucrose percentage. Peterson [34] found that applying potassium salt and GA_3 at concentrations of 10 and 100 mg/L to the foliage early in the growing season had little effect on either sucrose content or root yield. El-Fiki et al. [35] indicated that spraying GA_3 at 300 mg/L 70 days after sowing increased the TSS percentage by 18.9 and 14.2% and sucrose content by 24.1 and 12.2%, compared with the control treatment (without spraying) in the first and second seasons, respectively. In addition, it was concluded that foliar spraying of GA_3 70 days after sowing had a significant effect on root length, the fresh weight of roots, sucrose percentage, and root and sugar yields/fad that surpassed the same treatment when it was added 140 days after sowing. Despite the superiority of spraying GA_3 70 days after sowing compared with spraying 140 days after sowing, there were no significant differences on TSS and purity percentages in either season [27].

Most studies conducted on sugar beet crops were aimed at increasing root and sugar productivity per unit area. Therefore, many researchers have studied the effects of different fertilization levels and/or different growth regulators. Meanwhile, a limited number of these studies explored the effects of growth regulator application time on yield and quality traits. Therefore, the aim of this study is to determine the effect of nitrogen fertilizer levels and GA_3 concentrations and spraying times, as well as their influence on sugar beet growth, productivity, and quality to specifically reduce the gap between sugar production and consumption in Egypt.

2. Materials and Methods

The present investigation was conducted during the two successive winter seasons of 2014/2015 and 2015/2016 at Aweesh Al-Hagar Village, center of Mansoura, Dakahlia Governorate, Egypt. The crop for the previous two years had been Maize. From the experimental field area, soil samples were randomly taken at a depth of 0–30 cm of soil surface to estimate the soil's mechanical and chemical properties (Table 1).

Table 1. Soil properties (mechanical and chemical) of the experimental sites (0–30 cm) during the 2014/2015 and 2015/2016 seasons.

	Soil Analysis	**2014/2015**	**2015/2016**
Mechanical analysis	Sand (%)	21.55	21.90
	Silt (%)	29.84	30.29
	Clay	48.60	47.80
	Texture	Clay	Clay
Chemical analysis	Soil reaction pH	7.50	7.60
	ECe (dsm^{-1})	1.37	1.33
	Organic matter (%)	1.15	1.20
	Available N (ppm)	45.80	46.50
	Available P (ppm)	1.40	1.55
	Exchangeable (ppm)	120.20	135.30

The purpose of this was to study the effect of different nitrogen fertilizer levels and foliar applications of gibberellic acid (GA_3) and its application time as well as their influence on growth, yield, and quality of sugar beet, cv. Kawemira. A split-split-plot design with 4 replicates was used. The main plots (84 m^2) were assigned to three nitrogen fertilizer levels, i.e., 165, 220, and 275 kg N/ha. The sub-plots (21 m^2) were restricted to four GA_3 concentrations, i.e., 0 (tap water), 80, 160, and 240 mg/L, and the sub-sub plots (10.5 m^2) were sprayed once using a knapsack sprayer either at 60 or 120 days after planting (DAP). Nitrogen fertilizer was applied in the form of Urea (46% N), which was added in two equal doses after thinning (at the first and second irrigations). The experimental unit contained 5 ridges, which were 60 cm wide and 3.5 m long. The experimental field was well prepared through three ploughings followed by leveling. Both phosphorus fertilizer in the form of Calcium Superphosphate (15.5% P_2O_5) and potassium fertilizer in the form of Potassium

Sulphate (48% K_2O) were added during seed bed preparation, before ridging. Dry sugar beet balls were sown manually in dry soil at a rate of 3–4 balls per hill during the first week of November in both seasons. The experimental field was irrigated immediately after cultivation. Plants were thinned to secure one plant per hill, 30 days after sowing. All other agricultural practices were done in the same way that farmers usually do them in their fields.

At harvest, ten guarded plants were randomly chosen from each plot to decide the following characteristics: Root length (cm) was measured from the crown to the base of the root by a steel tape, root diameter (cm) was measured at the widest part of the proper root by a vernier caliper, and root and foliage fresh weights/plant were recorded separately in grams. All plants of the two inner ridges of each plot were harvested and cleaned. Roots and tops were separated and weighed in kilograms, then converted to estimate root and foliage yields in ton/ha. Quality parameters, including sucrose, TSS, and purity percentages were also estimated as follows: Total soluble solids percentage (TSS%) in roots was measured in the juice of fresh roots by using a hand refractometer, sucrose percentage was determined polarimetrically on a lead acetate extract of fresh macerated roots according to the method of Carruthers and Oldfield [36], apparent purity percentage was determined as a ratio between sucrose% and TSS% of the roots [36], and sugar yield (t/ha) was estimated by multiplying root yield (t/ha) by the sucrose percentage.

All collected data were statistically analyzed as the procedures of the split-split-plot design according to Gomez and Gomez [37] using the statistical analysis system (SAS) computer program. The bayesian least significant difference (BLSD) method was used to evaluate the differences between means at a 5% level of probability, as mentioned by Waller and Duncan [38].

