agronomy

MDPI

Article

Effect of Ammonium Sulphate Incorporated with Calcium Nitrate Fertilizers on Nutritional Status, Fruit Set and Yield of Pomegranate Trees cv. Wonderful

Naji Mordi Naji Al-Dosary [1,*], Mahmoud Abdel-Sattar [2,3] and Abdulwahed M. Aboukarima [1,4]

[1] Department of Agricultural Engineering, College of Food and Agriculture Sciences, King Saud University, P.O. Box 2460, Riyadh 11451, Saudi Arabia; abasyouny@ksu.edu.sa
[2] Department of Plant Production, College of Food and Agriculture Sciences, King Saud University, P.O. Box 2460, Riyadh 11451, Saudi Arabia; mmarzouk1@ksu.edu.sa
[3] Pomology Department, Faculty of Agriculture, Alexandria University, Aflaton St., Shatby, Alexandria P.O. Box 21545, Egypt
[4] Agricultural Research Centre, Agricultural Engineering Research Institute, Nadi El-Said St., Dokki, Giza P.O. Box 256, Egypt
* Correspondence: nalsawiyan@ksu.edu.sa; Tel.: +966-114693312

Citation: Al-Dosary, N.M.N.; Abdel-Sattar, M.; Aboukarima, A.M. Effect of Ammonium Sulphate Incorporated with Calcium Nitrate Fertilizers on Nutritional Status, Fruit Set and Yield of Pomegranate Trees cv. Wonderful. *Agronomy* **2022**, *12*, 971. https://doi.org/10.3390/agronomy12040971

Academic Editors: Othmane Merah, Purushothaman Chirakkuzhyil Abhilash, Magdi T. Abdelhamid, Hailin Zhang and Bachar Zebib

Received: 12 March 2022
Accepted: 16 April 2022
Published: 17 April 2022

Abstract: The effect of $(NH_4)_2SO_4$:$Ca(NO_3)_2$ ratios applied by fertigation on nutritional status, fruit set, yield, and marketable yield of pomegranate trees cv. Wonderful was evaluated. The trees were provided with five nutrient solutions with the same total nitrogen level (200 units/ha) but with different $(NH_4)_2SO_4$:$Ca(NO_3)_2$ ratios (100:0, 90:10, 80:20, 70:30, and 60:40). Increasing the $(NH_4)_2SO_4$ ratio from 60 to 100% significantly reduced the nitrogen (N), magnesium (Mg), calcium (Ca), and potassium (K) concentrations while significantly increasing P and Fe concentrations in pomegranate leaves. The highest $(NH_4)_2SO_4$ proportion (100%) induced a reduction in both chlorophyll content and dry matter values in pomegranate leaves. The maximum fruit set (33.65% and 31.40%) and the minimum fruit drop (6.74% and 6.25%) were recorded at the applied ratio of 60% of $(NH_4)_2SO_4$:40% of $Ca(NO_3)_2$. The applied proportion of 70% of $(NH_4)_2SO_4$:30% of $Ca(NO_3)_2$ provided the minimum fruit sunburn (9.54% and 9.74%) and fruit cracking (6.45% and 5.64%), maximum yield (33.62 and 33.00 kg/tree), and marketable yield (27.41 and 27.93 kg/tree) in the 2019 and 2020 seasons, respectively. Our results provide valuable information about the effects of partial replacement of nitrogen fertilizer from $(NH_4)_2SO_4$ with nitrogen fertilizer from $Ca(NO_3)_2$ on the growth characteristics of pomegranate trees cv. Wonderful.

Keywords: fertilization; fruit sunburn; marketable yield; semi-arid climate

1. Introduction

Pomegranate (*Punica granatum* L.; Punicaceae) is an ancient and common fruit grown in arid and semi-arid countries in a wide range of soils [1,2]. In Saudi Arabia, particularly within the Qassim region, which is described as an arid climate [3], the annual production of pomegranate in 2019 was 1,104,784.00 planted total trees in commercial orchards, and 895,597.00 of them produced fruit with a yield of 23,049 ton/year and the sold yield of 23,049.5 ton/year [4].

Pomegranate fruits are widely believed to promote human health because of their high nutritional benefits [1] and high antioxidant content [5]. The cultivar Wonderful is a late-season cultivar with high yield, large fruit, rich red aril, high juice content, and good palatability [6] and is usually consumed fresh or processed into juice, jams, syrup, and sauce [7]. Further, the Wonderful variety is red, big, with a bright appearance, its peel thickness is moderate, arils are small, red and present a good juice yield with high soluble solids content, high acidity (classified as sweet and sour variety), and a dark red color due to the high content of anthocyanins [8]. Moreover, it is one of the most commonly grown in the world [9], specifically because of its large size and the peel and arils have deep red color [10], which fits market requirements. However, the climate in regions where it is cultivated affects its yield [11].

Sustainable agriculture can be applied through the application of chemical fertilizers to help rejuvenate depleted soil fertility and enrich the pool of nutrients available to the plants, as well as overcome soluble nutrients loss during irrigation due to leaching. In addition, the application of chemical fertilizers to the soil significantly enhances pomegranate nutritional status and fruit yield, which could benefit the different plant parts [12]. Furthermore, the application of chemical fertilizers can provide nutrient requirements to enhance crop growth and yield [13] by nutrient availability. Appropriate fertilization is one of the most practical and effective ways of controlling and improving the yield and nutritional quality of crops for human consumption [14] as well as plant fertilization is an important reason for disease resistance [15]. However, the influence of fertilization on pomegranate susceptibility to infestation by Ectomyelois ceratoniae was reported by Torshiz et al. [16], who stated that the highest infestation rate was noted in unfertilized plants. Moreover, for horticultural tree production, the plant's nutritional status affects flowering, vegetative growth, fruit retention, and fruit set and has a noticeable effect on fruit quality and yield [17–20]. All nutrients are regularly supplied to the fruit trees through foliar fertilization [2,21,22], soil or ground fertilization [12,13], and fertigation [23], or delivered by a combination of methods [24]. However, the fertigation of nutrients to pomegranate has been shown to be an effective means of controlling the timing and placement of fertilizers to the root zone of the crop [25].

Nitrogen is the main nutritional requirement in horticultural trees [20]. It is necessary for many physiological and developmental processes such as photosynthesis [26], metabolite biosynthesis [27,28], and flowering [29]. Several horticultural practices could be used to enhance tree productivity [30]: however, suitable and efficient nitrogen application helps yields, profits, and environmental sustainability [31]. Calcium is the most important mineral in ensuring cell structure stability and mechanical strength [32]. The application of calcium to fruits provides protection against physiological deterioration and retardation of maturity and improves fruit quality [33–38]. Calcium is important in regulating the absorption of water by plant roots. Calcium also has an important role in binding the tissues, especially in the middle lamella, and plays an important part in reducing fruit cracking [39–41]. Furthermore, calcium increases cell turgor pressure [42] and stabilizes the cell membrane [43]. Moreover, within many fruit species, calcium disorders prevent fruit from achieving physiological maturity before harvesting and decrease the quality of the fruit [34]. There are many studies about the effects of calcium application on fruit quality, including modes of delivery (soil versus foliar), chemical forms, timing, etc. [36]. The effects of calcium application might also depend on the dose or chemical form, i.e., calcium chloride ($CaCl_2$) or calcium nitrate ($Ca(NO_3)_2$ [44,45]. When the nitrate form is applied, nitrogen might interact with calcium or have an effect by itself [46]. When chloride is applied in high concentrations, it can cause osmotic stress [47], in spite of the plants' osmoregulatory mechanisms [48,49].

Different studies have shown that for pomegranate tree cultivation, fertilization recommendations fluctuate according to region, tree age, climate, and fruit load [31]. Nevertheless, the literature on applying $(NH_4)_2SO_4$:$Ca(NO_3)_2$ as fertilization of pomegranate is scarce. The aim of this study was to assess the effect of ammonium sulfate combined with calcium nitrate on the concentration of some nutrients in the leaves, the fruit set, yield, and marketable yield of pomegranate trees cv. Wonderful.

2. Materials and Methods

2.1. Plant material, Experimental Site, and Fertilizer Treatments

The experiment was performed for two consecutive years, 2019 and 2020, in a commercial pomegranate (*Punica granatum* L. cv. Wonderful) orchard. This orchard is located in the Qassim region, Saudi Arabia. The dominant soil texture in the experimental site was sandy loam with average fractions of 54.1% sand, 15.4% clay, and 30.5% silt, as shown in

Table 1. The average pH, which is the negative logarithm of the hydrogen ion concentration and does not have a unit, was 8.1, and the average electrical conductivity was 1.79 dS/m, as shown in Table 1. The soluble cations and anions of the experimental soil samples are shown in Table 2. The region is arid [3], and the climate characteristics during the 2019 season, with mean annual minimum and maximum temperatures of 18.0 °C and 21.8 °C, as shown in Table 3, were acquired from statistics from the Ministry of Environment, Water and Agriculture. However, in season 2020, the climate characteristics had no more change; thus, only data for season 2019 are presented.

Table 1. Results of measurement of soil properties according to soil layers in the experimental site.

Soil Depth (cm)	Soil Fractions			Soil Texture	pH	Electrical Conductivity (dS/m)	$CaCO_3$ (%)
	Sand (%)	Clay (%)	Silt (%)				
0–30	57.9	14.9	27.2	Sandy loam	8.3	2.47	3.6
30–60	50.3	15.9	33.8	Loam	7.9	1.11	3.9
Average	54.1	15.4	30.5	Sandy loam	8.1	1.79	3.8

Table 2. Results of soluble cations and anions of the experimental soil samples.

Soil Depth (cm)	Soluble Cations (meq/L)				Soluble Anions (meq/L)		
	Na^+	Ca^{2+}	Mg^{2+}	K^+	HCO_3^-	Cl^-	SO_4^{2-}
0–30	2.0	9.6	13.0	0.1	1.3	13.3	10.1
30–60	4.3	3.6	2.4	0.8	2.1	6.0	3.0
Average	3.2	6.6	7.7	0.4	1.7	9.7	6.55

Table 3. Climate characteristics at Qassim region, Saudi Arabia during season of 2019.

Months	Relative Humidity (%)	Minimum Temperature (°C)	Maximum Temperature (°C)	Rainfall (mm)
January	66	9.2	22.3	4.4
February	67	8.9	21.8	17.9
March	48	10.9	26.3	1.7
April	48	16.0	30.8	14.2
May	35	23.0	38.8	1.2
June	21	26.8	44.2	0.0
July	22	26.2	44.3	0.0
August	22	25.9	43.7	0.0
September	24	24.9	42.9	0.0
October	41	21.5	37.1	1.3
November	69	14.1	26.9	27.8
December	63	8.6	32.7	3.9
Average	43.8	18.0	34.3	6.0
Minimum	21	8.6	21.8	0.0
Maximum	69	26.8	44.3	27.8
Total				72.4

In the experimental location, pomegranate trees cv. Wonderful were eight years old, had three trunks and a height of approximately 2.5–3.0 m, and were planted on a 3 × 5 m frame (667 trees/ha). The irrigation was conducted using a drip irrigation system with two lines/tree rows. Trees were fertilized with organic manure at a rate of 10 kg per tree in November of both seasons. All pomegranate trees were serviced using the normal agricultural practices applied in the pomegranate orchard, which follow the recommendations of the Ministry of Agriculture, Saudi Arabia. In the two successive seasons, phosphorus, potassium, and magnesium were added at a rate of 60, 192, and 50 units per hectare, respectively. The types of local fertilizers were sulfopotash (0–0–50.0 + 18 (s)) for potassium sulfate, ammonium sulfate (21.0–0–0–24 S) (ammonisul), diammonium phosphate (18-46-0), and magnesium sulfate heptahydrate (15.9% MgO, 47.8% $MgSO_4$) added with water irrigation (fertigation).

