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Article

The Application of Nitrogen Fertilization and Foliar Spraying with Calcium and Boron Affects Growth Aspects, Chemical Composition, Productivity and Fruit Quality of Strawberry Plants

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Abstract: Strawberries are rich in antioxidants and plant components to enhance cardiac health and regulate blood sugar. This experiment investigates the effects of N fertilization and foliar spraying with calcium (Ca) and boron (B) on growth, chemical composition of plant foliage, fruit yield, and quality of strawberry plants (*Fragaria* × *ananassa* Duch. cv. Fortuna). This experiment includes 12 treatments from the combination between four N fertilizers treatments (combinations of mineral and organic fertilizers) and three foliar spraying treatments with Ca+B at 2 and 4 mL/L in addition to the control treatment (spraying with tap water). Results show that the treatment where 50% of the recommended dose of N (50% RDN) was applied with mineral fertilizer + 100% organic N was the most effective one since it induced the highest values of plant height, number of crowns per plant, number of leaves per plant, fresh and dry weight per plant, especially when combined with the foliar application of Ca+B at the highest tested rate (4 mL/L). The highest values of N, P, K, Ca, B, and total carbohydrate contents were also scored for the combination of 50% RDN + 100% organic N and the foliar spraying with Ca+B at 4 mL/L in both growing seasons. In addition, the highest values of fruit yield per plant and per hectare, exportable fruit yield/ha, fruit firmness, fruit TSS, Vitamin C, total sugars, and anthocyanin, as well as the lowest values of total acidity were recorded for the combined treatment of 50% RDN + 100% organic and Ca+B at the highest rate (4 mL/L). The highest recorded value of length, diameter, and weight of fruit were scored by fertilizing strawberry plants with the recommended dose of mineral N (100% RDN) and spraying with Ca+B at the highest rate in both growing seasons. In conclusion, it could be suggested that fertilization of strawberry plants with half the recommended dose with mineral N fertilizer + 100% organic fertilizer and foliar spraying with Ca+B at 4 mL/L increases plant growth and improve yield parameters and fruit quality of the strawberry plants.

Keywords: strawberry; *Fragaria* × *ananassa*; plant growth; fertilization; total soluble solids; anthocyanins; chemical composition; fruit yield

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1. Introduction

Strawberry (*Fragaria* × *ananassa* Duch.) is one of the most important fruit crops grown in Egypt for fresh consumption, exportation, and processing, which belongs to the Rosaceae family [1]. The average area cultivated in 2019 with strawberries in Egypt was increased and reached about 16,248 ha, while the harvested area and total production in the world for the same year reached 396,401 ha and 8,885,028 tons, respectively [1]. Moreover, the total exportable fruit yield was 54 thousand tons of fresh fruit and about 140 thousand tons of frozen strawberries (individual quick freeze IQF) according to the statistics of the Food and

Agricultural Association of United Nations in the 2019 season [1]. Recently, Egypt is the top place in the world in the export of frozen strawberries, according to the report of the World Trade Center of the United Nations; the exported quantities amounted to 140 thousand tons, representing 20% of the global exports quantities, with a value of $165 million, representing 14.3% of the world's total exports for the year 2019 [1]. Strawberries are a rich source of vitamin C along with potassium and iron [2]. It also has a high content of fiber, secondary metabolites, and sugars. The high content of beneficial health compounds reduces blood clotting and decreases cardiovascular diseases [3].

The plant growth, as well as the yield and quality of strawberries, depending on the different agricultural treatments practiced during the growing season [4]. Strawberry plants need large amounts of fertilizers, due to their high total biomass production despite the small size of the plant [5]. Strawberries are one of the most susceptible plants in nutrients related disorders, and nutrient management is a key factor in ensuring a high yield and fruit quality [6]. Moreover, the fruit yield of strawberry cultivars depends on soil fertility and water availability during the growing season [7]. Therefore, to obtain a uniform high yield of good quality fruit, it is essential to provide adequate nutrients for proper plant nourishment [8]. Nowadays, organic products are becoming more famous around the world. Due to the great global market demand, the production of organic food has rapidly increased in the past decades [9]. Many studies indicated that applying compost manure to strawberry fields may play an important role in soil amendment, improving plant nutrition, and enhancing plant growth [10]. Intensive farming practices that result in high yield and quality also require extensive use of chemical fertilizers, which are costly and create environmental problems [11]. One of the application methods of plant nutrient minerals is foliar feeding. In this method, the availability and use efficiency of the required elements from plants are relatively high. Ca is one of the most important macronutrients for strawberry cultivation. The beneficial effects of Ca on maintaining fruit quality and increasing shelf life are well documented by many researchers [12,13]. Pre- and post-harvest application of Ca have been practiced commercially in many fruits for improving quality, delaying senescence, reducing post-harvest decay, and controlling the physiological disorders [14]. Foliar applications of Ca during vegetative growth have been reported to delay ripening and mold development in strawberries [15]. On the other hand, B is an important micronutrient that is essential in stabilizing certain constituents of cell walls structure and function and activity of plasma membrane, improvement of cell division, and tissue differentiation [16]. In addition, Rafeii and Pakkish [17] revealed that applying B increased net photosynthetic rate that could be attributed to the increase in chlorophylls content of leaves. Moreover, B deficiency reduces pollen germination and growth of pollen tubes, which consequently results in the development of malformed fruits, which lowers marketable yield and deteriorates fruit quality [18,19]. Considering the negative effects of chemical fertilizers application on the environment and food safety, this work studies the effects of supplementing organic and/or inorganic N fertilizer combined with foliar spraying of B and Ca on plant growth, fruit yield, fruit quality and chemical composition of strawberry fruit.