3. Results

3.1. Impacts of Nitrogen Fertilizer Levels on Sugar Beet Growth and Yield Parameters

The results listed in Table 2 show that increasing nitrogen fertilizer level from 165 to 220 and 275 kg/ha significantly increased root length, root diameter, root fresh weight/plant, foliage fresh weight/plant, and root yield/ha in both seasons. The highest values of root length (32.9 and 32.8 cm), root diameter (11.5 and 11.2 cm), root fresh weight (919.8 and 876.8 g/plant), foliage fresh weight (535.9 and 492.5 g/plant), and root yield (75.9 and 72.6 t/ha) were obtained by adding 275 kg N/ha in the first and second seasons, respectively. On the other hand, fertilizing sugar beet plants with 165 kg N/ha resulted in the lowest values of these traits. However, N-fertilizer at 275 kg/ha significantly increased root length by 14.2 and 13.1%, root diameter by 17.3 and 17.9%, root fresh weight/plant by 25.5 and 21.8%, foliage fresh weight/plant by 40.4 and 37.8%, and root yield/ha by 25.7 and 22.3% compared with the application of 165 kg N/ha in the first and second seasons, respectively.

Foliage yield/ha, sucrose, TSS, and purity percentages, as well as sugar yield/ha were markedly affected by different nitrogen fertilizer levels (Table 3). The obtained results showed that adding 275 kg N/ha resulted in the highest values of foliage yield (43.9 and 40.5 t/ha) and sugar yield (13.544 and 13.059 t/ha), but at the same time it decreased sucrose percentage (17.9 and 18%), TSS percentage (24.2 and 23.6%), and purity percentage (73.8 and 76.3%) in the first and second seasons, respectively. Results showed that foliage and sugar yields/ha were significantly increased with each increase in nitrogen level, while the exception (no significant differences) on sugar yield was detected between the rate of 165 and 220 kg N/ha in the first season only. On the other hand, increasing the nitrogen fertilizer level from 165 to 275 kg/ha markedly decreased percentages of sucrose by 12.7 and 11.3%, TSS by 8 and 7.8%, and purity by 5.4 and 3.5% in the first and second seasons, respectively.

Table 2. Means of root length (cm), root diameter (cm), root fresh weight (g/plant), foliage fresh weight (g/plant), and root yield (t/ha) as affected by nitrogen fertilizer levels and gibberellic acid (GA_3)spraying concentrations and its application time in the 2014/2015 (I) and 2015/2016 (II) seasons.

Traits Treatments	**Root Length (cm)**		**Root Diameter (cm)**		**Root Fresh Weight (g/plant)**		**Foliage Fresh Weight (g/plant)**		**Root Yield (t/ha)**	
	I	**II**	**I**	**II**	**I**	**II**	**I**	**II**	**I**	**II**
A. Nitrogen fertilizer levels										
165 kg N/ha.	28.8c	29.0c	9.8c	9.5c	732.8c	720.0c	381.6c	357.5c	60.4c	59.4c
220 kg N/ha.	30.5b	30.7b	10.8b	10.6b	819.1b	805.1b	455.6b	431.3b	67.7b	66.6b
275 kg N/ha.	32.9a	32.8a	11.5a	11.2a	919.8a	876.8a	535.9a	492.5a	75.9a	72.6a
F. Test	*	*	*	*	*	*	*	*	*	*
B. GA_3 spraying concentrations										
GA_3 at 0 mg/L	29.7b	30.0b	10.2d	9.9c	784.6d	767.2d	384.2d	356.3d	64.4d	63.0d
GA_3 at 80 mg/L	30.1b	30.3b	10.6c	10.3b	812.9c	795.4c	441.7c	418.8c	67.1c	65.6c
GA_3 at 160 mg/L	31.4a	31.3a	10.9b	10.6a	840.0b	810.8b	487.1b	445.4b	69.6b	67.2b
GA_3 at 240 mg/L	31.7a	31.7a	11.1a	10.8a	858.0a	829.0a	517.9a	487.9a	70.9a	68.8a
F. Test	*	*	*	*	*	*	*	*	*	*
C. GA_3 spraying times										
60 DAP	30.8a	31.0a	10.8a	10.6a	834.8a	803.9a	472.1a	435.5a	68.7a	66.8a
120 DAP	30.7a	30.7a	10.6b	10.3b	813.0b	797.3b	443.3b	418.7b	67.3b	65.6b
F. Test	NS	NS	*	*	*	*	*	*	*	*
D. Interaction effects										
A × B	NS	NS	NS	NS	*	NS	*	*	*	NS
A × C	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
B × C	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
A × B × C	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

* and NS indicate significance at 5% level of probability, and not significant, respectively. Means followed by the same letter(s) is/are not significantly differ at 5% level of probability; DAP = Days after planting.

3.2. Impacts of Foliar Applications of GA_3 on Sugar Beet Growth and Yield Parameters

Data collected in Table 2 reveal that increasing the concentration of GA_3 from 0 to 80, 160, and 240 mg/L significantly increased root length, root diameter, root fresh weight/plant, foliage fresh weight/plant, and root yield/ha in the two seasons. However, no significant differences were detected between the concentration of 0 mg/L (control) and 80 mg/L on root length. Additionally, the differences between plants treated with GA_3 at 160 mg/L and those treated with 240 mg/L did not reach the significance limit in both seasons for the same trait. In the first season, foliar spraying of GA_3 with 240 mg/L recorded an increase in root length by 6.7, 5.3, and 1%, root diameter by 8.8, 4.7, and 1.8%, root fresh weight/plant by 9.4, 5.5, and 2.1%, foliage fresh weight/plant by 34.8, 17.3, and 6.3%, as well as increasing root yield/ha by 10.2, 5.7, and 2.0% compared with the applications of 0, 80, and 160 mg/L, respectively. The same trend was recorded in the second season, where the increase was estimated as 5.7, 4.6, and 1.3% in root length, 9.1, 4.9, and 1.9% in root diameter, 8.1, 4.2, and 2.2% in root fresh weight/plant, 36.9, 16.5, and 9.5% in foliage fresh weight/plant, and 9.2, 4.9, and 2.4% in root yield/ha.