The experiment was performed with a completely randomized block design, using five fertilization treatments and four replications per treatment per year (each replicate was performed in an individual tree). A total of 40 trees were selected as uniform as possible in growth and vigor (i.e., 5 treatments × 4 replicates × 2 trees per replicate = 40 trees). The fertilization treatments were composed of different ratios of $(NH_4)_2SO_4$:$Ca(NO_3)_2$ as follows: 100:0, 90:10, 80:20, 70:30, and 60:40 (Table 4). The two fertilizers were added at different times to prevent aggregation with different amounts, as shown in Table 4. Total nitrogen concentration in each nutrient solution was identical at 200 units/ha, and the total calcium concentration in each nutrient solution differed between 0 and 144 units/ha. The control fertilization treatments were composed of 100% ammonium sulfate $(NH_4)_2SO_4$) and 0% calcium nitrate ($Ca(NO_3)_2$. Fertilizer was prepared by diluting the commercial products with water and supplied in irrigation water separately. Nitrogen was carried out every two days, and, on the third day, calcium fertilization was added. Fertilization was carried out throughout the growing season of pomegranate, except for the dormancy period, which runs from the first of October to the seventh of March. The irrigation operations remained the same throughout the year. Trees were harvested manually in the third week of October in both years when the fruits reached the ripening stage and became fully collared, based on general fruit appearance.

Table 4. Applied amounts of $(NH_4)_2SO_4$ and a partial substitute of $Ca(NO_3)_2$ fertigation.

$(NH_4)_2SO_4$: $Ca(NO_3)_2$ Ratio	$(NH_4)_2SO_4$			$Ca(NO_3)_2$			Total N Unit/ha	Total CaO Unit/ha
	Amount (kg)	No. of Units/ha		Amount (kg)	No. of Units/ha			
		N	CaO		N	CaO		
100:0	952.38	200	0	0	0	0	200	0
90:10	857.14	180	0	133.33	20	36	200	36
80:20	761.90	160	0	266.66	40	72	200	72
70:30	666.67	140	0	400.00	60	108	200	108
60:40	571.43	120	0	533.32	80	144	200	144

2.2. Measurement of Nutritional Status

A total of 50 leaves were collected manually from non-fruiting shoots in the middle part of each tree in the second week of October of each year. The nutritional status of the pomegranate trees was estimated by determining the leaf mineral constituents and total leaf chlorophyll content. The total chlorophyll content of leaves was determined using fresh leaf samples, according to the method described by Yadava [50], using the Chlorophyll Meter SPAD-502 (Konica Minolta Sensing, Inc., Made in Japan). The SPAD-502 measurements were conducted on fresh leaf samples, and the adaxial side of the leaves was always placed toward the emitting window of the instrument, and major veins were avoided.

In order to determine the leaf mineral contents, the leaves were washed with tap water and distilled water and then dried at 65−70 °C for 72 h [51]. A 1 g sample of dried ground leaf material from each tree was then digested with sulfuric acid and hydrogen peroxide, according to Evenhuis and De Waard [52]. The nitrogen (N) content (%) of the digested solution was determined by the micro-Kjeldahl method following the methods described by Chapman and Pratt [53], and total N and P were calorimetrically determined according to the methods described by Evenhuis [54] and Murphy and Riley [55], respectively. Additionally, K (%) was determined by flame photometry, as described by Jackson [56], and the Ca (%), Mg (%), and Fe (ppm) contents were determined using an atomic absorption spectrophotometer (Perkin Elmer 3300) according to Carter [57]. For dry matter (DM), samples of 50 leaves from the middle part of non-fruiting shoots on each tree were collected in the first week of August. Then, the leaves were washed carefully with tap water and distilled water, then dried at 65–70 °C to constant weight and weighed for leaf dry matter (dry biomass) according to Abdel-Sattar and Mohamed [58].

2.2.1. Percentages of Fruit Set and Fruit Drop

At the time of flowering (April in both years), two main branches growing in different directions were selected and tagged on each tree, and the percentages of fruit set and fruit drop were determined as follows:

$$Percentages\ of\ fruit\ set = \frac{Total\ number\ of\ developed\ fruitlets}{Total\ number\ of\ perfect\ flowers} \quad (1)$$

$$Percentages\ of\ fruit\ drop = (1 - \frac{Total\ numberof\ fruit\ set}{Total\ number\ of\ fruit\ at\ harvest}) \quad (2)$$

2.2.2. Percentages of Fruit Sunburn, Fruit Cracking, Tree Yield, and Marketable Yield

Trees were harvested manually in the third week of October in both years when the fruits reached the ripening stage and became fully collared. The numbers of sunburned and cracked fruit were determined for each treatment, and the percentages of fruit sunburn, fruit cracking, and marketable fruit were determined as follows:

$$Percentages\ of\ fruit\ sunburn = \frac{Total\ number\ of\ sunburned\ fruit}{Total\ number\ of\ fruit} \quad (3)$$

$$Percentages\ of\ fruit\ cracking = \frac{Total\ number\ of\ cracked\ fruit}{Total\ number\ of\ fruit} \quad (4)$$

At the time of harvest, five fruits from each tree were collected and weighed, and the average weight was calculated. In addition, the total number of fruits was counted, and the average total yield per tree (kg/tree) was calculated, and number of damaged fruits and marketable fruit were determined as follows:

$$Nmber\ of\ damage\ fruit\ (kg/tree) = Total\ number\ of\ cracked\ fruit + Total\ number\ of\ sunburned\ fruit \quad (5)$$

$$Marketable\ fruit\ (kg/tree) = Total\ number\ of\ fruit - Total\ number\ of\ damage\ fruit \quad (6)$$

2.3. Statistical Analysis

The data were analyzed using analysis of variance (ANOVA), as reported by Gomez and Gomez [59], and the means of the various treatments were compared using the least significant difference (LSD) test. All analyses were performed in SAS version 9.13 [60] using the 5% level of significance.

3. Results and Discussion

3.1. Climatic Data

The values presented in Table 3 show that the total annual rainfall in the Qassim region during 2019 was approximately 72.4 mm. The rainfall peaks in November (27.8 mm), while the lowest rainfall occurs in May (1.2 mm), and no rainfall in June, July, August, and September (Figure 1). The variations in monthly air temperatures are illustrated in Figure 2, and mean monthly minimum and maximum temperatures ranged from 8.6 to 26.8 °C and from 21.8 to 44.3 °C, respectively (Table 3). The variation of monthly air relative humidity is depicted in Figure 3, and ranges were from 21 to 69% in the Qassim region, Saudi Arabia, and the monthly average air humidity was 43.8% (Table 3).

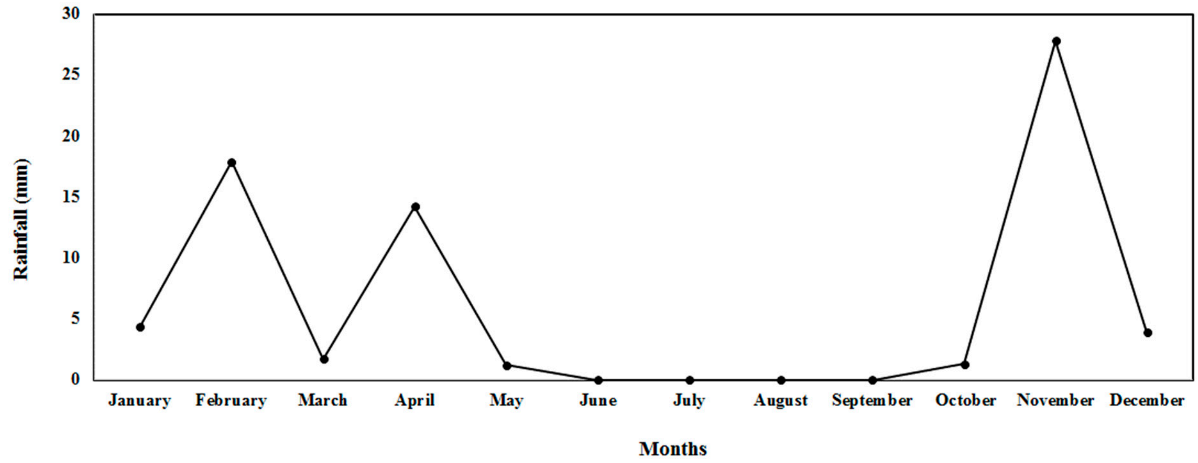


Figure 1. Monthly variations in rainfall in the Qassim region, Saudi Arabia, during the 2019 season.

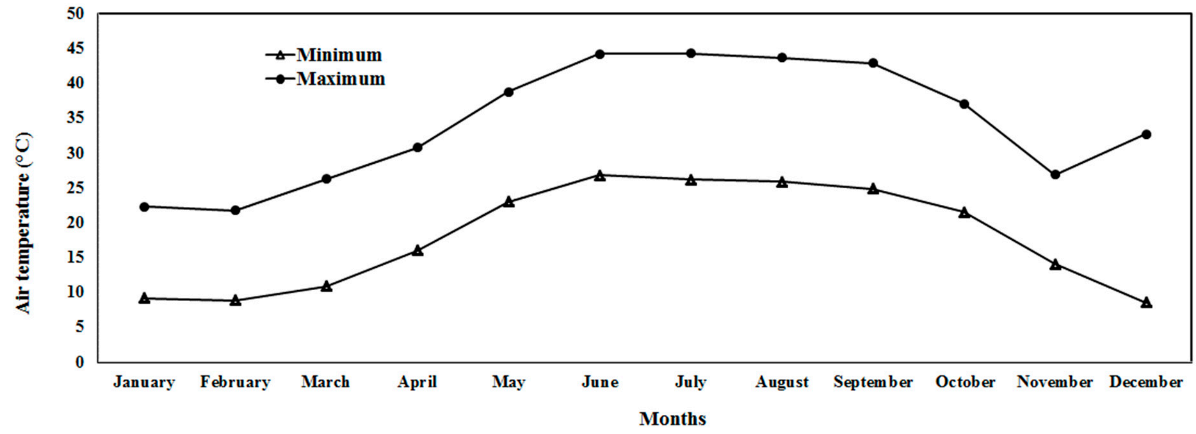


Figure 2. Monthly variations in air temperatures in the Qassim region, Saudi Arabia, during the 2019 season.

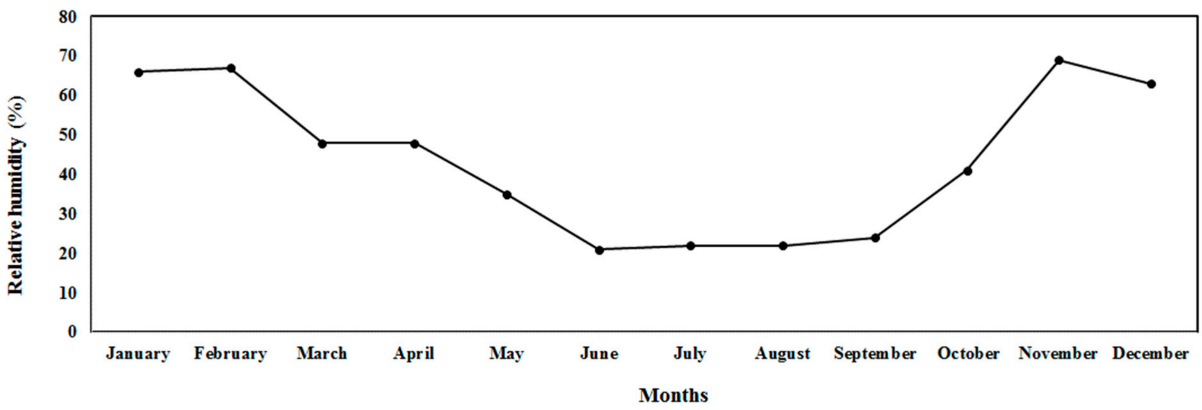


Figure 3. Monthly variations in air relative humidity in the Qassim region, Saudi Arabia, during the 2019 season.