2. Materials and Methods

2.1. Experimental Site

Two field experiments were carried out during the two successive winter seasons of 2017/2018 and 2018/2019 in a private sector farm at Kafr El-Sohby, Qouloubia Governorate, Egypt. The experimental area was located at an altitude of 45 m above mean sea level between 30.45 N latitude and 31.10 E longitude to investigate the effect of mineral and organic N fertilizers, as well as the effect of foliar spraying with Ca and B on growth, chemical composition, fruit yield and quality of strawberry plants (*Fragaria* × *ananassa* Duch cv. Fortuna). The soil of the experimental field was sandy in texture. The mechanical analysis was determined according to Jackson [20], whereas chemical analysis was performed according to Black et al. [21]. Soil mechanical and chemical properties are shown in Table 1.

Table 1. Physical and chemical properties of the soil used in the two growing seasons.

Physical Parameters		Chemical Parameters			
		Cations mmol/L		Anions mmol/L	
Coarse sand	19.4%	Ca^{++}	3.9	CO_3^-	0.0
Fine sand	35.7%	Mg^{++}	2.125	HCO_3^-	5.6
Silt	26.6%	Na^+	3.22	Cl^-	5.23
Clay	19.3%	K^+	1.16	SO_4^-	3.56
Texture class	Sandy				
Soil pH	7.58	Available N 26.6 mg/kg			
EC (dS/m)	1.77	Available P 13.8 mg/kg			
Organic matter	0.78%	Available K 172 mg/kg			

2.2. Experimental Treatments

The experiments included 12 treatments resulting from the combination of four N fertilization treatments and three foliar spraying treatments as follows:

2.2.1. Nitrogen Fertilizer Treatments (Soil Application)

S1—Recommended dose of mineral N fertilizer (100% RDN) in the form of ammonium nitrate [NH_4NO_3, 33.5%]. Nitrogen was used at a rate of 476 kg N/ha as recommended by the Ministry of Agriculture of Egypt.

S2—50% recommended dose of mineral N fertilizer (50% RDN) (238 kg N/ha) + 50% organic N fertilizer by compost (20 and 20.3 ton/ha, which was equivalent to 50% of RDN in the first and second growing seasons, respectively).

S3—50% recommended dose of mineral N fertilizer (238 kg N/ha) + 75% organic N fertilizer by compost (30 and 30.6 ton/ha, which was equivalent to 75% of RDN in the first and second growing seasons, respectively).

S4—50% recommended dose of mineral N fertilizer (238 kg N/ha) + 100% organic N fertilizer by compost (40 and 40.9 ton/ha, which was equivalent to 100% of RDN in the first and second growing seasons, respectively).

The amounts of organic N fertilizer (compost) were obtained from Nile Company and added during soil preparation as base dressing, while mineral N fertilizer was added in-season through fertigation.

The chemical analysis of the used compost in the first and second seasons is shown in Table 2.

Table 2. Chemical parameters of the compost used in the experiments of the study.

Items	2017/2018	2018/2019
N%	1.19	1.17
P%	0.65	0.69
K%	1.49	1.43
C:N ratio	17:1	18:1
Organic matter (%)	32.47	33.92
pH	6.78	6.89
EC (dS/m)	3.14	3.42
Specific weight (kg/m^3)	612 kg	627 kg

2.2.2. Foliar Spraying Treatments

F1—Control treatment (spraying with tap water).

F2—Ca + B (caboron) at 2 mL/L

F3—Ca + B (caboron) at 4 mL/L

Caboron is a commercial product provided by Leili Agrochemistry Co. Ltd. (Beijing, China) and contains 60 g/L of Ca and 15 g/L of B.

The spraying treatments started 30 days after transplanting and were repeated at 15 day intervals (from November 1st to the end of April).

2.3. Experiment Design and Layout

The area of each experimental plot was 12.80 m^2, including one bed of 8.0 m long and 1.6 m wide. Each bed included four rows, and plants were transplanted at 0.25 m apart between the rows and 0.15 m in the same row. Transplanting was performed on September 20 in both growing seasons, when plants reached the stage of 3–4 true leaves (60 days after sowing). A sprinkler and drip irrigation system was used in the first month after transplanting, while after that, the beds were covered with white plastic mulch with a thickness of 40 µm. After mulching irrigation was applied with drip irrigation until the end of the growing season.

The experiment was a factorial one, including two factors, namely, N fertilization (N) and foliar spraying (FS) with four and three levels, respectively. The layout was designed according to the randomized complete blocks design with 12 treatments representing the combinations between the treatments of the tested factors, e.g., four fertilization treatments and three foliar spraying treatments. All the treatments were replicated three times. All other agricultural practices required for strawberry production were carried out according to the recommendations of the Ministry of Agriculture of Egypt.

2.4. Data Recorded

2.4.1. Vegetative Growth Characteristics

Five plants were taken from each experimental plot as a representative sample 120 days after transplanting, and plant height, number of leaves and crowns per plant, fresh weight, as well as dry weight per plant, were recorded.

The analyses of the chemical composition of plant foliage include the determination of total N [22], phosphorus [23], potassium [24], Ca, B [25], and total carbohydrates content [26].

2.4.2. Fruit Yield and Its Components

The fruit yield and yield components determination included:

- Exportable yield (ton/ha): It was calculated as the weight of harvested fruits at the ripe stage during November, December, and January after discarding the misshaped and infected fruits (unmarketable yield),
- Total fruit yield (ton/ha): It was calculated as the weight of all fruits harvest throughout the growing season,
- Fruit yield per plant (g): It was calculated based on the fruit yield/plot divided by the number of plants/plot.

2.4.3. Physical Parameters of Fruit Quality

A random sample of 10 fruits at the marketable stage from each experimental plot was collected to determine the average fruit weight (g), length, and diameter (cm) using a Vernier caliper.