As shown in Table 3, significant effects were found in foliage yield/ha, sucrose, and TSS percentages, as well as sugar yield/ha due to GA_3 foliar spraying concentrations. This was clear in both seasons of study, while the differences in purity percentage in both seasons did not reach the level of significance due to the effect of GA_3 concentration. Foliar spraying of GA_3 at 240 mg/L gave the highest values of foliage yield (42.5 and 40.0 t/ha) in the first and second season, respectively. On the contrary, along with each increase in GA_3 concentration, the percentage of sucrose, TSS, and purity had negative impacts. Regarding sugar yield/ha, as the concentration of GA_3 increased to 160 mg/L, sugar beet plants produced more sugar yield by about 5.3 and 4.4%, 2.2 and 1.5%, and 2.1 and 1.0% against concentrations of 0, 80, and 240 mg/L in the first and second season, respectively.

Table 3. Means of foliage yield (t/ha), sucrose (%), TSS (%), purity (%), and sugar yield (t/ha) as affected by nitrogen fertilizer levels and GA_3 spraying concentrations and its application time in the 2014/2015 (I) and 2015/2016 (II) seasons.

Traits Treatments	**Foliage Yield (t/ha)**		**Sucrose (%)**		**TSS (%)**		**Purity (%)**		**Sugar Yield (t/ha)**	
	I	**II**	**I**	**II**	**I**	**II**	**I**	**II**	**I**	**II**
A. Nitrogen fertilizer levels										
165 kg N/ha.	31.3c	29.1c	20.5a	20.3a	26.3a	25.6a	78.0a	79.1a	12.356b	12.025c
220 kg N/ha.	37.3b	35.5b	18.8b	19.0b	24.9b	24.3b	75.4b	78.3a	12.703b	12.650b
275 kg N/ha.	43.9a	40.5a	17.9c	18.0c	24.2c	23.6c	73.8c	76.3b	13.544a	13.059a
F. Test	*	*	*	*	*	*	*	*	*	*
B. GA_3 spraying concentrations										
GA_3 at 0 mg/L	31.4d	29.1d	19.5a	19.6a	25.7a	25.0a	76.0a	78.2a	12.504b	12.254b
GA_3 at 80 mg/L	36.1c	34.5c	19.3ab	19.3ab	25.4ab	24.7ab	75.9a	77.9a	12.892a	12.604ab
GA_3 at 160 mg/L	39.9b	36.6b	19.1b	19.1b	25.2b	24.5b	75.5a	77.8a	13.171a	12.792a
GA_3 at 240 mg/L	42.5a	40.0a	18.3c	18.5c	24.3c	23.8c	75.5a	77.7a	12.904a	12.663a
F. Test	*	*	*	*	*	*	NS	NS	*	*
C. GA_3 spraying times										
60 DAP	38.7a	35.7a	19.4a	19.5a	25.4a	24.8a	76.3a	78.4a	13.208a	12.935a
120 DAP	36.3b	34.4b	18.7b	18.8b	24.9b	24.2b	75.1a	77.4a	12.527b	12.221b
F. Test	*	*	*	*	*	*	NS	NS	*	*
D. Interaction effects										
A × B	*	*	NS	NS	NS	NS	NS	NS	NS	NS
A × C	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
B × C	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
A × B × C	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

* and NS indicate significance at 5% level of probability, and not significant, respectively. Means followed by the same letter(s) is/are not significantly differ at 5% level of probability; DAP = Days after planting.

3.3. Impact of GA_3 Spraying Times on Sugar Beet Growth and Yield Parameters

Data presented in Table 2 illustrate that root diameter, root fresh weight/plant, foliage fresh weight/plant, and root yield/ha was significantly affected by GA_3 spraying times in the two seasons, while no significant differences were detected in root length in the two seasons. Spraying sugar beets with GA_3 for the first time (60 DAP) significantly surpassed spraying plants for the second time (120 DAP) by 1.9 and 2.9% for root diameter, 2.7 and 0.8% for root fresh weight/plant, 6.5 and 4% for foliage fresh weight/plant, and 2.1 and 1.8% for root yield/ha in the first and second seasons, respectively.

As shown in Table 3, foliage yield/ha, sucrose, and TSS percentages, as well as sugar yield/ha were significantly affected by GA_3 spraying times. On the other hand, GA_3 spraying times exhibited insignificant effects in purity percentage in both seasons. Foliar application of GA_3 at 60 DAP exceeded the same treatment of its application at 120 DAP for foliage yield by 6.6 and 3.9%, sucrose percentage by 3.6 and 3.6%, TSS percentage by 2 and 2.5%, and sugar yield by 5.6 and 5.8% in the first and second season, respectively.

3.4. Interactive Effects of GA_3 and Nitrogen Fertilization on Growth and Yield of Sugar Beet

The interaction of nitrogen fertilizer levels and concentrations of GA_3 foliar spraying significantly affected root fresh weight/plant (Figure 1) and root yield/ha (Figure 2) in the first season. Root fresh weight/plant and root yield/ha were significantly increased with increasing nitrogen fertilizer levels and GA_3 foliar spraying concentrations, where the highest values of root fresh weight (971.5 g/plant) and root yield (80.4 t/ha) were obtained from 275 kg N/ha and foliar spraying with GA_3 at 240 mg/L. On the other hand, the lowest values of the above-mentioned traits were recorded with the application of 165 kg N/ha and foliar spraying with tap water. No significant differences were detected for root fresh weight/plant (Figure 3) and root yield/ha (Figure 4) in the second season. Sugar beet importance is not confined only to the root yield but also to its byproducts, where its foliage is considered to be a good source of livestock feed. The results reveal that the interaction effect of nitrogen fertilizer levels and GA_3 foliar concentrations on root fresh weight/plant and root yield/ha in the first season were similar to those effects seen on foliage fresh weight/plant (Figures 5 and 6) and foliage yield/ha (Figures 7 and 8) in both seasons. It should be noted that fertilizing beets with 275 kg N/ha and foliar spraying with GA_3 at 240 mg/L resulted in the highest means of foliage fresh weight (610 and 572.5 g/plant) and foliage yield (50.5 and 46.7 t/ha) over the two seasons, respectively. Such results are mainly due to the role of nitrogen in increasing cell division, protein content, and potassium and phosphorous utilization, in addition to the role of GA_3 in increasing the enzymatic and non-enzymatic antioxidants activities/levels and stimulating the production of mRNA molecules in the cells.