3.2. *Effect of $(NH_4)_2SO_4$:$Ca(NO_3)_2$ Ratios on Nutritional Status in the Leaves*

The leaf nutrient concentrations reported in this study were determined from leaves sampled during the end of the season. Significant treatment effects were detected for leaf N, P, K, Ca, Mg, and Fe concentrations (Table 5; $p < 0.05$) in both seasons. Generally, our results denoted that increasing the $(NH_4)_2SO_4$ ratio from 60 to 100% and decreasing the $Ca(NO_3)_2$ ratio from 40 to 0% significantly reduced the N, K, Ca, and Mg concentrations and significantly increased the P and Fe concentrations in pomegranate leaves. Many studies reported a reduction in plant growth if ammonium was the dominant source of N in the nutrition solution [61]. However, in some cases, using ammonium as part of total N stimulated plant growth [62,63]. In a previous study with pepper [64], the application of NH_4:NO_3 at 25:75 resulted in the highest N, phosphorus, and potassium. In general, the decrease in the accumulation of N, K, Ca, and Mg using high concentrations of $(NH_4)_2SO_4$ in the nutrient solution may be due to nutritional imbalances in plants [65], highlighting the antagonistic effect of $(NH_4)_2SO_4$ in relation to the absorption of these cations. The suppression in the accumulation of N, K, Ca, and Mg is because they are ions that compete for the same ammonium absorption sites [66,67], especially when ammonium shows high concentration in the culture medium, as observed in this study. This ionic imbalance occurs due to changes in the cation's inflow and outflow rates in the plasma membrane, with the transport of these ions to the cell vacuole followed by their secretion into xylem vessels [67]. Furthermore, such a result may be due to ammonium's tendency to reduce the absorption of cations by competition for absorption sites [68], decreasing the concentration of calcium, magnesium, and potassium [69].

Table 5. Main effects of the $(NH_4)_2SO_4$:$Ca(NO_3)_2$ ratio on the N, P, K, Ca, Mg, and Fe in pomegranate leaves cv. Wonderful in the seasons of 2019 and 2020.

Season	$(NH_4)_2SO_4$:$Ca(NO_3)_2$	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Fe (mg/kg)
2019	100:0	1.45 e	0.43 a	1.14 e	0.47 e	0.40 d	127.00 a
	90:10	1.63 d	0.39 b	1.24 d	0.62 d	0.42 cd	124.50 b
	80:20	1.73 c	0.35 c	1.33 c	0.75 c	0.43 c	121.00 c
	70:30	1.80 b	0.34 cd	1.38 b	0.85 b	0.47 b	118.25 d
	60:40	2.08 a	0.33 d	1.42 a	0.94 a	0.54 a	115.50 e
	LSD (5%)	0.04	0.02	0.02	0.03	0.02	2.02
2020	100:0	1.53 e	0.45 a	1.17 e	0.47 e	0.41 d	129.25 a
	90:10	1.64 d	0.38 b	1.26 d	0.64 d	0.45 c	125.50 b
	80:20	1.75 c	0.33 c	1.34 c	0.77 c	0.48	121.00 c
	70:30	1.84 b	0.32 c	1.41 b	0.93 b	0.49 b	117.25 d
	60:40	2.14 a	0.29 d	1.45 a	0.98 a	0.56 a	114.00 e
	LSD (5%)	0.03	0.02	0.03	0.03	0.02	1.93

Mean values within a column for each season that are followed by different letters are significantly different at $p \leq 0.05$.

Nitrogen (N) concentration in leaves was significantly decreased with the increasing proportion of $(NH_4)_2SO_4$. N concentration ranged between 1.45% and 2.08% in the 2019 season and in the 2020 season. These values differ slightly, as shown in Table 5. N concentration had reached a maximum level in the ratio of $(NH_4)_2SO_4$:$Ca(NO_3)_2$ of 60:40. The lower accumulation of N in the leaf was observed in the combination of $(NH_4)_2SO_4$:$Ca(NO_3)_2$ of 100:0. This means the N concentration in plant leaves depends strongly on nitrogen application rate and growth stage, being high in young and well-fertilized plants and low in nitrogen-deficient plants or those close to harvest [70].

Phosphorus (P) concentration in leaves was significantly increased with the increasing proportion of $(NH_4)_2SO_4$. P concentration ranged between 0.33% and 0.43% in the season of 2019 and the 2020 season. Furthermore, these values differ slightly, as shown in Table 5. P concentration had reached the maximum level in the $(NH_4)_2SO_4$:$Ca(NO_3)_2$ ratio of 100:0. However, in the study of Assimakopoulou et al. [14] on the effect of four NH_4:NO_3 ratios in the nutrient solution (0:100; 25:75; 50:50; and 75:25) on the growth and nutrient concentrations of four kales hybrids, the leaf P concentration increased gradually by increasing ammonium concentration in the nutrient solution.

Leaf analysis is the diagnostic nutrient technique for pomegranate orchards soil that had supplied adequate potassium, which was reflected in leaf nutrient content. In the present experiment, potassium (K) concentrations in leaves were significantly decreased with the increasing proportion of $(NH_4)_2SO_4$. In addition, K concentration ranged between 1.14% and 1.42% in the 2019 season and in the 2020 season. These values differ slightly, as shown in Table 5. Regarding the data of leaf analysis of different pomegranate orchards, the leaf K content in the pomegranate orchards exhibited a range of 0.45–2.51% [71], and the potassium content of pomegranate leaves varied from 1.61 to 9.91% with a mean value 4.90% [72]. The inclusion of $(NH_4)_2SO_4$:$Ca(NO_3)_2$ in a ratio of 60:40 in the nutrient solution led to an increase in the K concentration of leaves, as shown by peak values of 1.42% and 1.45% in the year 2019 and year 2020, respectively. Generally, the effect of $(NH_4)_2SO_4$:$Ca(NO_3)_2$ at a ratio of 100:0 on treated plants presented lower K concentrations in leaves at 1.14% and 1.17% in the year 2019 and year 2020, respectively. High $Ca(NO_3)_2$ supply led to an increase in K concentration in leaves. Furthermore, high $(NH_4)_2SO_4$ supply led to decreased K concentration in leaves. A negative effect of $(NH_4)_2SO_4$ ratio on K concentration has been found in pomegranate leaves, i.e., an apparent antagonistic relationship between $(NH_4)_2SO_4$ ratio and K concentration in leaves has been distinguished. This antagonism may be related to the direct competition between uptake of K and NH_4 at the root absorption site.

The concentration of calcium (Ca) in leaves was significantly decreased with the increase in $(NH_4)_2SO_4$. Ca concentration ranged between 0.47% and 0.94% in the 2019 season and in the 2020 season, and these values differ slightly, as shown in Table 5. Ca concentration reaches its peak in the $(NH_4)_2SO_4$:$Ca(NO_3)_2$ ratio of 60:40. However, the lower accumulation of calcium in the leaf was observed in $(NH_4)_2SO_4$:$Ca(NO_3)_2$ ratio of 100:0. Moreover, Tabatabaei et al. [73] claimed that increased the NH_4 ratio in the nutrition solution from 0 to 75% through the application of four nutrient solutions of differing NH_4:NO_3 ratios (0:100, 25:75, 50:50, and 75:25), significantly reduced the calcium concentration under hydroponically grown strawberries conditions. Furthermore, the lower accumulation of calcium in plants due to the increase in ammonium concentration in the nutritive solution probably is related to the fact that calcium absorption occurs only in young roots, specifically in meristematic zones, where endoderm cells are not suberized [66], and the excess of ammonium causes injuries to these root structures, decreasing their development [74,75].

Magnesium (Mg) concentration in leaves was significantly decreased with the increase in $(NH_4)_2SO_4$. This is in agreement with those results reported by Na et al. [76]. In this study, Mg concentrations ranged between 0.40% and 0.54% in leaves (Table 5) in the 2019 season and in the 2020 season. These values differ slightly, as shown in Table 5. The concentration of Mg had reached a maximum level at an $(NH_4)_2SO_4$:$Ca(NO_3)_2$ ratio of 60:40, possibly because the high calcium portion had increased the Mg uptake [36]. In a previous study, Mg concentration in leaves of pomegranate also had reached maximum levels when $Ca(NO_3)_2$ in a concentration of 4% was applied with boric oxide (Boron trioxide, B_2O_3) in a concentration of 3% or 1.5% [18].

The concentration of iron (Fe) in the leaves was significantly increased with the increase in $(NH_4)_2SO_4$. Fe concentrations ranged between 115.5 and 127.0 mg/kg in leaves in the 2019 season and in the 2020 season, and these values differ slightly, as shown in Table 5. Fe concentration reaches its peak with the highest ratio of $(NH_4)_2SO_4$:$Ca(NO_3)_2$ at 100:0. However, the lower accumulation of iron in the pomegranate leaf was observed at an $(NH_4)_2SO_4$:$Ca(NO_3)_2$ ratio of 60:40. The increased iron concentration at the highest $(NH_4)_2SO_4$ ratio can be attributed to a lower dry matter accumulation [77], and this is confirmed by dry matter in this study.

The increasing or decreasing in nutrition elements related to the proportions of $(NH_4)_2SO_4$ or $Ca(NO_3)_2$ in this study was in linear form, as shown in both Figures 4 and 5. However, the results obtained in this study illustrate that regardless of the history of pomegranate cultivation, fertilizer requirements for pomegranate are not well understood, even though there has been significant scientific research on this subject [78–82].