Fruit firmness (g/cm^2) was determined in a random sample of ten fruits from each experimental plot by using a Chatillon Penetrometer N.4 (AMETEK Sensors, Test & Calibration, San Luis Obispo, CA, USA) and a GauGe–R with a needle 3 mm in diameter [27].

2.4.4. Chemical Parameters of Fruit Quality

A random sample of 10 fruits from each experimental plot at the fully ripen stage was taken to determine the total soluble solids (T.S.S.%) with the use of a hand refractometer (38-01 OPTi Multiple Scale Digital Handheld Refractometer, Bellingham + Stanley, Xylem Analytics Germany Sales GmbH and Co. KG, WTW, Weilheim, Germany). In contrast, the total titratable acidity (T.T.A.%), ascorbic acid (mg/100 g fresh weight (f.w.)) and anthocyanin content (mg/100 g f.w.) were determined according to the methods described by the Association of Official Analytical Chemists [28]. In addition, total sugars content (%) was determined colorimetrically (Model UV752/UV754-Single Beam UV/Vis Spectrophotometer, YK Scientific, Shanghai, China) using the method previously described by Nelson [29].

2.5. Statistical Analysis

All data obtained in both seasons of the study were subjected to analysis of variance (ANOVA), and when significant differences were detected, the Least Significant Test (L.S.D.) was used for comparison of means [30]. The results of ANOVA, which show the significant interaction between the tested factors, are provided as Supplementary Material Table S1.

3. Results and Discussion

3.1. Vegetative Growth Parameters

Data presented in Table 3 revealed that fertilizing strawberry plants with 50% RDN + 100% organic treatment [50% recommended dose of mineral N fertilizer (238 kg N/ha) + 100% organic N fertilizer by compost] resulted in the highest values of the tested plant growth parameters, however, without being significantly different from the control treatment (100% of mineral fertilizer). On the other hand, the combinations of 50% of mineral N fertilizer with either 50% organic fertilizer resulted in decreased values for the tested parameters compared to the control treatment. The improvement in plant growth, due to the combined supplementation of mineral and organic N could be attributed to the slow release of N in organic fertilizers, which may better fulfill the plant requirements during the later stages of the growing season, while mineral fertilizers can compensate for the needed N in early to mid-stages, due to the presence of both nitrates and ammonium N in the tested mineral fertilizer. According to Agehara [31], the early season applications of N increased significantly early and total fruit yield, due to larger leaf area and higher shoot dry weight. Besides, organic fertilizers play a vital role in improving soil physical properties and reducing pH value which affects the availability and uptaking of soil nutrients from plants and consequently improves plant growth parameters [32]. The findings of this study agree with those reported by Hassan [33], who also suggested that the combination of mineral and organic N fertilizers resulted in improved plant growth. Moreover, Loyd et al. [34] reported that compost application significantly improved several parameters related to crop production, including soil salinity, microbial activity, soil nitrate content, soil pH, and plant establishment. Similarly, Khalil and Agah [35], who tested the application of mineral, organic, and biofertilizers, suggested that the combination of three different NPK sources resulted in higher plant production and fruit yield and quality compared to single treatments, while Yadav et al. [36] also suggested that the integration of organic and mineral fertilizers improved soil health and crop productivity. However, the response to N rates depends on the cultivar, and cultivars sensitive to N fertilization are more prone to delayed flowering and lower early yield when excessive N is applied [37]. According to Iatrou and Papadopoulos [38], overfertilization of N may improve vegetative growth, but reduces significantly harvest index, although they also suggest that the response to N fertilization may differ depending on the cultivar. Similarly, Santos and Chandler [39] suggested a differential response of strawberry cultivars to N fertilization rates in terms of canopy diameter, total marketable yield and fruit weight, and number, while according to Sas et al. [40] N form may affect the development of root and improve vegetative growth of strawberry plants.

Table 3. Effect of nitrogen fertilizer application and foliar spraying with Ca and B on vegetative growth parameters of the strawberry plant during 2017/2018 and 2018/2019 seasons.

Treatments		2017/2018					2018/2019				
Nitrogen Fertilizers	Foliar Spray	Plant Height (cm)	No. of Crowns/Plant	No. of Leaves/Plant	Total Fresh Weight (g/Plant)	Total Dry Weight (g/Plant)	Plant Height (cm)	No. of Crowns/Plant	No. of Leaves/Plant	Total Fresh Weight (g/Plant)	Total Dry Weight (g/Plant)
100% mineral N		21.7	2.5	21.6	87.7	17.81	21.0	2.9	21.1	86.2	17.46
50% mineral N + 50% organic N		19.1	1.9	18.3	75.4	15.34	18.3	1.9	17.2	68.2	14.85
50% mineral N + 75% organic N		20.5	2.1	19.7	81.7	17.61	19.8	2.3	19.3	80.3	17.08
50% mineral N + 100% organic N		22.8	2.8	22.9	92.1	19.75	22.2	3.0	22.5	89.6	19.33
LSD at 5%		1.42	0.37	1.41	5.02	2.04	1.30	0.18	1.52	3.81	1.96
	Control	20.1	2.0	19.3	80.4	16.68	19.6	2.2	18.9	76.5	15.91
	Ca+B at 2 mL/L	21.7	2.3	20.4	83.8	17.26	20.3	2.5	20.2	81.3	17.08
	Ca+B at 4 mL/L	22.5	2.6	22.2	88.4	18.94	21.1	2.8	21.1	85.2	18.55
LSD at 5%		1.23	0.32	1.22	4.35	1.74	1.12	0.15	1.32	3.31	1.71
	Control	20.6	2.1	20.2	83.5	16.75	20.2	2.6	19.6	82.6	16.36
100% mineral N	Ca+B at 2 mL/L	21.8	2.6	21.1	87.5	17.59	21.1	2.9	21.6	85.6	17.12
	Ca+B at 4 mL/L	22.9	2.9	23.6	92.2	19.10	21.8	3.2	22.2	90.4	18.92
	Control	18.1	1.7	17.1	71.2	14.65	17.6	1.8	16.2	63.2	13.12
50% mineral N + 50% organic N	Ca+B at 2 mL/L	19.3	1.9	18.2	75.4	14.62	18.4	1.9	17.4	69.3	15.11
	Ca+B at 4 mL/L	20.1	2.1	19.7	79.8	16.75	18.9	2.2	18.2	72.3	16.32
	Control	19.6	1.8	18.6	78.4	16.98	19.2	2.0	18.1	75.6	16.27
50% mineral N + 75% organic N	Ca+B at 2 mL/L	20.4	2.0	19.5	81.	17.11	19.7	2.4	19.3	80.9	16.85
	Ca+B at 4 mL/L	21.7	2.4	21.1	85.	18.75	20.6	2.6	20.5	84.6	18.12
	Control	22.1	2.5	21.6	88.7	18.35	21.5	2.6	21.9	85.6	17.89
50% mineral N + 100% organic N	Ca+B at 2 mL/L	22.8	2.8	22.8	91.2	19.75	22.2	3.1	22.5	89.7	19.27
	Ca+B at 4 mL/L	23.5	3.2	24.5	96.2	21.16	22.9	3.3	23.2	93.5	20.85
LSD at 5%		2.46	0.64	2.44	8.7	3.48	2.24	0.30	2.64	6.62	3.41