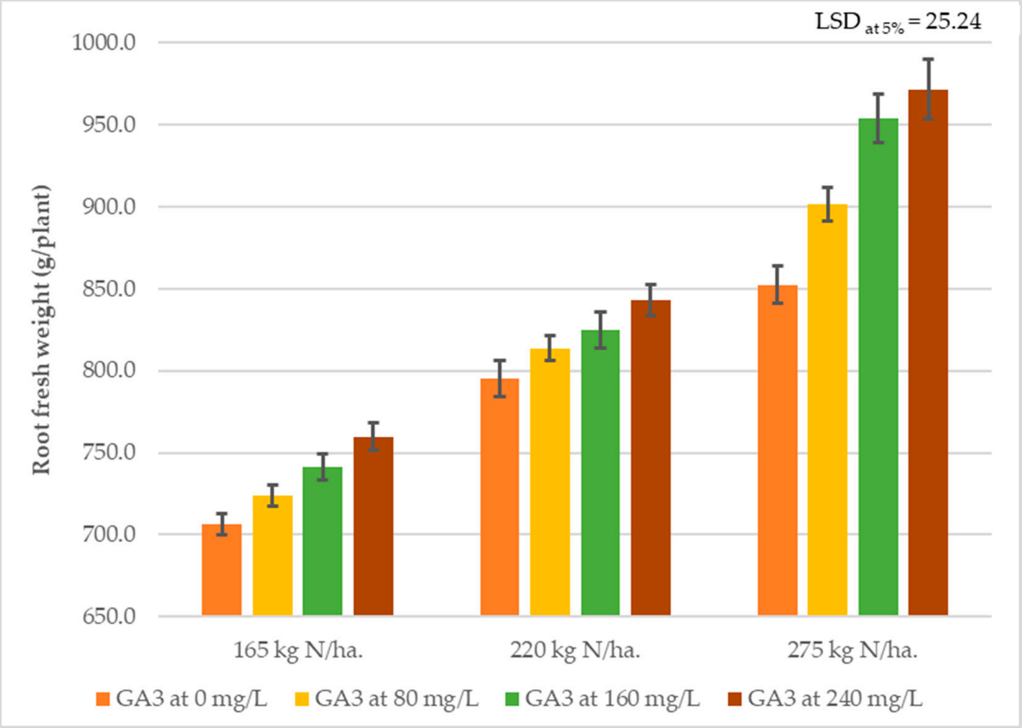

Figure 1. Root fresh weight (g/plant) as affected by the interaction between nitrogen fertilizer levels and GA_3 spraying concentrations in the first season (2014/2015).

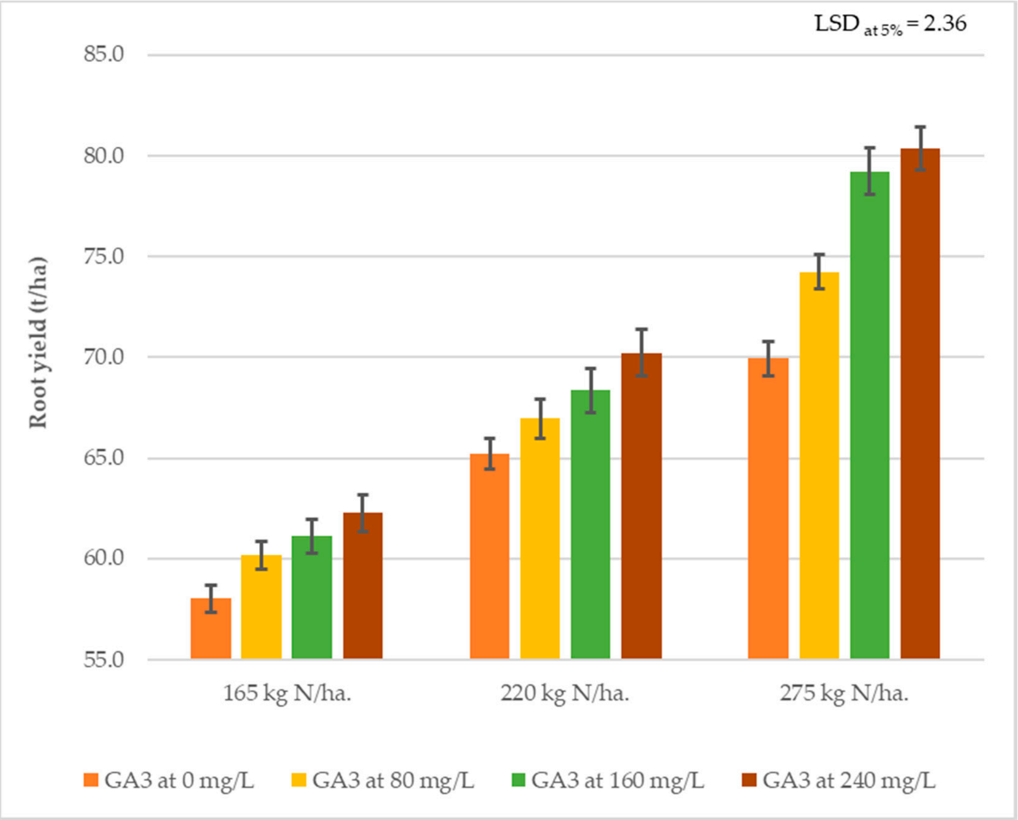

Figure 2. Root yield (t/ha) as affected by the interaction between nitrogen fertilizer levels and GA_3 spraying concentrations in the first season (2014/2015).