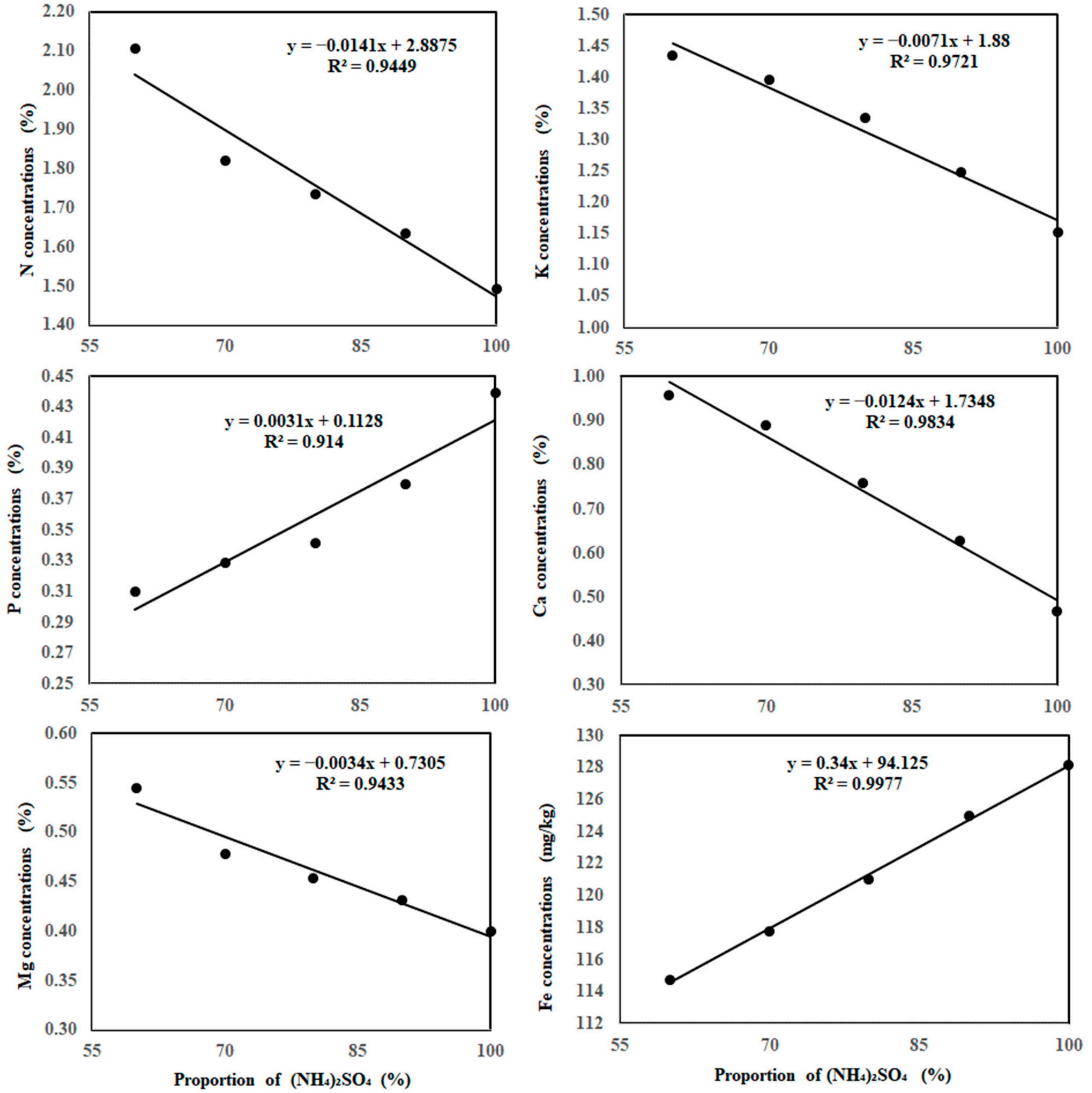


Figure 4. Concentrations of N, P, K, Ca, Mg, and Fe as average of two seasons in pomegranate leaves cv. Wonderful as a function of increasing proportions of $(NH_4)_2SO_4$ in relation to $Ca(NO_3)_2$ at season end.

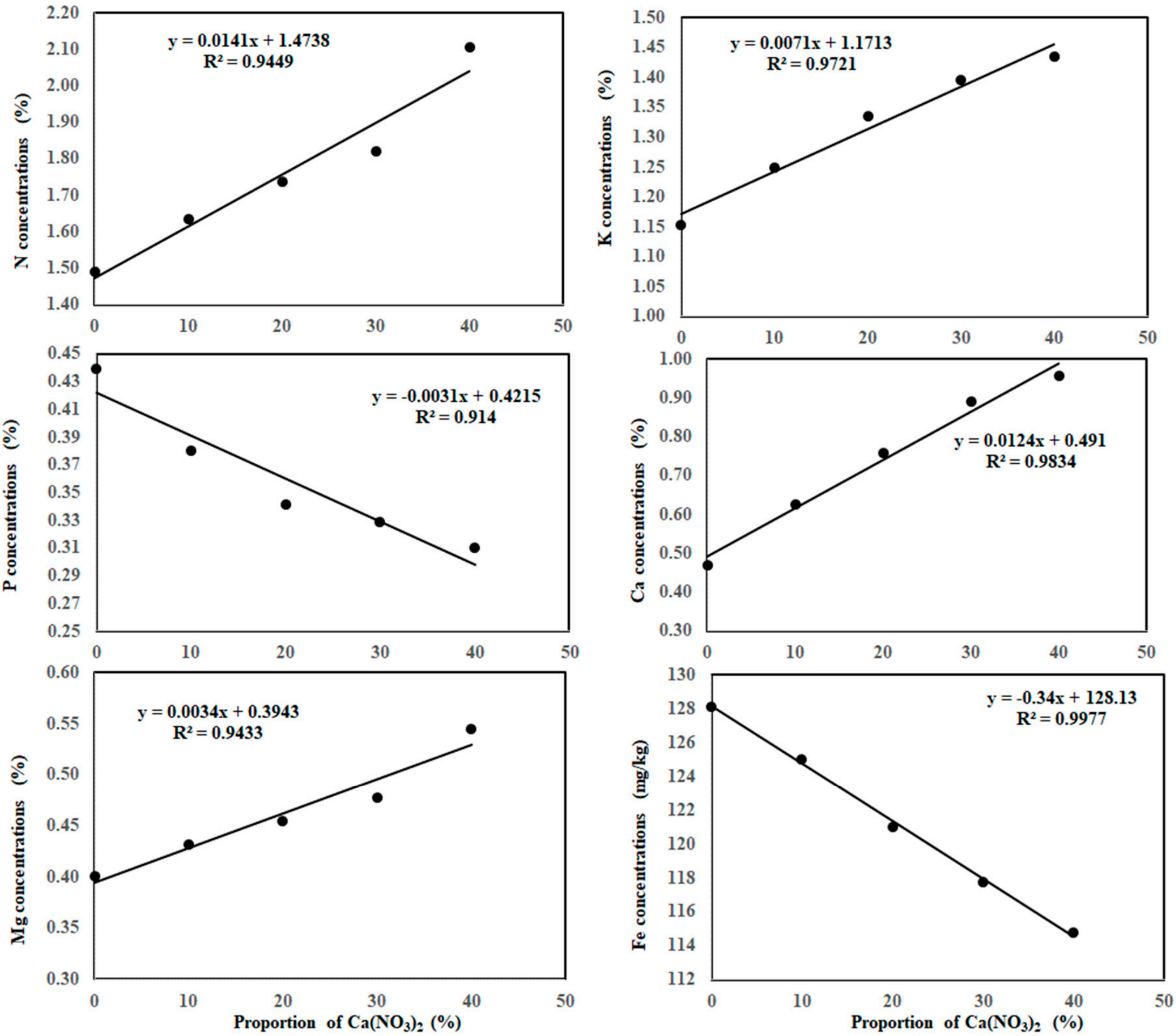


Figure 5. Concentrations of N, P, K, Ca, Mg, and Fe as average of two seasons in pomegranate leaves cv. Wonderful as a function of increasing proportions of $Ca(NO_3)_2$ in relation to $(NH_4)_2SO_4$ at season end.

There was an antagonistic effect between $Ca(NO_3)_2$ and P and Fe nutrients (Figure 5). The leaf nutrient concentrations in this study differed from those reported for pomegranate cv. Wonderful evaluated by Hamouda, Elham, and Zahran [83] (N in the range of 1.9–2.77%, P in the range of 0.48–0.9%, K in the range of 0.63–1.11%, Ca in the range of 3.38–5.38%, Mg in the range of 0.37–0.45%, and Fe in the range of 251–578%). This suggested that pomegranate leaf nutrient concentrations are more sensitive to cultivation site and conditions, fertilization type, fertilization application method, etc.

Despite its long history of cultivation, fertilization requirements for specific nutrients are not entirely understood for pomegranate because scientific literature on this subject is limited [84]. However, there are currently no established leaf tissue nutrient sufficiency reference ranges based on pomegranate-specific research [81]. The aim of the present study is to document the effects of $(NH_4)_2SO_4$:$Ca(NO_3)_2$ ratios on leaf nutrient concentration of pomegranate cv. Wonderful. The data reported herein add to the body of the knowledge regarding leaf macronutrient and micronutrient concentrations detected in pomegranate cv. Wonderful cultivated in the Qassim region, Saudi Arabia. This is significant because this is an area in which growers of pomegranate cv. Wonderful can know the nutrient status of their trees for the purposes of attaining fertilization recommendations for the current and upcoming growing season. Further studies are needed to determine leaf nutrient sufficiency standards for pomegranate, including the 'Wonderful' cultivar.

3.3. Effect of $(NH_4)_2SO_4$:$Ca(NO_3)_2$ Ratios on Chlorophyll Contents in the Leaves

In the current study, the incorporated forms and level of nitrogen fertilizer could significantly influence the chlorophyll content (expressed as SPAD units) of pomegranate leaves cv. Wonderful in both seasons with the value of SPAD ranging from 40.98 to 45.78 in the 2019 season and the range was 41.08 to 46.40 in the 2020 season (Figure 6).

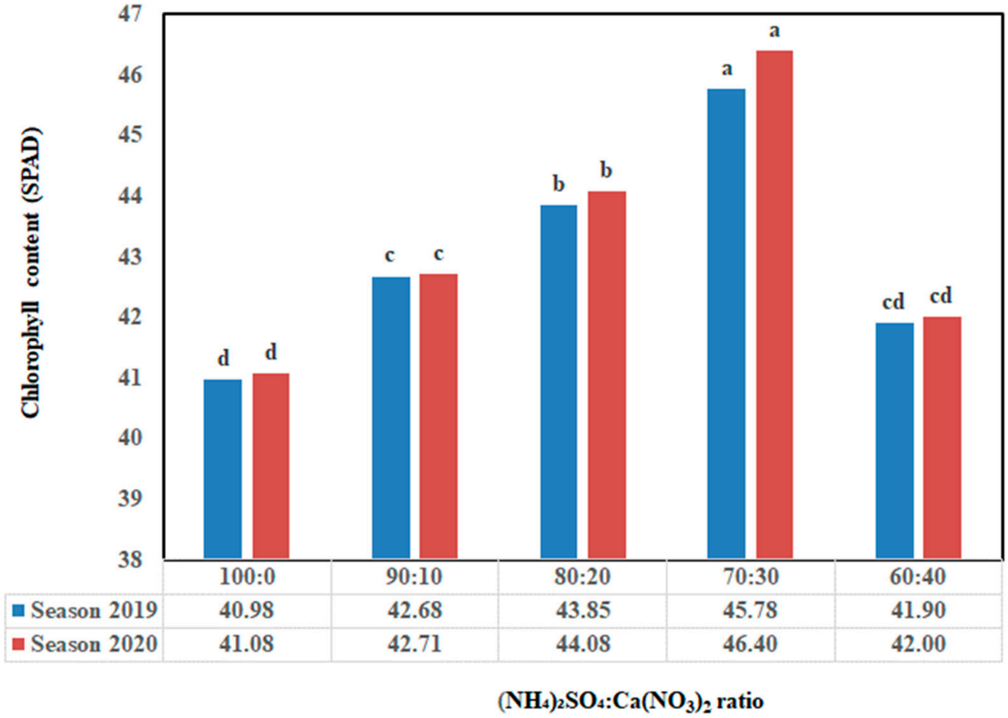


Figure 6. The chlorophyll contents of pomegranate leaves cv. Wonderful in the 2019 and 2020 seasons as influenced by $(NH_4)_2SO_4$:$Ca(NO_3)_2$ ratios (mean values for each season that are followed by different letters are significantly different at $p \leq 0.05$).

Regarding the effects of proportions of $(NH_4)_2SO_4$ in relation to $Ca(NO_3)_2$ at season end, it was observed that chlorophyll content followed a quadratic curve (Figure 7). Furthermore, the same trend was observed with increasing proportions of $Ca(NO_3)_2$ in relation to $(NH_4)_2SO_4$ for chlorophyll content (Figure 8). The presence of NH_3 in the solution increased the absorption of NH_4 [85]. Both high as well as low levels of calcium inhibit the chlorophyll formation in the peanut and linseed plants, as observed by Pal and Laloraya [86]. They suggested that calcium levels seem to affect chlorophyll formation through its control of the uptake of minerals essential for chlorophyll biosynthesis and such general effects as controlling the hydration state of the membranes and the cytoplasm. However, calcium deficit can interrupt the photosynthetic process and reduce carboxylation efficiency, stomatal behavior, photosynthesis capacity, and quantum yield [87].