Regarding the effect of Ca+B (caboron), the results showed that application at the highest rates (4 mL/L) statistically increased plant vegetative growth compared to the control treatment in terms of plant height, number of crown and leaves/plant, and fresh and dry weights/plant in both growing seasons (Table 3). Moreover, in most of the tested parameters, no significant differences were observed between the two application rates, e.g., plant height, number of crowns per plant and total dry weight of the plant in the first growing season and plant height, number of leaves per plant, and total dry weight of the plant in the second growing season. On the other hand, the beneficial effects of Ca+B at 4 mL/L were more profound for the number of leaves per plant, and total fresh weight of plant in the first growing season, and for the number of crowns per plant and total fresh weight of plants in the second growing season. Similar to our study, Wójcik and Lewandowski [41] suggested that applying Ca or B increased the content of the corresponding elements in leaves and fruit, while Hassan [42] and Hamail et al. [43] reported that foliar spraying with different forms of Ca affected plant growth parameters, such as total leaf area and fresh weight, number of leaves per plant and leaf area, respectively. Moreover, Rafeii and Pakkish [17] suggested that foliar spraying of B may increase vegetative growth be increasing photosynthetic compounds.

The combined application of mineral and organic N with foliar spraying of Ca+B resulted in improved plant growth for all the tested parameters, while the highest values were recorded consistently for the combined application of 50% mineral N + 100% organic N with foliar spraying of Ca+B at the highest rate (4 mL/L). However, in most cases, no significant differences were observed from the treatments of 50% mineral N + 100% organic N and foliar spraying of Ca+B at 2 mL/L or 100% mineral N and foliar spraying of Ca+B at 4 mL/L. In contrast, the lowest values were observed for the plants treated only with 50% mineral N + 50% organic N, except for the case of total dry weight per plant in the first growing season, where the lowest values were recorded for the combined application of 50% mineral N + 50% organic N and foliar spraying of Ca+B at 2 mL/L. Our results suggest that N availability combined with Ca and B may improve root development and minerals uptake from plants, while N form may affect soil pH, and therefore, regulate minerals availability and micronutrients solubility in soil solution and further affect plant development [40].

3.2. Chemical Constituents of Plant Foliage

Regarding the effect of N application on the mineral composition of leaves, a varied response was observed (Table 4). In particular, in the first growing season, N and Ca content was the highest when N was supplemented in mineral form (100% of RDN) or in 50% RDN + 100% organic form. Phosphorus (P) and potassium (K) were the highest for the treatment of 50% mineral N + 100% organic N, being significantly different only from the treatment of 50% mineral N + 50% organic N. Finally, B and total carbohydrates contents were significantly higher for the 50% mineral N + 50% organic N. Similarly, in the second growing season minerals and total carbohydrates content were the highest for the treatments of 100% mineral N and 50% mineral N + 100% organic N, except for the case of phosphorus content which was the highest when 50% mineral N + 100% organic N was applied. The application of organic fertilizers at 100% of RDN consistently increased minerals and total carbohydrates content at levels similar to the treatment of 100% mineral N. This effect could be attributed to the reduction of soil pH and the release of nutrients in the soil through organic matter decomposition that may increase minerals uptake by plants [40]. On the other hand, increasing the applied rates of compost also improves soil physicochemical characteristics and soil microbiota content, and further increases nutrients availability [34,42]. In the same context, Bielinski [39] suggested that applying organic manure increases soil organic matter and the availability of P, as well as the exchange of Mg, Mn, and Zn in soil solution. In contrast, Hassan [33] reported that N supplementation in the form of mineral fertilizers significantly increased nutrients content in leaves compared to organic N.

Table 4. Effect of nitrogen fertilizer application and foliar spraying with Ca and B on chemical constituents of plant foliage during 2017/2018 and 2018/2019 seasons.