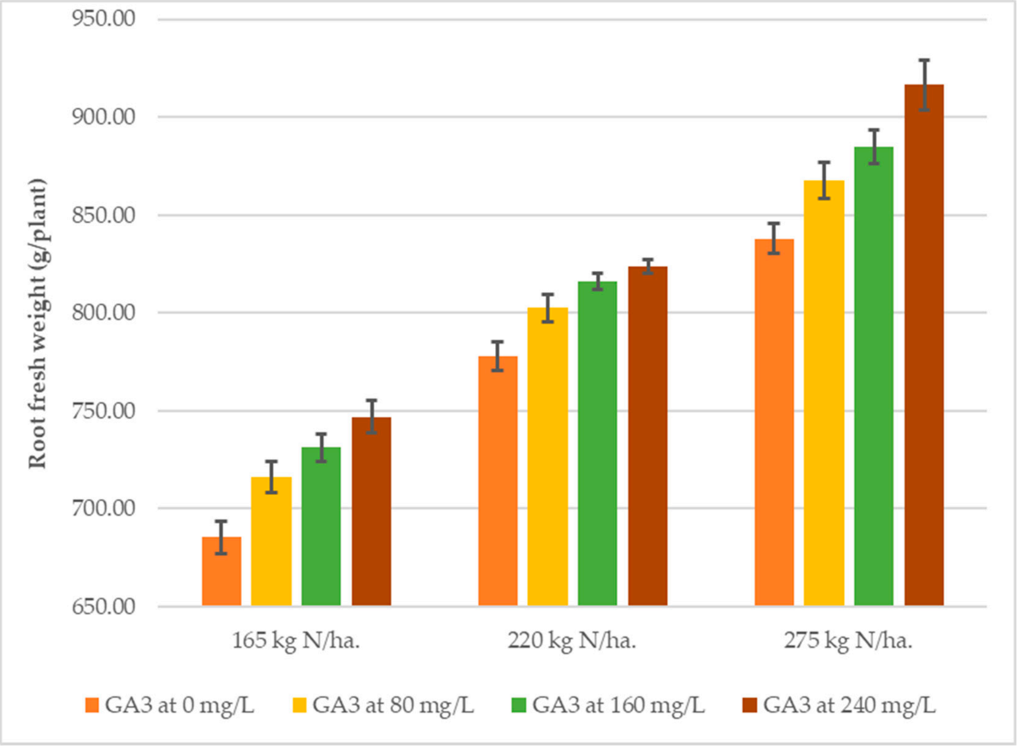

Figure 3. Root fresh weight (g/plant) as affected by the interaction between nitrogen fertilizer levels and GA_3 spraying concentrations in the second season (2015/2016).

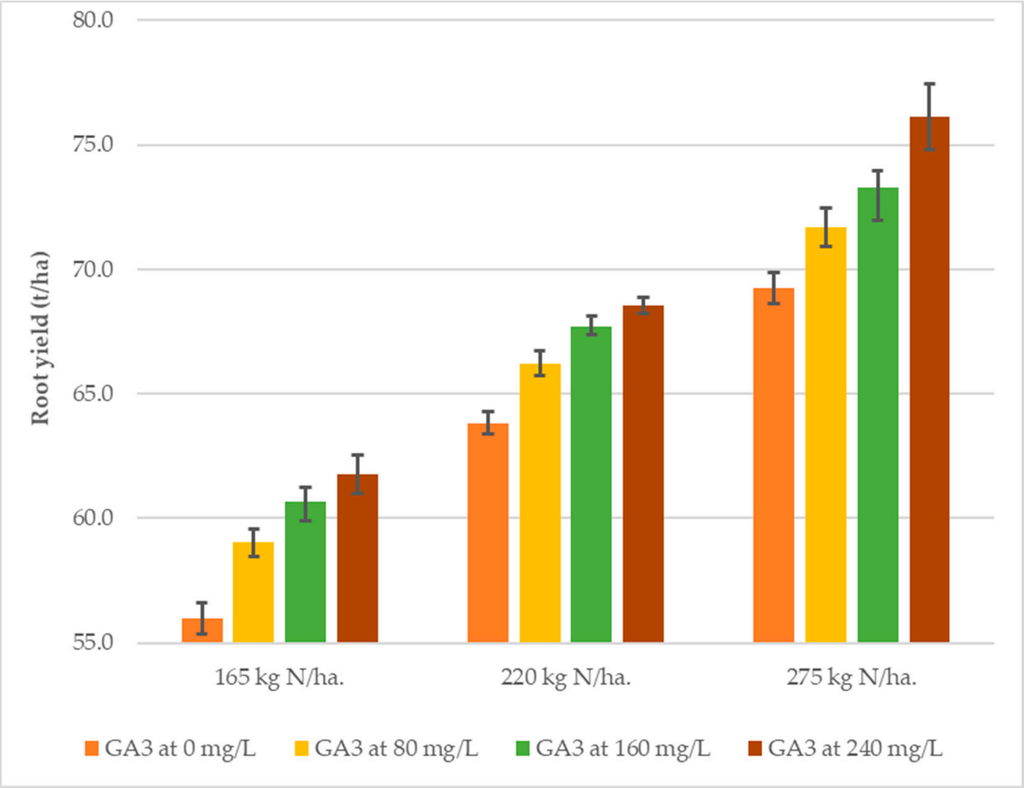

Figure 4. Root yield (t/ha) as affected by the interaction between nitrogen fertilizer levels and GA_3 spraying concentrations in the second season (2015/2016).