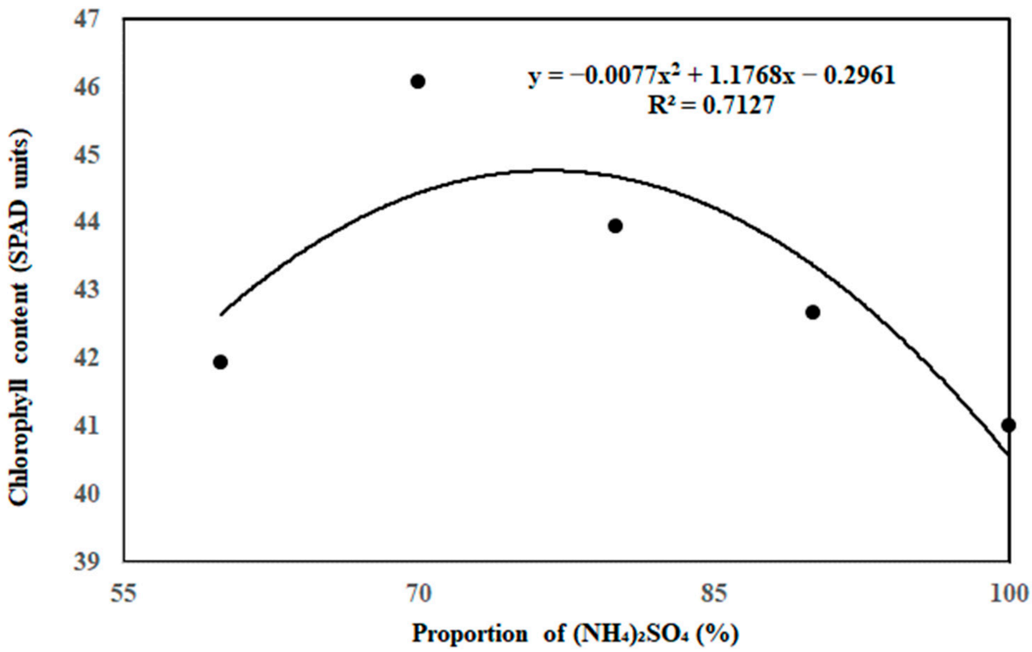


Figure 7. Changes of chlorophyll content (SPAD units) as average of two seasons in pomegranate leaves cv. Wonderful as a function of increasing proportions of $(NH_4)_2SO_4$ in relation to $Ca(NO_3)_2$ at season end.

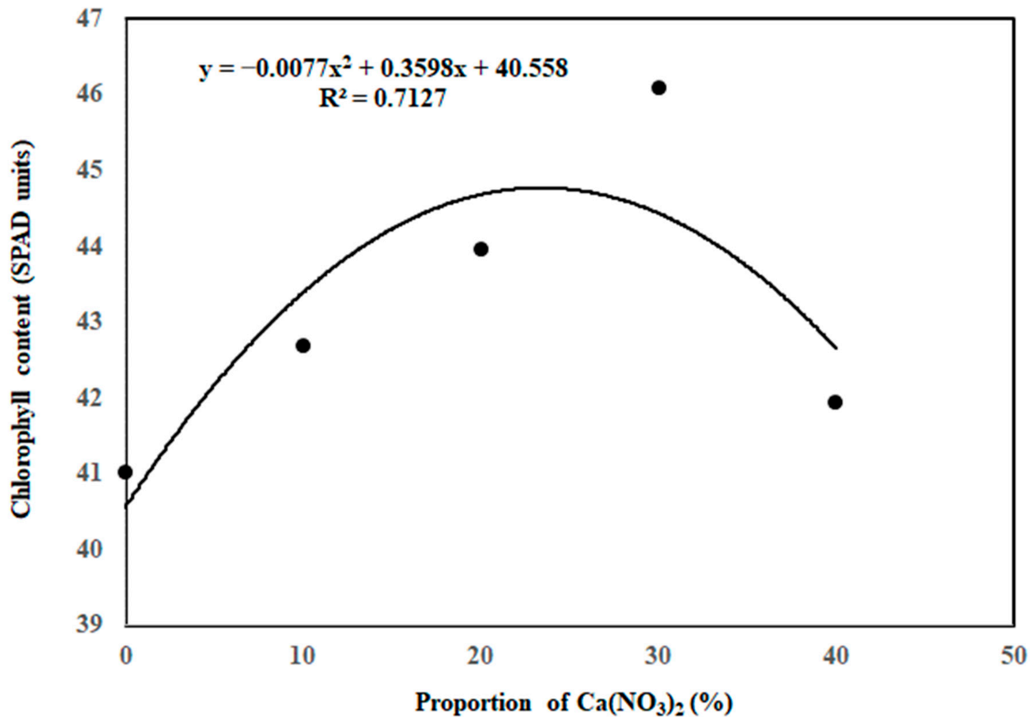


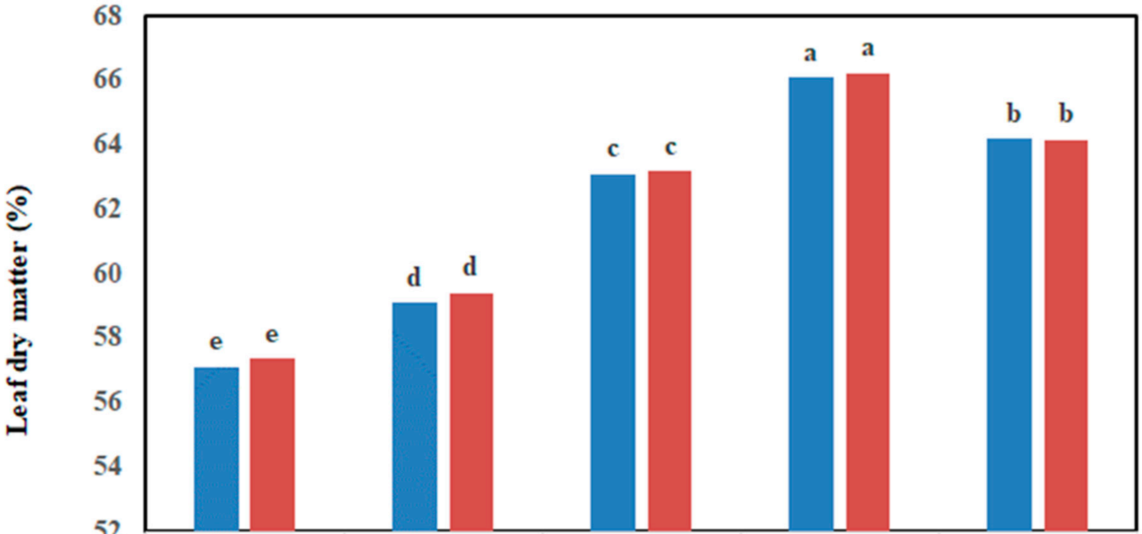
Figure 8. Changes of chlorophyll content (SPAD units) as average of two seasons in pomegranate leaves cv. Wonderful as a function of increasing proportions of $Ca(NO_3)_2$ in relation to $(NH_4)_2SO_4$ at season end.

The maximum value for the chlorophyll content in this experiment occurred with $(NH_4)_2SO_4$:$Ca(NO_3)_2$ at a ratio of 70:30 (45.78 and 46.40 SPAD in the two years, respectively), as shown in Figure 6. The direct relation between the nitrogen supply and chlorophyll content is reported widely [88–92] as it is attributed mainly to the fact that 50 to 70% of a leaf's total nitrogen is a constituent of enzymes associated with the synthesis of chloroplasts and chlorophyll [66].

In our experiment, it is notable that, at the maximum proportion of $(NH_4)_2SO_4$, there was a decrease in chlorophyll content value, indicating damage caused by the excess of this cation [93]. Excess of ammonium changes several metabolic reactions, inducing an increase in the content of reactive oxygen species, O_2 and H_2O_2, which can cause oxidative peroxidation [94], reducing chlorophyll a and b contents [95], and a lower photosynthetic activity [96,97]. As a result of these reactions, leaves showed chlorosis and necrosis symptoms, with a lower green color index [98].

3.4. Effect of $(NH_4)_2SO_4$:$Ca(NO_3)_2$ Ratios on Leaf Dry Matter

The leaf dry matter of pomegranate leaves cv. Wonderful increased as the $(NH_4)_2SO_4$:$Ca(NO_3)_2$ ratio increased from 60:40 to 70:30, but it decreased to the lowest value in the 100:0 treatment (Figure 9). However, Yang et al. [92] observed the shoot dry weight of pakchoi plants increased as the ammonium/nitrate ratio increased from 0:8 mM to 2:6 mM and 4:4 mM and then decreased to the lowest value when the ratio reached 8:0 mM. However, higher biomass (dry weight) was in the 4:4 and 2:6 ammonium/nitrate treatments (2.3 and 2.2-fold compared to 8:0, respectively).



	100:0	90:10	80:20	70:30	60:40
Season 2019	57.11	59.09	63.10	66.10	64.20
Season 2020	57.35	59.41	63.19	66.23	64.17

$(NH_4)_2SO_4$:$Ca(NO_3)_2$ ratio

Figure 9. The leaf dry matter of pomegranate leaves cv. Wonderful in the 2019 and 2020 seasons as influenced by $(NH_4)_2SO_4$:$Ca(NO_3)_2$ ratio (mean values for each season that are followed by different letters are significantly different at $p \leq 0.05$).

The highest leaf dry matter percentage of pomegranate leaves cv. Wonderful occurred when the trees were treated with 70% ammonium: 30% nitrate in both the 2019 (66.10%) and 2020 (66.23%) seasons. Lower dry matter percentages occurred with the treatment of 50% ammonium: 50% nitrate in the first year and 25% ammonium:75% nitrate in the second year. The slight differences between the two years may be due to differences in temperature and/or light conditions. Additionally, Zhang et al. [99] suggested that spinach had the highest biomass as ammonium/nitrate ratios were 25/75 and 50/50. In addition, Tabatabaei, Fatemi, and Fallahi [73] utilized four nutrient solutions of differing NH_4:NO_3 ratios (0:100, 25:75, 50:50, and 75:25) to observe their effect on yield, calcium concentration, and photosynthesis rate in strawberry. They reported that plants fertilized with a solution with 75% NH_4 had lower leaf fresh and dry weights than those with 25%

NH_4. Regarding the effects of proportions of $(NH_4)_2SO_4$ in relation to $Ca(NO_3)_2$ at season end, we observed that leaf dry matter percentages followed a quadratic curve (Figure 10). Dry matter decreased with the increasing proportion of $(NH_4)_2SO_4$, and the lowest dry matter percentage occurred when $(NH_4)_2SO_4$ reached 100%, compared to plants given other treatments containing $Ca(NO_3)_2$. Furthermore, the same quadratic curve trend was observed with increasing proportions of $Ca(NO_3)_2$ in relation to $(NH_4)_2SO_4$ (Figure 11).