Treatments		2017/2018						2018/2019					
Nitrogen Fertilizers	**Foliar Spray**	**N %**	**P %**	**K %**	**Ca %**	**B (ppm)**	**Total Carbohydrates %**	**N %**	**P %**	**K %**	**Ca %**	**B (ppm)**	**Total Carbohydrates %**
100% mineral N		2.15	0.219	2.23	1.85	53.9	17.91	2.17	0.226	2.27	1.80	66.6	20.02
50% mineral N + 50% organic N		1.89	0.205	1.94	1.58	49.3	14.14	1.86	0.205	1.97	1.45	57.1	15.25
50% mineral N + 75% organic N		1.93	0.218	2.13	1.67	56.5	15.07	1.94	0.214	2.17	1.61	62.0	17.14
50% mineral N + 100% organic N		2.18	0.225	2.28	1.90	64.4	19.86	2.20	0.235	2.35	1.85	68.2	21.13
LSD at 5%		0.12	0.007	0.13	0.21	3.2	1.42	0.08	0.006	0.12	0.23	3.21	2.82
	Control	1.95	0.204	2.01	1.66	48.9	15.27	1.96	0.212	2.06	1.58	55.3	16.58
	Ca+B at 2 mL/L	2.05	0.220	2.18	1.77	57.6	16.85	2.05	0.223	2.20	1.71	64.8	18.78
	Ca+B at 4 mL/L	2.11	0.225	2.24	1.83	61.6	18.11	2.11	0.225	2.28	1.74	70.3	19.80
LSD at 5%		0.10	0.006	0.11	0.18	2.78	1.23	0.07	0.005	0.10	0.20	2.80	2.45
100% mineral N	Control	2.04	0.206	2.12	1.78	49.3	16.12	2.09	0.219	2.18	1.69	56.7	18.06
	Ca+B at 2 mL/L	2.18	0.226	2.26	1.86	53.2	17.81	2.17	0.228	2.29	1.87	68.2	20.17
	Ca+B at 4 mL/L	2.24	0.224	2.31	1.92	59.2	19.82	2.26	0.231	2.34	1.85	74.9	21.84
50% mineral N + 50% organic N	Control	1.82	0.192	1.82	1.46	45.2	12.91	1.79	0.196	1.86	1.37	51.8	13.24
	Ca+B at 2 mL/L	1.91	0.204	1.94	1.61	51.0	14.32	1.87	0.208	1.97	1.48	58.2	15.80
	Ca+B at 4 mL/L	1.96	0.218	2.06	1.68	51.8	15.21	1.93	0.212	2.08	1.52	61.3	16.71
50%mineral N + 75% organic N	Control	1.89	0.211	2.01	1.56	48.3	13.82	1.84	0.206	1.97	1.51	54.1	15.21
	Ca+B at 2 mL/L	1.94	0.220	2.21	1.71	58.2	15.16	1.97	0.219	2.19	1.64	63.2	17.92
	Ca+B at 4 mL/L	1.98	0.223	2.18	1.76	63.2	16.24	2.02	0.217	2.28	1.68	68.9	18.31
50% mineral N + 100% organic N	Control	2.08	0.209	2.11	1.84	52.8	18.26	2.14	0.226	2.23	1.78	58.8	19.81
	Ca+B at 2 mL/L	2.17	0.231	2.31	1.91	68.3	20.14	2.21	0.237	2.38	1.86	69.8	21.26
	Ca+B at 4 mL/L	2.29	0.236	2.42	1.96	72.3	21.20	2.26	0.241	2.45	1.93	76.2	22.34
LSD at 5%		0.21	0.012	0.23	0.36	5.56	2.46	0.14	0.010	0.20	0.40	5.58	4.90

Regarding the foliar application of Ca+B, mineral composition and total carbohydrates of leaves were improved regardless of the application rate, except for the case of B content (both growing seasons) and total carbohydrates content (second growing season), which was the highest at the highest rate of Ca+B (Table 4). The combined application of N and Ca+B resulted in higher content of N, P, K, and Ca for the treatments of 100% mineral N and 50% mineral N + 100% organic N in the first growing season, regardless of the Ca+B rate (Table 2). Boron content was the highest for the treatment of 100% mineral N and 50% mineral N + 100% organic N at both Ca+B rates, while total carbohydrates content increased for the treatments of 100% mineral N and 50% mineral N + 100% organic N (both Ca+B rates) and 100% mineral N (Ca+B at 4 mL/L). In the second growing season, a varied response was observed, although the highest values were consistently recorded for the combined application of 50% mineral N + 100% organic N and Ca+B at 4 mL/L. According to Farid et al. [44], foliar application of nutrients is more efficient in meeting plant requirements and promotes its availability through foliage. This could also be associated with the improved plant growth parameters in our study, since better nutrients availability induces plant growth. Moreover, Wójcik and Lewandowski [41] suggested that the foliar application of Ca and B increased the leaf content of both elements over the unsprayed plants. On the other hand, the supplementation of organic compost may affect soil pH and nutrients availability in soil and their uptake from plants [10]. Hassan [42] also reported that applying high rates of K fertilizers and microbial inoculum, combined with foliar application of Ca, resulted in the highest content of N, P, and K in leaves.