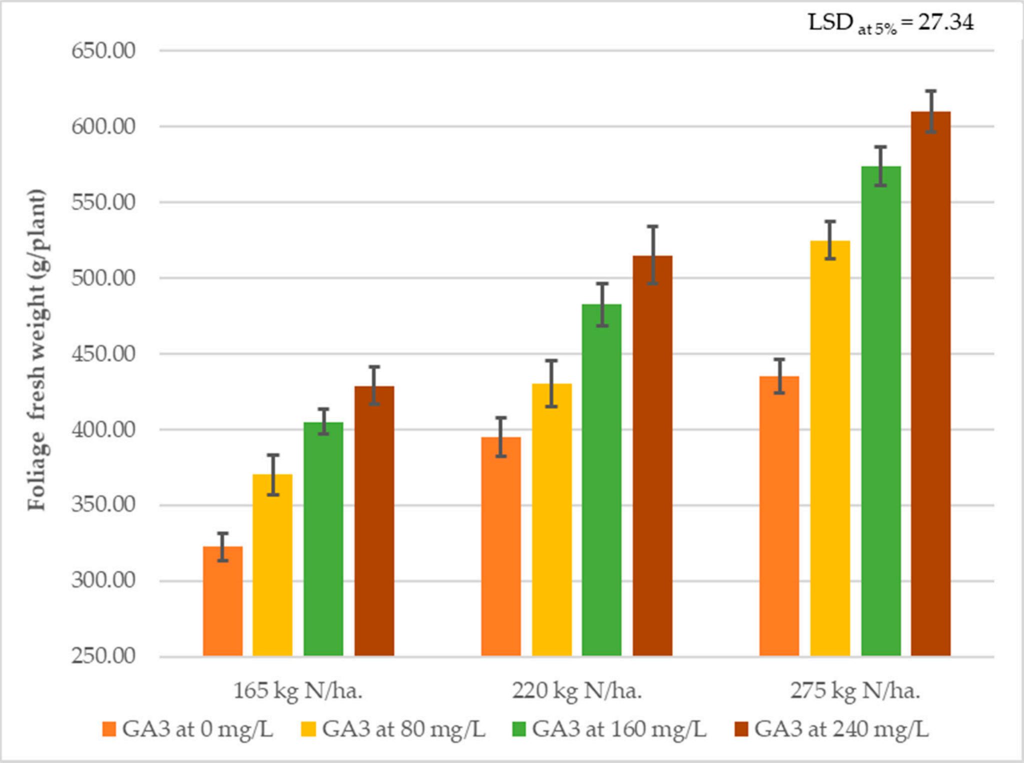

Figure 5. Foliage fresh weight (g/plant) as affected by the interaction between nitrogen fertilizer levels and GA_3 spraying concentrations in the first season (2014/2015).

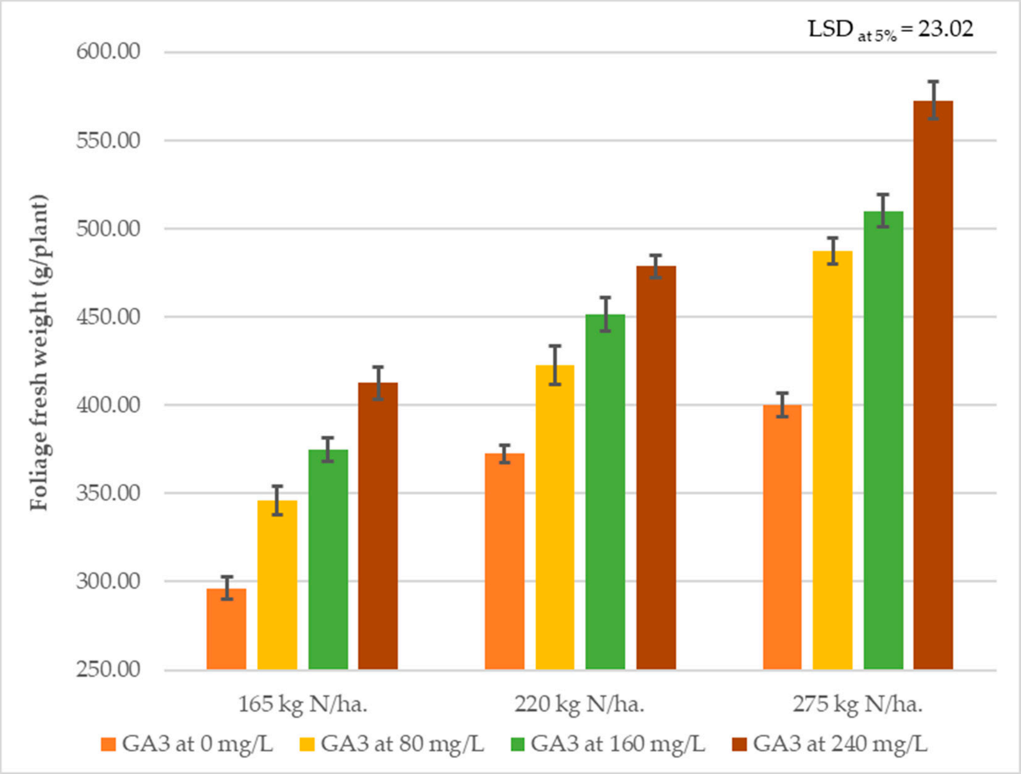

Figure 6. Foliage fresh weight (g/plant) as affected by the interaction between nitrogen fertilizer levels and GA_3 spraying concentrations in the second season (2015/2016).