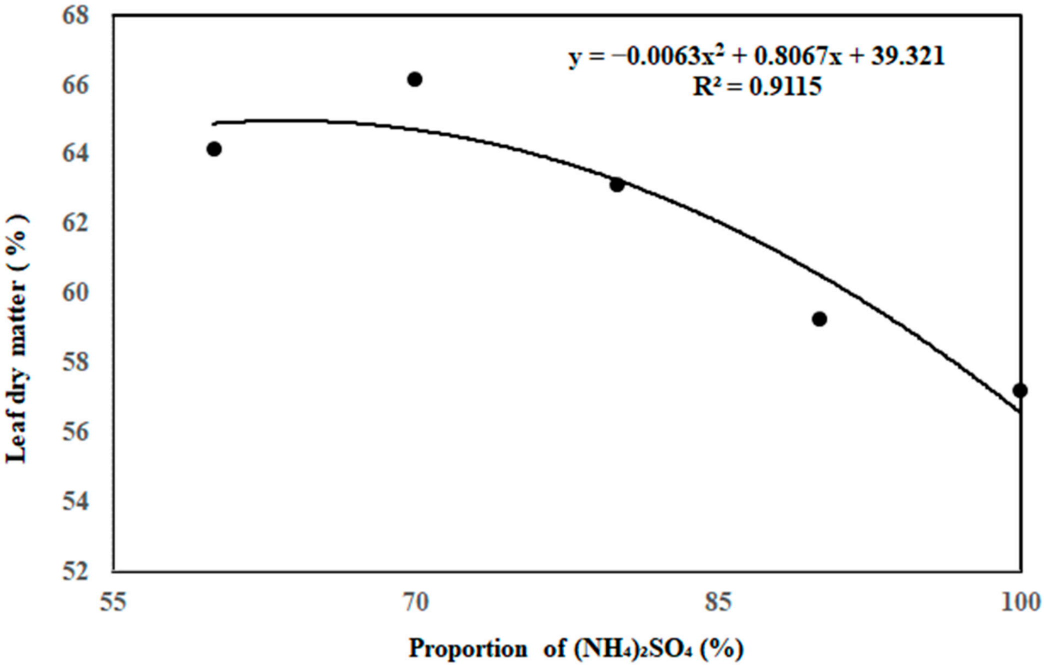


Figure 10. Changes of leaf dry matter as average of two seasons in pomegranate leaves cv. Wonderful as a function of increasing proportions of $(NH_4)_2SO_4$ in relation to $Ca(NO_3)_2$ at season end.

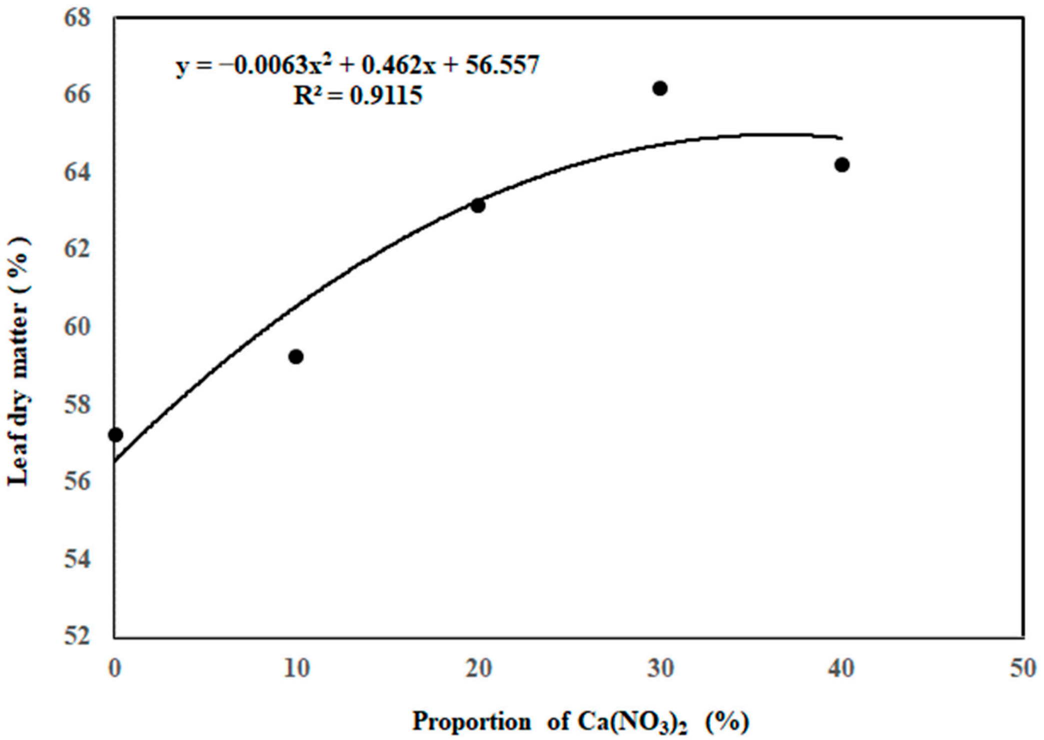


Figure 11. Changes of leaf dry matter as average of two seasons in pomegranate leaves cv. Wonderful as a function of increasing proportions of $Ca(NO_3)_2$ in relation to $(NH_4)_2SO_4$ at season end.

3.5. Changes in Fruit Characteristics with Changes in $(NH_4)_2SO_4$:$Ca(NO_3)_2$ Ratios

3.5.1. Percentage of Fruit Set

The fruit set is determined as the number of set fruits divided by the total number of flowers. Regarding the percentage of fruit set in response to differing $(NH_4)_2SO_4$:$Ca(NO_3)_2$ ratios, it is evident from the data presented in Table 6 that all studied ratios resulted in a significant increase in fruit set percentage compared with the control (100:0) in both experimental seasons. The maximum fruit set (33.65% in 2019 and 31.40% in 2020) was obtained using a combination with a higher concentration of $Ca(NO_3)_2$ and a lower concentration of $(NH_4)_2SO_4$. The most effective combination was a 40% $Ca(NO_3)_2$:60% $(NH_4)_2SO_4$ ratio, i.e., applying total N units and $Ca(NO_3)_2$ units of 200/ha and 144/ha.

Table 6. Effect of $(NH_4)_2SO_4$:$Ca(NO_3)_2$ ratio on percentages of fruit set, fruit drop, fruit cracking, and fruit sunburn of pomegranate trees cv. Wonderful in 2019 and 2020.

Season	$(NH_4)_2SO_4$:$Ca(NO_3)_2$ ratio	Fruit Set (%)	Fruit Drop (%)	Fruit Cracking (%)	Fruit Sunburn (%)
2019	100:0	17.40 e	31.72 a	19.91 a	7.81 c
	90:10	20.23 d	23.44 b	15.49 b	8.09 bc
	80:20	27.16 c	17.53 c	11.38 c	8.98 ba
	70:30	31.85 b	8.05 d	6.45 e	9.54 a
	60:40	33.65 a	6.74 d	9.56 d	10.08 a
	LSD (5%)	0.93	1.75	1.21	1.14
2020	100:0	16.19 e	32.19 a	20.19 a	7.14 d
	90:10	21.13 d	22.10 b	14.19 b	8.39 c
	80:20	25.66 c	16.58 c	10.09 c	9.20 bc
	70:30	29.92 b	7.79 d	5.64 e	9.74 b
	60:40	31.40 a	6.25 d	8.20 d	10.77 a
	LSD (5%)	0.87	2.19	1.68	0.92

Mean values within a column for each treatment and season that do not have a common letter are significantly different at $p \leq 0.05$.

The result indicated that vegetative and reproductive growth of pomegranate trees cv. Wonderful may be manipulated without causing injury to the trees by supplying various ratios $(NH_4)_2SO_4$:$Ca(NO_3)_2$, with a 60:40 mix as the most favorable. Zhu et al. [100] speculated that appropriate NH_4/NO_3 ratios might improve nitrogen absorption and assimilation owing to the suitable pH value and thus promote the growth of flowering Chinese cabbage. Additionally, calcium nitrate can help to reduce the flower and berry dropping rate for grapes [101].

In this study, the range of percentage of fruits set in the two seasons was 17.40 to 33.65% in 2019 and 16.19 to 31.40% in 2020. The positive effects of applying $(NH_4)_2SO_4$:$Ca(NO_3)_2$ at a 60:40 ratio to increase fruit set could be attributed to improved net photosynthesis [102]. However, in a previous study, El-Khawaga, Zaeneldeen, and Yossef [103] reported a percentage of fruit set of pomegranate trees cv. Wonderful grown under saline groundwater conditions with electric conductivity of 1.8 dS/m of 29.54% and 30.35% in the 2009 and 2010 seasons, respectively. When the pomegranate trees cv. Wonderful were grown in a saline environment with electric conductivity of 6 dS/m, fruit set percentages decreased to 25.1% and 24.42% in the 2009 and 2010 seasons, respectively. Additional studies in India [104] showed a maximum fruit set of 25.84%.

The minimum percentages of fruit set were 17.40% and 16.19% in the 2019 and 2020 seasons, respectively, were recorded under the treatment combination of 0% $Ca(NO_3)_2$:100% $(NH_4)_2SO_4$. The interaction effect of nitrogen and calcium significantly affects the percentage of the fruit set of pomegranate trees cv. Wonderful in the present study. Such findings may be attributed to changes in the ratio of bisexual and male flowers according to plant age, position within the plant, and environment [84,105] or due to fertilization treatments. Under agricultural production conditions, the male/female flower ratio in pomegranate can impact crop productivity and yield [106]. The percentage of flowers that are male in pomegranate can be significant and more than 60 to 70%, depending on variety and season [107,108]. Moreover, the changes in the percentage of fruits set of pomegranate trees cv. Wonderful in the present study may be due to the mechanisms by which growth and development and physiology of plants are affected by fertilization interaction. In our study, the percentage of fruit set of pomegranate trees cv. Wonderful reached 33.65% in the 2019 season and 31.41% in the 2020 season. This occurred when we applied total N units and $Ca(NO_3)_2$ units of 200/ha and 144/ha, respectively, indicating prolonged availability of nutrients during the growth, flowering, and fruiting period [109]. Furthermore, the higher fruit set might be attributed to favorable climatic conditions during flowering, which produced more bisexual flowers, and the application of a nutrition ratio that set more fruits [104].

3.5.2. Percentage of Fruit Drop

Regarding the percentages of fruit drop (%) in response to various combinations of $(NH_4)_2SO_4$:$Ca(NO_3)_2$, it is evident from the data presented in Table 6 that all studied treatments resulted in a significant decrease in fruit drop % compared with the control in both experimental seasons. On the other hand, the $(NH_4)_2SO_4$:$Ca(NO_3)_2$ ratio at 60:40 gave the lowest value of fruit drop % in both seasons. The best results concerning fruit drop % were obtained by applying a total N of 200 units/ha plus a total CaO of 144 units/ha (6.74% and 6.25% in the two seasons, respectively). In fact, adding $(NH_4)_2SO_4$:$Ca(NO_3)_2$ would improve the plant's performance and will result in retaining more fruit per tree (Table 6.). However, an unbalanced $(NH_4)_2SO_4$:$Ca(NO_3)_2$ ratio may affect solubility and availability of other nutrients by changing the pH near the roots [110], which affects fruit drop. Furthermore, the NO_3–N/NH_4–N ratio has great significance in constructed wetland systems by affecting plant growth [111]. In an experiment conducted by Torshiz et al. [112], adding biofertilizer to the organic fertilizers also could improve the plant performance and will result in retaining more fruit per tree. In contrast, the highest fruit drop % was recorded by the control treatment of NH_4:NO_3 ratio at 100:0 (31.72% and 32.19% in both seasons). The low fruit drop is probably due to favorable climatic conditions during flowering and fruit development, as shown in [104].

3.5.3. Percentage of Fruit Cracking

Analysis of variance clearly showed a significant effect on the percentage of fruit cracking between $(NH_4)_2SO_4$:$Ca(NO_3)_2$ ratios, as shown in Table 6. The range of percentage of fruit cracking in the two seasons was 6.45 to 19.91% in 2019, and in 2020, it was 5.64 to 20.19%. In general, cracking varies from 10 to 70%, depending upon the prevailing environmental conditions. Various factors are responsible for fruit cracking which include fluctuation in soil moisture regimes, climate, tree nutrition, and cultivars [113]. It is noteworthy that fruit cracking was much higher in the plants treated with an $(NH_4)_2SO_4$:$Ca(NO_3)_2$ ratio of (100:0) than in other treatments in both years (19.91% and 201.195), respectively. Furthermore, the fertilization dose of 30% $Ca(NO_3)_2$:70% $(NH_4)_2SO_4$ ratio, i.e., applying total N units and $Ca(NO_3)_2$ units of 200/ha and 108/ha, respectively, led to decreases in the percentage of fruit cracking in both the 2019 and 2020 seasons compared with control fertilization treatment, again depending on the specific treatment (Table 6). The effect of calcium application on decreasing pomegranate fruit cracking has been attributed to the stabilization of membrane systems and the formation of calcium pectates and cell walls, which increase the rigidity of the middle portion and cell wall of the fruit [114]. Furthermore, calcium is the most important mineral nutrient for the mechanical resistance and stability of the cell structure of the fruit. In calcium deficiency, middle lamellae enlarge, thin out, and then fruit cracking occurs [115]. Davarpanah et al. [116] reported that calcium fertilization reduces fruit cracking in pomegranate.