3.3. Fruit Yield Parameters

Fruit yield and yield parameters are presented in Table 5. The highest values of yield parameters were recorded when mineral fertilizer at 50% of RDN was supplemented with 75% or 100% organic N, except for the case of total yield per plant in the first growing season where the treatment of 50% of mineral N + 100% of organic N was the most efficient. Similarly, the foliar application of Ca+B, at any rate, resulted in the highest values for all the recorded yield parameters, except for total yield per plant of the first growing season, where only the highest rate of Ca+B showed the best results. These findings were also reflected the combined effects of N soil application and foliar spraying of Ca and B, where N application at 50% in mineral form and at 75% or 100% at organic form combined with foliar application of Ca+B improved significantly yield parameters. In contrast, the lowest yield was recorded for the plants treated with 50% of mineral and organic fertilizers without the foliar application of Ca and B. The highest total yield per ha and per plant and exportable yield in case of fertilization using half of the recommended dose of N as mineral and other as compost may be attributed to the balanced availability of N throughout the growing period. According to the literature, N application rates, as well as N form, may affect the total yield and number of fruits per plant [33,42], while the time of application is also important, since the improved vegetative growth (high leaf area and shoot dry matter) is also associated with increased yield [31]. Moreover, N availability in perennial crops, such as strawberry, is essential after the renovation period. This is due to applications after the growth stage that improve N use efficiency and increase N partitioning to new growth and fruit [45]. This was also evident in the study of Iatrou and Papadopoulos [46], who observed a significant effect of N application in the second growing season without significant effects on fruit weight, but only on fruit number and consequently on total fruit yield. However, increased mineral N fertilization may delay flowering and time of first harvesting, and consequently, it may result in a lower yield [37], while according to Santos and Chandler [39], there is a genotype-dependent response to N fertilization regimes in the strawberry crop. On the other hand, according to Khalil and Agah [35] and Yadav et al. [36], the combination of organic and chemical N fertilizers proved to increase significantly total fruit yield and yield parameters—this is in accordance with the results of the present study. In contrast, Loyd et al. [34] suggested that although compost application is beneficial to several soil physicochemical parameters, the effects on yield are more profound when plants are grown under suboptimal conditions. Moreover, the foliar application of Ca and micronutrients has improved yield parameters accompanied by increased plant growth [12,15]. In contrast to our study, Wójcik and Lewandowski [41], who studied the effect of foliar applications of Ca and B on strawberry fruit yield, did not observe significant differences probably due to lower N rates applied compared to our study (50 or 60 kg/ha vs. 476 kg/ha) that did not allow adequate vegetative growth to support increase fruit yield.

Table 5. Effect of nitrogen fertilizer application and foliar spraying with Ca and B on fruit yield and its components of strawberry plants during 2017/2018 and 2018/2019 seasons.

Treatments		2017/2018			2018/2019		
Nitrogen Fertilizers	Foliar Spray	Exportable Yield (ton/ha)	Total Yield (g)/Plant	Total Yield (ton/ha)	Exportable Yield (ton/ha)	Total Yield (g)/Plant	Total Yield (ton/ha)
100% mineral N		12.61	558	51.90	13.70	582	55.14
50% mineral N + 50% organic N		10.87	521	44.72	12.61	557	46.67
50% mineral N + 75% organic N		15.13	602	57.04	16.37	645	59.90
50% mineral N + 100% organic N		16.25	649	61.02	17.61	668	62.78
LSD at 5%		2.14	32.1	4.14	2.23	36.4	3.82
	Control	12.44	546	50.71	13.70	577	52.97
	Ca+B at 2 mL/L	13.61	579	53.38	15.04	615	56.16
	Ca+B at 4 mL/L	15.08	622	56.90	16.46	646	59.23
LSD at 5%		1.86	27.9	3.60	1.94	31.69	3.32
	Control	11.85	531	48.93	12.49	543	51.45
100% mineral N	Ca+B at 2 mL/L	12.30	552	50.57	13.70	586	55.04
	Ca+B at 4 mL/L	13.68	591	56.21	14.94	617	58.88
	Control	9.18	496	42.10	11.13	519	44.07
50% mineral N + 50% organic N	Ca+B at 2 mL/L	10.85	525	45.02	12.78	562	46.90
	Ca+B at 4 mL/L	12.59	542	47.02	13.94	591	49.07
	Control	14.16	547	53.88	14.63	611	56.54
50% mineral N + 75% organic N	Ca+B at 2 mL/L	14.86	586	56.69	16.49	642	59.78
	Ca+B at 4 mL/L	16.35	674	60.61	17.99	682	63.42
	Control	14.58	612	57.97	16.58	636	59.90
50% mineral N + 100% organic N	Ca+B at 2 mL/L	16.46	653	61.28	17.25	672	62.90
	Ca+B at 4 mL/L	17.70	682	63.83	18.99	697	65.59
LSD at 5%		3.72	55.9	7.20	3.88	63.3	6.64

3.4. Physical Parameters of Fruit

The physical parameters of fruit (length, diameter, weight, and firmness) are presented in Table 6. The application of N fertilizer in 100% mineral form resulted in the highest values of fruit dimensions and individual fruit weight; however, no significant differences were observed from fruit obtained from plants treated with 50% mineral N + 75% organic N or 50% mineral N + 100% organic N. This finding suggests that fruit dimensions and consequently fruit weight is not affected by N fertilization as soon as plants receive the adequate amounts of this important mineral. On the other hand, fruit firmness was the highest for 50% mineral N + 100% organic N in both growing seasons. The results of our study agree with literature reports which suggest that N fertilization does not affect mean fruit weight, but is essential for total fruit number [46], whereas Nestby [47] reported that the higher fruit number may result in smaller fruit, due to competition between fruit for assimilates. Similar results were reported by Hassan [33], who also did not detect significant differences in fruit dimensions between plants that received the recommended amounts of N either in mineral or organic form. In contrast, Khalil and Agah [35] reported that fruit size was larger in strawberry plants treated with various forms of fertilizers (mineral and organic fertilizers and biofertilizers) compared to plants that received only mineral fertilizers.

Table 6. Effect of nitrogen fertilizer application and foliar spraying with Ca and B on fruit physical parameters of strawberry plants during 2017/2018 and 2018/2019 seasons.