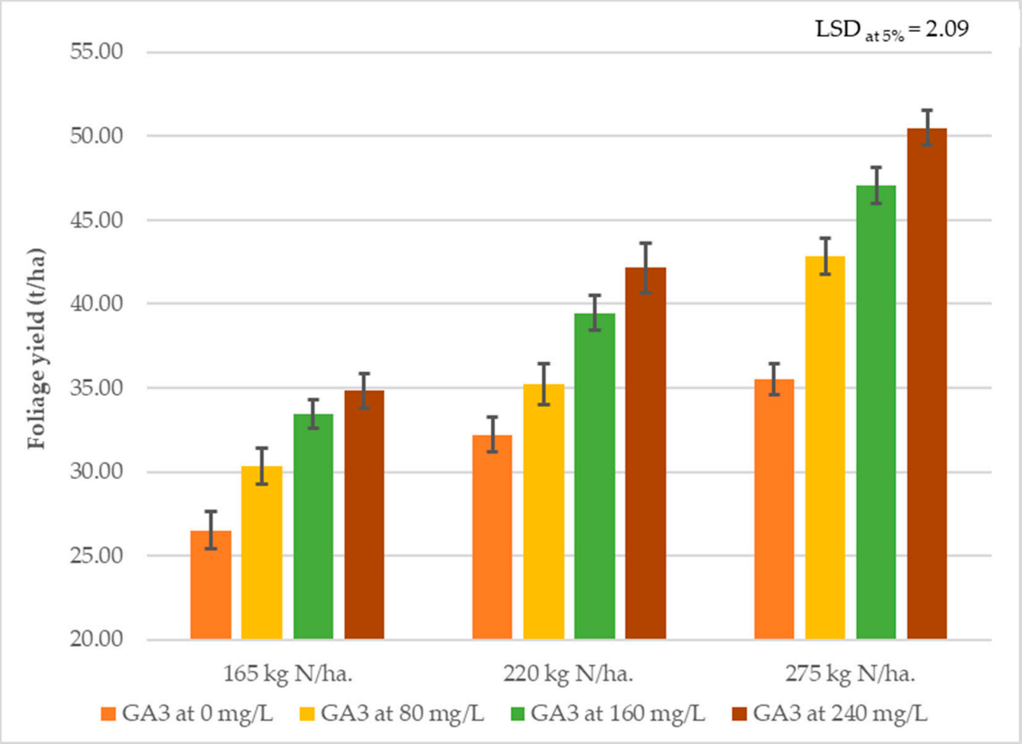

Figure 7. Foliage yield (t/ha) as affected by the interaction between nitrogen fertilizer levels and GA_3 spraying concentrations in the first season (2014/2015).

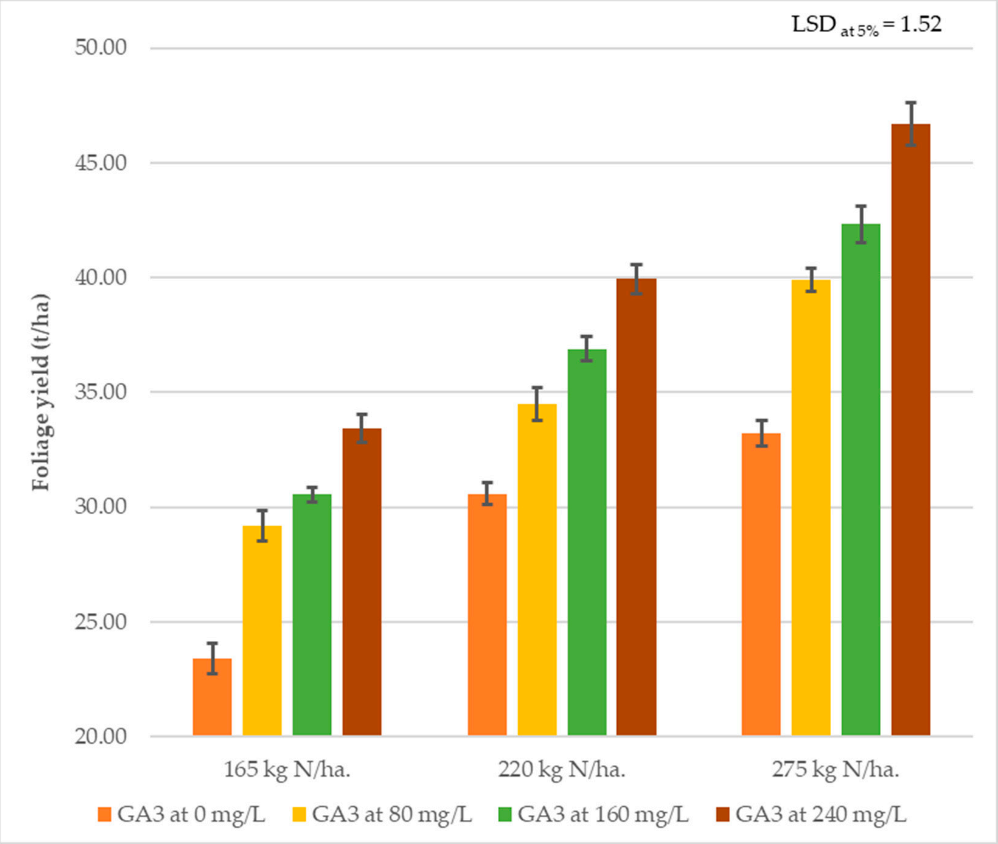

Figure 8. Foliage yield (t/ha) as affected by the interaction between nitrogen fertilizer levels and GA_3 spraying concentrations in the second season (2015/2016).