Nutrient deficiency is an important factor in pomegranate fruit cracking [117]. Therefore, the effects of $(NH_4)_2SO_4$:$Ca(NO_3)_2$ ratio in the reduction of fruit cracking may be somewhat attributed to the positive effects of these fertilizer combinations for providing sufficient nutrients. Results of leaf mineral analysis also support this idea. In a previous study conducted by Hegazi et al. [118], they observed the average percentage of fruit cracking of pomegranate fruits cv. Wonderful growing in Egypt was 5.5% in season 2012, and in season 2013, it was 4.2% for 3-year-old Wonderful Pomegranate trees, spaced at 3×4 m under a drip irrigation system grown in sandy soil and sprayed with water only. Furthermore, Abou El-Wafa [119] observed the average percentage of fruit cracking of pomegranate fruits cv. Wonderful growing in Egypt varied between 5% and 6% in the 2011 and 2012 seasons, respectively, for trees planted at 5×5 m apart in sandy soil under drip irrigation and sprayed with water only. Additionally, Harhash et al. [120] mentioned that the average percentage of fruit cracking of pomegranate fruits cv. Wonderful varies between 9.96% and 13.84% in the 2016 and 2017 seasons, respectively. The different magnitude of the cracking percentage is dependent upon weather, heredity, variety, fruit growth, and cultivational practices [121].

3.5.4. Percentage of Fruit Sunburn

Sunburn status was estimated as the percentage of sunburned fruits on each tree relative to the total number of fruits on the tree just before harvest. The maximum sunburn (10.08 and 10.77%) was observed at a treatment combination of 40% $Ca(NO_3)_2$:60%$(NH_4)_2SO_4$ in both years (Table 6). The minimum sunburn (7.81 and 7.14%) as shown in Table 6 in the first and second seasons, respectively, was obtained by applying a fertilization potion of 0% $Ca(NO_3)_2$:100% $(NH_4)_2SO_4$ ratio, i.e., applying total N of 200 units/ha and $Ca(NO_3)_2$ of 0 units/ha. In a previous study conducted by Bakeer [122], it was claimed that ammonium nitrate fertilizer and calcium chloride foliar spray reduced fruit cracking and sunburn of pomegranate cv. Manfalouty. However, Harhash et al. [120] mentioned that the average percentage of fruit sunburn of pomegranate fruits cv. Wonderful varied between 11.32% and 11.79% in the 2016 and 2017 seasons, respectively. Our observations shown in Table 6 reveal that fertilization with different NH_4:NO_3 ratios (80:20, 70:30, and 60:40) has no significant positive effects on sunburn of fruit in pomegranate, and other factors should be taken into consideration to reduce this disorder. In fact, to combat this adverse character, we need methods to reduce the direct sunlight, as shading and mulching with kaolin are among the horticultural practices that have been considered in recent years [123–125].

3.6. Changes in Fruit Yield and Marketable Yield (kg/tree) upon $(NH_4)_2SO_4$:$Ca(NO_3)_2$ Ratios

3.6.1. Yield

For both years, tree yield showed significant differences among different treatments (Figure 12). As we did not observe any changes in climate conditions within two years, differences between treatments in one year may be related to the effects of fertilizers. Control trees showed the lowest yield in both years. Therefore, combined treatments of $(NH_4)_2SO_4$:$Ca(NO_3)_2$ in ratios from 60 to 80 for $(NH_4)_2SO_4$ and 10 to 40 for $Ca(NO_3)_2$ showed to be more effective than their individual treatments of 100:0. Trees treated with a combination of $(NH_4)_2SO_4$:$Ca(NO_3)_2$ in a ratio of (70:30) had the highest yield of 32.62 kg/tree in 2019 and 33.00 kg/tree in 2020 (Figure 12). Some of the differences in the yield of the two successive years might be due to the maturation of trees [112]. However, Harhash et al. [120] mentioned that the average yield of pomegranate trees cv. Wonderful varies between 10.55 kg/tree and 13.16 kg/tree in the 2016 and 2017 seasons, respectively. Furthermore, Salama, El Gammal, and Shaddad [126] showed that the yield was 16.30 kg/tree in 2017 and 16.00 kg/tree in 2018 for pomegranate trees cv. Wonderful (*Punica granatum*) sprayed with water only, aged seven years old, grown in sandy soil, and spaced 3×5 m apart under a drip irrigation system.

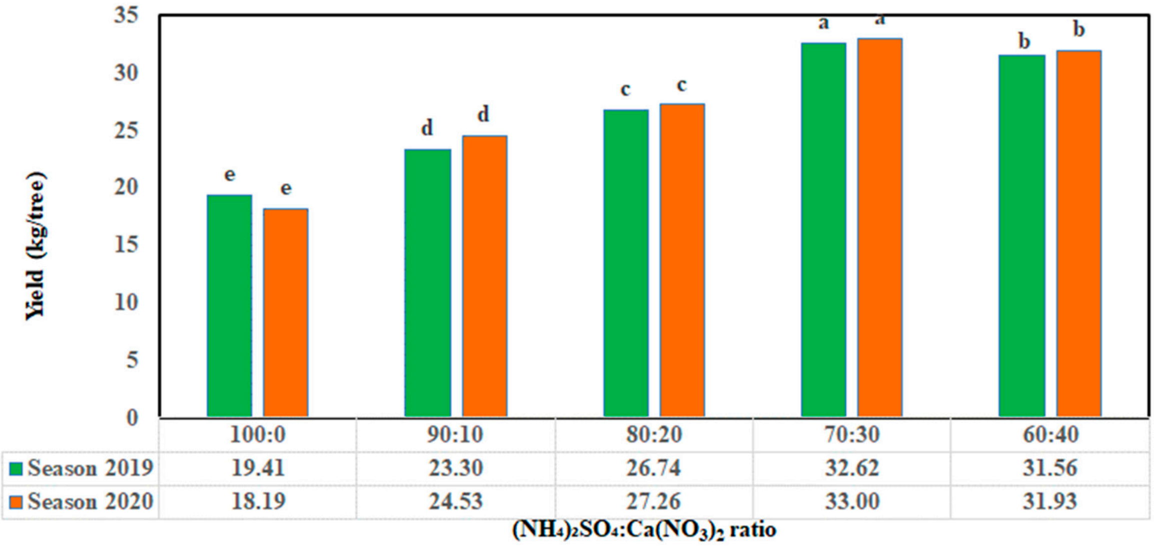


Figure 12. Yield of pomegranate trees cv. Wonderful in the 2019 and 2020 seasons as influenced by $(NH_4)_2SO_4$:$Ca(NO_3)_2$ ratio (mean values for each season that are followed by different letters are significantly different at $p \leq 0.05$).

Our results indicated that the average yield (32.81 kg/tree) of plants treated with applying $(NH_4)_2SO_4$:$Ca(NO_3)_2$ at a ratio of 70:30 was 1.75 fold of control plants (18.79 kg/tree). The improvement effect of $Ca(NO_3)_2$ level on the yield of pomegranate trees may be attributed to calcium fertilization, increasing leaf area, and dry mass production, and these lead to more carbohydrate production [127], reflected in increasing fruit set percentage and consequently improved yield [126]. Results of our work and similar studies, such as [73,128,129], indicate that combined treatments of NH_4:NO_3 had better fruit yield than their individual treatments. As we did not observe any changes in climate conditions within two years, differences between treatments in one year may be related to the effects of fertilizers. Therefore, combined treatments of $(NH_4)_2SO_4$:$Ca(NO_3)_2$ were shown to be more effective than their individual treatments. The effects of proportions of ammonium in relation to nitrate followed with a quadratic form for yield (Figure 13). Furthermore, the same trend was observed with increasing proportions of nitrate in relation to ammonium for yield (Figure 14).

3.6.2. Marketable Yield

By exploring the data presented in Figure 15, it is clear that the marketable yield was significantly affected by combined treatments of $(NH_4)_2SO_4$:$Ca(NO_3)_2$. The marketable yield reached maximum values of 27.41 kg/tree and 27.93 kg/tree in the 2019 and 2020 seasons, respectively. Generally, the highest marketable yield was achieved by adding fertilization at a 30% $Ca(NO_3)_2$:70% $(NH_4)_2SO_4$ ratio, i.e., applying total nitrogen units and calcium units of 200 and 108 per hectare, respectively, in the first and second seasons. Finally, the lowest marketable yield recorded at 14.02 kg/tree and 13.22 kg/tree occurred with the combination of 0% $Ca(NO_3)_2$:100% $(NH_4)_2SO_4$ in both seasons. The finding showed that adding $Ca(NO_3)_2$ in different percentages in integration with $(NH_4)_2SO_4$ gave the highest marketable yield, and this may be attributed to the fact that calcium fertilization can increase fruit set percentage and is consequently reflected in marketable yield [126]. Moreover, the results may be due to the effectiveness of two combinations of $(NH_4)_2SO_4$:$Ca(NO_3)_2$ on plant chemical components and improvement in vegetative characteristics that are related positively to the plant yield [130]. For optimum uptake and growth, each plant species requires a different amount of NO_3–N/NH_4–N ratio [131]. Most of the plants grew well when they were provided with a mixture of NO_3–N and NH_4–N rather than either of these components alone [132,133]. The results of Abou El-Wafa [119] observed the average percentage of marketable yield of Wonderful pomegranate fruits growing in Egypt varies between 65% and 61% in the 2011 and 2012 seasons, respectively, for trees planted 5×5 m apart in sandy soil under a drip irrigation system and sprayed with water only. In the current study, the combined application of nitrogen and calcium fertilizers resulted in a significantly improved percentage of marketable yield of pomegranate trees cv. Wonderful compared with the control treatment, suggesting that 200 N units/ha, 108 Ca units/ha, phosphorus, potassium, and magnesium at a rate of 60, 192, and 50 units per hectare, respectively, are all important in increasing fruit yield, and lacking any one of these nutrients has an adverse effect.

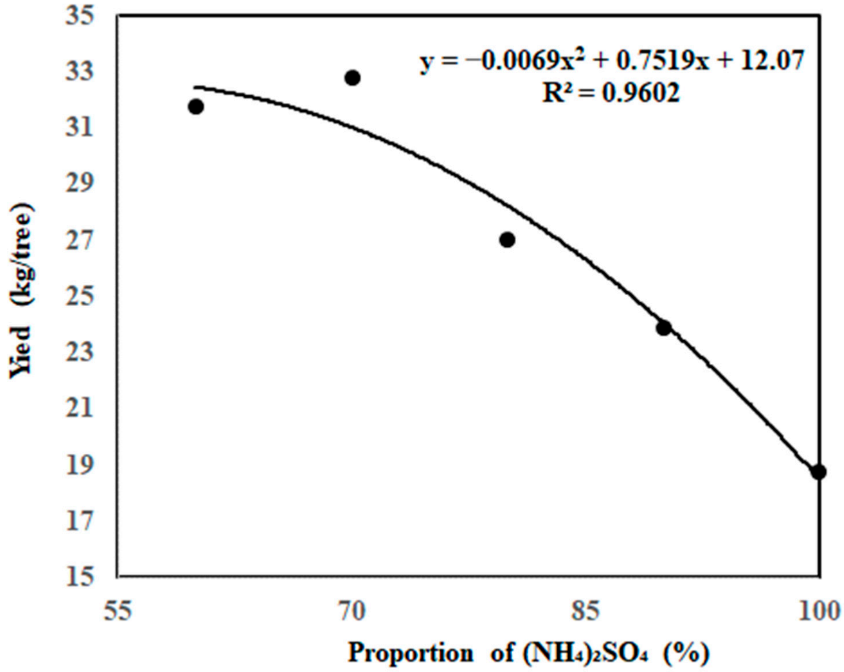


Figure 13. Changes of yield of trees as average of two seasons of pomegranate trees cv. Wonderful as a function of increasing proportions of $(NH_4)_2SO_4$ in relation to $Ca(NO_3)_2$.