Treatments		2017/2018				2018/2019			
Nitrogen Fertilizers	**Foliar Spray**	**Fruit Length (cm)**	**Fruit Diameter (cm)**	**Fruit Weight (g)**	**Fruit Firmness (g/cm^2)**	**Fruit Length (cm)**	**Fruit Diameter (cm)**	**Fruit Weight (g)**	**Fruit Firmness (g/cm^2)**
100% mineral N		5.63	3.67	26.50	212	5.78	3.79	27.13	225
50% mineral N + 50% organic N		4.95	3.04	18.90	236	5.12	3.17	19.46	236
50% mineral N + 75% organic N		5.29	3.43	21.76	257	5.43	3.53	22.83	269
50% mineral N + 100% organic N		5.47	3.57	24.63	267	5.60	3.67	25.40	282
LSD at 5%		0.41	0.46	2.17	21.4	0.42	0.43	2.43	9.34
	Control	5.12	3.27	21.42	228	5.28	3.40	22.32	241
	Ca+B at 2 mL/L	5.33	3.42	22.95	241	5.49	3.55	23.55	254
	Ca+B at 4 mL/L	5.53	3.60	24.47	260	5.67	3.67	25.25	265
LSD at 5%		0.36	0.40	1.89	18.6	0.37	0.37	2.11	8.13
100% mineral N	Control	5.43	3.51	25.20	196	5.62	3.66	25.70	213
	Ca+B at 2 mL/L	5.65	3.65	26.80	217	5.78	3.78	27.30	229
	Ca+B at 4 mL/L	5.82	3.86	27.50	224	5.94	3.93	28.40	235
50% mineral N + 50% organic N	Control	4.81	2.93	17.50	219	5.95	3.10	18.30	227
	Ca+B at 2 mL/L	4.93	3.05	18.70	231	5.10	3.17	19.20	238
	Ca+B at 4 mL/L	5.12	3.16	20.50	258	5.31	3.25	20.90	244
50% mineral N + 75% organic N	Control	5.07	3.21	20.20	246	5.26	3.32	21.60	259
	Ca+B at 2 mL/L	5.25	3.43	21.70	254	5.41	3.58	22.40	263
	Ca+B at 4 mL/L	5.47	3.67	23.40	273	5.64	3.71	24.50	287
50% mineral N + 100% organic N	Control	5.18	3.43	22.80	251	5.32	3.52	23.70	266
	Ca+B at 2 mL/L	5.51	3.56	24.60	265	5.69	3.68	25.30	287
	Ca+B at 4 mL/L	5.73	3.74	26.50	287	5.81	3.82	27.20	295
LSD at 5%		0.71	0.80	3.78	37.2	0.73	0.74	4.23	16.25

With regard to the effect of foliar spraying with Ca and B, applying the highest rate (4 mL/L) resulted in the largest fruit size and fruit weight, as well as to the highest firmness, although no significant differences from the rate of 2 mL/L were observed in the case of fruit dimensions and fruit weight. Similarly, the combined application of 100% of RDN in mineral form and foliar spraying with Ca and B at 4 mL/L resulted in the highest overall values for fruit dimensions and fruit weight, while fruit firmness was the highest when applying 50% mineral N + 100% organic N was combined with foliar spraying of Ca and B at 4 mL/L. In contrast, the lowest values were recorded for the treatment of 50% mineral N + 50% organic N with no foliar application of Ca and B, while the lowest firmness was observed for plants treated with 100% mineral N and no foliar application of Ca and B. According to Khalil and Agah [35], the combination of foliar spraying and soil application of organic and mineral fertilizers resulted in the largest fruit size and fruit weight in strawberry plants, whereas Wójcik and Lewandowski [41] suggested that foliar application of Ca and B had no effect on mean fruit weight, but was beneficial to fruit firmness, since Ca is considering a key ingredient of cell walls and increased contents could contribute to improved fruit firmness. Moreover, Gariglio et al. [48] reported that increasing N rates may increase fruit size up to a rate which is cultivar depended and further increase in N application does not have an impact on fruit size and weight, a finding which agrees with the results of our study.

3.5. Chemical Composition of Fruit

The chemical composition of fruit in relation to N fertilization and foliar spraying with Ca and B is presented in Table 7. Our results showed that applying 50% mineral N + 100% organic N significantly, or applying Ca and B at the highest rate (4 mL/L), significantly improved most of the tested parameters (e.g., total soluble solids, vitamin C, total sugars, and anthocyanins content), while titratable acidity was the highest in fruit treated with 100% mineral N or those that received no foliar application of Ca and B. These trends were also observed in the case of combined application of N fertilizers and foliar spraying with Ca and B where again the combination of 50% mineral N + 100% organic N and foliar application of Ca and B (4 mL/L) resulted in the highest values for total soluble solids, vitamin C, total sugars and anthocyanins content, whereas the combination of 100% mineral fertilizer and foliar application of Ca and B (4 mL/L) was the most beneficial for titratable acidity. Contrasting reports in the literature refer to the effect of N fertilization on the total soluble solids content. While Weber et al. [32] and Ojeda-Real et al. [49] did not observe significant effects of increasing N rates, Agehara [31] reported a linear decrease in soluble solids content with increasing N rates up to 192 kg/ha. On the other hand, Khalil and Agah [35] and Hassan [33] reported that the combined application of mineral, organic and biofertilizers improved the TSS content over the mineral fertilization. Moreover, the foliar application of nutrients improved TSS content over the control [44], while Bakshi et al. [12] and Wójcik and Lewandowski [41] suggested that increasing Ca application through foliar spraying also improved the total soluble solids content in fruit.

Table 7. Effect of nitrogen fertilizer application and foliar spraying with Ca and B on fruit quality parameters of strawberry plants during 2017/2018 and 2018/2019 seasons.