4. Discussion

Nitrogen is an essential element for plants. It is considered to be a major constituent of many biomolecules, including protein and chlorophyll, and it also has an important role in many physiological processes [39]. Our results show that the highest values of root dimensions (length and diameter), root and foliage fresh weights/plant, root and foliage yields/ha, and sugar yield/ha resulted from the increase of nitrogen fertilizer up to the highest level (275 kg N/ha). The increase in the above mentioned traits with the increase of applied levels of nitrogen fertilizer may be attributed to the role of nitrogen in enhancing rapid early growth, encouraging the uptake and utilization of other nutrients including potassium and phosphorous, increasing protein content through synthesize amino acids, and controlling the overall growth of the plant [40,41]. Similar results have been reported by Abdelaal and Tawfik [16], Mekdad [17], Afshar et al. [21], and Zarski et al. [22]. A moderate supply of nitrogen fertilizer is an essential limiting factor for optimum yield, but the excess in nitrogen fertilizer amounts may result in an increase in root yield with lower sucrose content and juice purity [4–7]. Over fertilizing sugar beet with more nitrogen than needed for maximum sucrose production led to decreased sucrose yield [8,9]. With increasing nitrogen supply, sugar concentration decreased, while root yield, sugar yield, and white sugar yield increased and reached maximum values when sugar beet was fertilized at 159, 136, and 129 kg N/ha, respectively [42]. Increasing nitrogen fertilizer levels led to a significant decrease in TSS%, though there was a partitioning of more photosynthetic metabolites to sugar beet tops than to the roots [43]. Additionally, Prvulovic et al. [14] concluded that, when the nitrogen supply increased, the α-amino-N concentration increased considerably and sucrose decreased. Dastorani and Armin [44] reported that an increase in nitrogen levels reduced the impure sugar content, while it increased both root and sugar yields as well as the content of a-amino and sodium. Moreover, it has been stated by Mekdad and Shaaban [45] that, with an increase in the nitrogen fertilizer level from 190 to 290 kg/ha, the sucrose, extractable sugar, and purity percentages decreased. The resulting increase in TSS and sucrose percentages by using the lowest nitrogen rate (165 kg/ha) in our study may be attributed to the fact that it gave the lowest root size and moisture content, therefore the concentration of TSS% and sucrose% increased. Regarding this, Abd El-Lateef et al. [6], Abdelaal and Tawfik [16], and Mekdad and Rady [18] came to the same conclusion.

Gibberellic acid is responsible for stimulating the production of mRNA molecules in the cells, and mRNA, produced in this form, codes for the hydrolytic enzymes, which in turn improves the chances of fast growth [46]. The observed increase in both root length and diameter, root and foliage fresh weights/plant, root and foliage yields/ha, and sugar yield/ha with the gradual increase of spraying with GA_3 concentrations (Tables 2 and 3) might explain why GA_3 is one of the most favorable substances for improving plant growth through encouraging the canopy to grow more, thus increasing utilization of solar radiation in a good photosynthesis that produces more carbohydrates that are transported to roots. This is in addition to its role in increasing the activities/levels of enzymatic and non-enzymatic antioxidants and vita organic osmolytes, which improves sugar content, chlorophyll content, and leaf area index [47]. Such results are in agreement with those stated by Qotob et al. [48], who reported that spraying sugar beets with GA_3 led to an increase in N use efficiency, which resulted in enhanced plant growth and productivity. Given the effect of GA_3 concentrations on quality traits in sugar beet roots, it can be concluded that lower sucrose percentage resulting from using higher concentrations of GA_3 may be attributed to the fact that higher concentrations of GA_3 may reduce dry matter percentage and thus increase the water content of the root [49,50]. Moreover, the negative effects of GA_3 on sucrose, TSS, and purity percentages, as well as its positive effects on total sugar yield, was mentioned by Abdou [27].

The superior effect of GA_3 spraying at 60 days after planting compared with spraying at 120 days after planting for all studied traits (Tables 2 and 3) can be attributed to the fact that plants were in their first half of life, thus the absorption efficiency was high, which enabled plants to absorb the full dose, which consequently promoted root and vegetative growth [27]. Early spraying of GA_3 leads to rapid leaf growth during the vegetative growth phase; therefore, photosynthesis production in the leaves achieves more than the basic needs of the plant, which leads to sugar beet plants storing photosynthesis products, thereby increasing sucrose. This occurs naturally when the foliage growth reaches its maximum size under appropriate climatic conditions. Nelson and Wood [33] came to the same conclusion when they reported that applying gibberellic acid at 100 mg/L, 3 to 6 weeks before harvest time (late stage), decreased the sucrose percentage. Additionally, the superior effect of GA_3 on growth and yield was also mentioned by Rahman et al. [51] when they reported that spraying GA_3 on Soybean 30 days after sowing significantly increased all growth and yield parameters.

5. Conclusions

Generally, for raising sugar yield/ha, it can be concluded that fertilizing sugar beet plants with 275 kg N/ha or the foliar application of GA_3 with a concentration of 160 mg/L 60 days after planting is the recommended treatment. Meanwhile, fertilizing sugar beet plants with the same dose (275 kg N/ha) or foliar application of GA_3 with a concentration of 240 mg/L 60 days after planting is the recommended treatment for raising foliage and root yields/ha under the ecological circumstances of this research.

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