Treatments		2017/2018					2018/2019				
Nitrogen Fertilizers	Foliar Spray	TSS %	Total Acidity %	V. C (mg/100 g f.w)	Total Sugars %	Anthocyanin (mg/100 g f.w.)	TSS %	Total Acidity %	V. C (mg/100 g f.w.)	Total Sugars %	Anthocyanin (mg/100 g f.w.)
100% mineral N		9.86	0.79	47.95	6.85	81.0	10.50	0.82	48.84	7.08	84.9
50% mineral N + 50% organic N		10.50	0.75	50.37	7.09	86.7	10.70	0.77	51.88	7.32	88.0
50% mineral N + 75% organic N		10.80	0.73	53.86	7.38	90.9	11.23	0.76	55.45	7.56	93.0
50% mineral N + 100% organic N		11.36	0.66	55.45	7.78	93.2	11.53	0.70	57.23	7.86	95.5
LSD at 5%		0.46	0.07	4.82	0.41	4.28	0.39	0.06	4.37	0.36	2.84
	Control	10.15	0.78	49.77	7.08	84.1	10.57	0.80	51.18	7.29	86.7
	Ca+B at 2 mL/L	10.60	0.73	51.66	7.28	87.7	10.97	0.76	53.22	7.47	90.2
	Ca+B at 4 mL/L	11.15	0.68	54.28	7.46	91.9	11.42	0.72	55.66	7.60	94.1
LSD at 5%		0.42	0.06	4.19	0.36	3.72	0.40	0.05	3.80	0.31	2.47
	Control	9.30	0.76	46.36	6.63	74.3	10.10	0.79	47.17	7.01	80.2
100% mineral N	Ca+B at 2 mL/L	9.80	0.79	47.93	6.78	81.2	10.50	0.83	48.62	7.08	84.7
	Ca+B at 4 mL/L	10.50	0.82	49.56	7.07	87.5	10.90	0.86	50.75	7.15	89.8
	Control	10.0	0.70	48.75	6.94	82.7	10.20	0.74	50.08	7.20	84.2
50% mineral N + 50% organic N	Ca+B at 2 mL/L	10.40	0.75	50.24	7.08	86.3	10.60	0.77	51.63	7.31	87.5
	Ca+B at 4 mL/L	11.10	0.81	52.12	7.25	91.1	11.30	0.82	53.74	7.46	92.4
	Control	10.30	0.68	51.52	7.18	88.5	10.80	0.72	52.84	7.32	89.9
50% mineral N + 75% organic N	Ca+B at 2 mL/L	10.80	0.74	53.24	7.32	90.8	11.30	0.76	55.42	7.57	93.2
	Ca+B at 4 mL/L	11.30	0.78	56.85	7.64	93.6	11.60	0.80	58.11	7.81	96.1
	Control	11.0	0.61	52.46	7.58	91.2	11.20	0.65	54.63	7.65	92.7
50% mineral N + 100% organic N	Ca+B at 2 mL/L	11.4	0.65	55.26	7.87	92.8	11.50	0.71	57.21	7.94	95.6
	Ca+B at 4 mL/L	11.70	0.72	58.64	7.91	95.7	11.90	0.75	59.86	7.99	98.4
LSD at 5%		0.84	0.12	8.39	0.71	7.45	0.80	0.10	7.60	0.62	4.94

Similarly, the foliar application of nutrients improved ascorbic acid content [14,44], while increasing N application rates also had a beneficial effect on ascorbic acid content [49]. The same authors reported similar trends for titratable acidity (citric acid content) [43], which according to Nestby [47], could be related to N deficiency. In addition, Yadav et al. (2016) and Hassan (2015) did not record significant differences in ascorbic acid content between different fertilization treatments, including mineral fertilizers, farmyard manure, composts, and *Azotobacter* inoculation.

Regarding the total sugars content, Ojeda-Real et al. [49] reported decreasing trends with increasing N application rates which contrasts with our findings. Agehara [31] also suggested that the reduced total sugars content recorded in fruit from plants treated with increased N rates could be attributed to the partitioning of sugars to a higher number of fruits or to a dilution effect, due to the increase of fruit size.

In contrast, Weber et al. [32] reported that N fertilization at rates equivalent to 66% of RDN improved total sugars content through the increase of fructose and glucose. However, these contradictions should also be attributed to the lower application rates in that report compared to our study, which indicates that N deficiency may affect sugar biosynthesis and total sugars content in strawberry fruit. Moreover, Bakshi et al. [12] reported that the foliar application of Ca and B significantly improved total sugars content, a finding which is in accordance with our results. According to Chandrakar et al. [14], the foliar application of micronutrients may increase total sugars content through the hydrolysis of polysaccharides, as well as to induce the conversion of organic acids to soluble sugars. This finding is also in accordance with our results, since applying Ca and B at the highest rate resulted in an increase of total sugars and a decrease of titratable acidity, which is expressed as citric acid content. Yadav et al. [2] and Wang and Lin [36] also reported an increase in total sugars content of fruit when plants were treated with organic compost, while Hassan [33] suggested an increase in total sugars content after applying biofertilizers.

N fertilization regime may affect fruit anthocyanin content, and according to Khalil and Agah [35], the combination of mineral, organic, and biofertilizers proved beneficial to that particular quality parameter. However, according to Weber et al. [32], N application rates did not affect total anthocyanins content, which indicates that N form rather than total application rate is essential for the formation of anthocyanins [36,42]. Moreover, the pre-harvest application of Ca and micronutrients significantly improved anthocyanins content over the control (untreated) plants [12].

4. Conclusions

In conclusion, the results of the present study highlight the effect of the fertilization regime on plant growth, fruit yield, and fruit quality. It could be suggested that the foliar application of Ca+B at 4 mL/L combined with the fertilizer treatment of 50% RDN with chemical N fertilizer + 100 % RDN with organic N could significantly improve plant growth, total and marketable yield, and fruit quality. Moreover, applying organic fertilizers could improve soil physicochemical parameters in the long term, which is very important in practicing sustainable cropping systems in horticulture and reducing chemical inputs in the production chain.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/horticulturae7080257/s1, Table S1: Basal Dopamine (DA) values reported by individual manuscript.

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