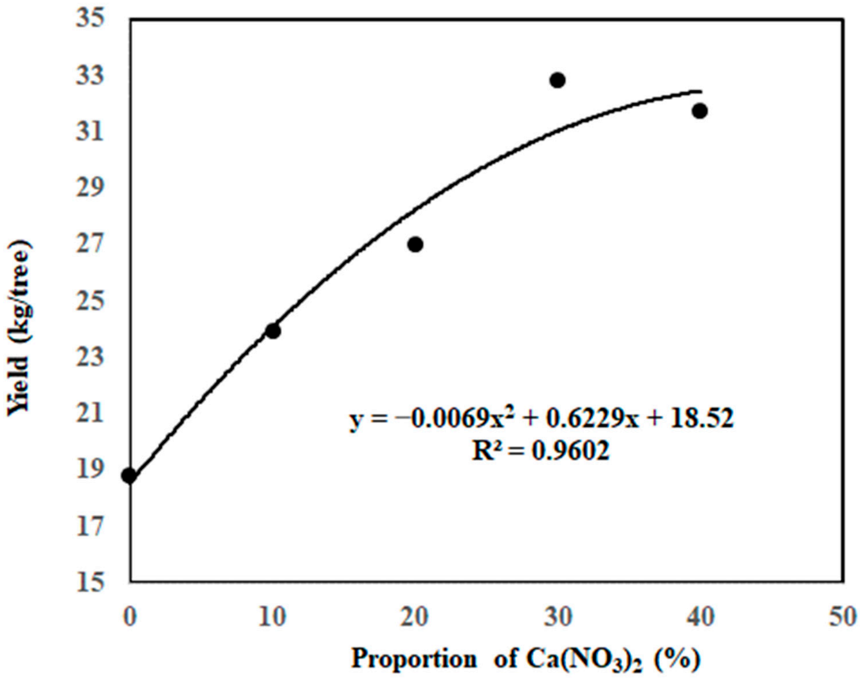


Figure 14. Changes of yield of trees as average of two seasons of pomegranate trees cv. Wonderful as a function of increasing proportions of $Ca(NO_3)_2$ in relation to $(NH_4)_2SO_4$.

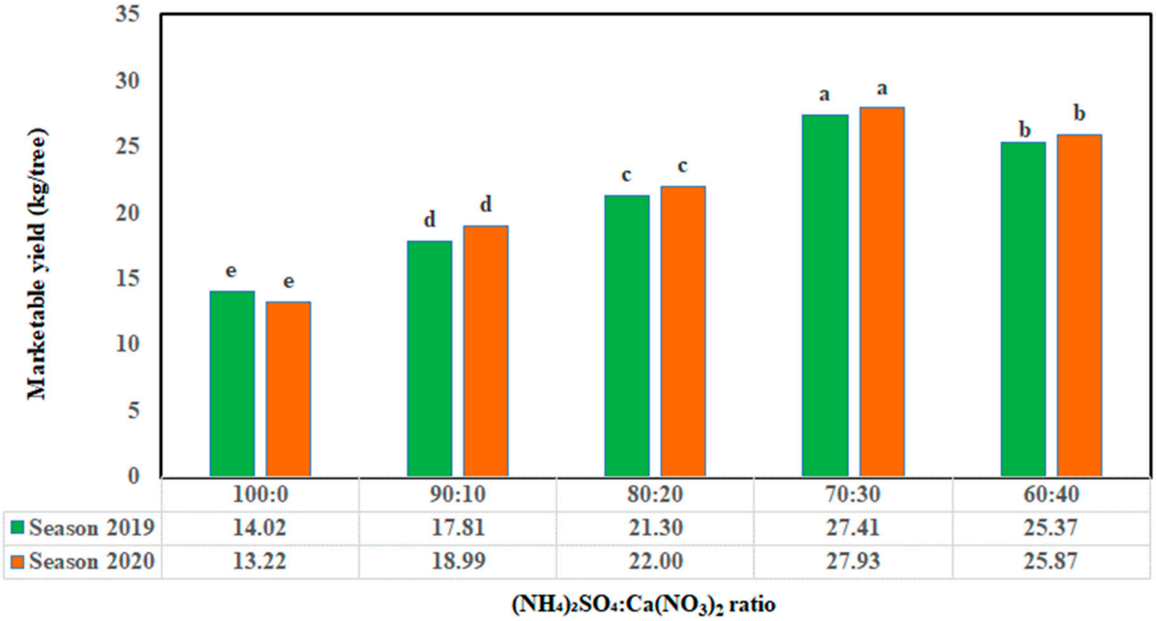


Figure 15. Marketable yield of pomegranate trees cv. Wonderful in the 2019 and 2020 seasons as influenced by $(NH_4)_2SO_4$:$Ca(NO_3)_2$ ratio (mean values for each season that are followed by different letters are significantly different at $p \leq 0.05$).

4. Conclusions

In conclusion, our study has shown that different $(NH_4)_2SO_4$:$Ca(NO_3)_2$ ratios affect the fruit set and yield of pomegranate trees cv. Wonderful. The results have demonstrated that $(NH_4)_2SO_4$:$Ca(NO_3)_2$ at a ratio of 70:30 is the most suitable ratio, as it improves yield and enhances chlorophyll content, and subsequently increases dry matter accumulation. Furthermore, the results revealed that $(NH_4)_2SO_4$:$Ca(NO_3)_2$ at a 60:40 ratio is the most suitable ratio, as it improved the accumulation of nutrient elements (N, K, Ca, and Mg). Moreover, the application of $(NH_4)_2SO_4$:$Ca(NO_3)_2$ at 60:40 enhanced fruit set % and decreased fruit drop %. Furthermore, the application of $(NH_4)_2SO_4$:$Ca(NO_3)_2$ at 70:30 reduced fruit cracking %. Complementary application of the two chemical fertilizers can be a fertilizer management strategy in pomegranate orchards cv. Wonderful, in particular in the Qassim region, Saudi Arabia. Hence, the integrated application of a 30% $Ca(NO_3)_2$:70% $(NH_4)_2SO_4$ ratio may be practiced to achieve proper productivity and quality of pomegranate trees cv. Wonderful. However, 200 units of nitrogen per hectare, 108 units of calcium per hectare, phosphorus, potassium, and magnesium at a rate of 60, 192, and 50 units per hectare, respectively, are all important in increasing fruit yield and quality and lacking any one of these nutrients has an adverse effect. Lastly, any management practices that require a constant demand for nitrogen units and an increase in calcium units are considered promising ways to increase the pomegranate production cv. Wonderful.

Author Contributions: Conceptualization, N.M.N.A.-D. and M.A.-S.; Methodology, N.M.N.A.-D., M.A.-S. and A.M.A.; Data acquisition, M.A.-S., and A.M.A.; Data analysis, N.M.N.A.-D. and M.A.-S.; Investigation, N.M.N.A.-D. and M.A.-S.; Resources, N.M.N.A.-D., M.A.-S., and A.M.A.; Writing-original draft preparation, N.M.N.A.-D. and M.A.-S.; Writing-review and editing, N.M.N.A.-D., M.A.-S. and A.M.A.; Supervision, M.A.-S.; Funding acquisition, N.M.N.A.-D. and M.A.-S. All authors have read and agree to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Acknowledgments: Research team acknowledges respect and gratitude to the Deanship of Scientific Research, Researchers Support Services Unit, Agricultural Research Center, and College of Food and Agriculture Sciences at the King Saud University, Saudi Arabia for their technical support.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Selahvarzi, Y.; Zamani, Z.; Fatahi, R.; Talaei, A.-R. Effect of deficit irrigation on flowering and fruit properties of pomegranate (*Punica granatum* cv. Shahvar). *Agric. Water Manag.* **2017**, *192*, 189–197. [CrossRef]
2. Davarpanah, S.; Tehranifar, A.; Zarei, M.; Aran, M.; Davarynejad, G.; Abadía, J. Early Season Foliar Iron Fertilization Increases Fruit Yield and Quality in Pomegranate. *Agronomy* **2020**, *10*, 832. [CrossRef]
3. Modaihsh, A.S.; Sallam, A.S.; Ghoneim, A.M.; Mahjoub, M.O. Assessing salt-affected degraded soils using remote sensing. Case study: Al-Qassim region, Saudi Arabia. *J. Food Agric. Environ.* **2014**, *12*, 383–388.
4. GASTAT (General Authority for Statistics). Agricultural Production Survey Bulletin. Kingdom of Saudi Arabia, 2019. Available online: https://www.stats.gov.sa (accessed on 1 March 2022).
5. Legua, P.; Melgarejo, P.; Abdelmajid, H.; Martínez, J.J.; Martinez, R.; Ilham, H.; Hafida, H.; Hernández, F. Total Phenols and Antioxidant Capacity in 10 Moroccan Pomegranate Varieties. *J. Food Sci.* **2012**, *77*, C115–C120. [CrossRef] [PubMed]
6. Palou, L.; Carlos, H.; Aguilar, G.; David, G. Combination of postharvest antifungal chemical treatments and controlled atmosphere storage to control gray mold and improve storability of 'Wonderful' pomegranates. *Postharvest Biol. Technol.* **2007**, *43*, 133–142. [CrossRef]
7. Mashavhathakha, K.L. Yield and Quality of Pomegranate on Selected Geographical Areas in Western Cape Province, South Africa. Master's Thesis, University of South Africa, Pretoria, South Africa, 2014. Unpublished.
8. Mansour, N. Promising Impacts of Humic Acid and Some Organic Fertilizers on Yield, Fruit Quality and Leaf Mineral Content of Wonderful Pomegranate (*Punica granatum* L.) Trees. *Egypt. J. Hortic.* **2018**, *45*, 105–119. [CrossRef]
9. Melgarejo-Sánchez, P.; Martínez, J.J.; Hernández, F.; Legua, P.; Martínez, R.; Melgarejo, P. The pomegranate tree in the world: New cultivars and uses. *Acta Hortic.* **2015**, *1089*, 327–332. [CrossRef]
10. Franck, N. The cultivation of Pomegranate cv. Wonderful in Chile. In *Zaragoza: CIHEAM/Universidad Miguel Hernández Options Méditerranéennes: Série A, Proceedings of the II International Symposium on the Pomegranate, Madrid, Spain, 19–21 October 2011*; Melgarejo, P., Valero, D., Eds.; CIHEAM: Paris, France, 2012; Volume 103, pp. 97–99.
11. Mohamed, A.S.; Ali, A.A.M.; Nassar, H.N.; Elsawy, A.M. Performance of Manfalouty and Wonderful pomegranate cultivars under four Egyptian climate regions. *J. Hortic. Sci. Ornam. Plants* **2020**, *12*, 169–181. [CrossRef]
12. Almutairi, K.F.; Abdel-Sattar, M.; Mahdy, A.M.; El-Mahrouky, M.A. Co-application of mineral and organic fertilizers under deficit irrigation improves the fruit quality of the Wonderful pomegranate. *PeerJ* **2021**, *9*, e11328. [CrossRef]
13. Baghdadi, A.; Halim, R.A.; Ghasemzadeh, A.; Ramlan, M.F.; Sakimin, S.Z. Impact of organic and inorganic fertilizers on the yield and quality of silage corn intercropped with soybean. *PeerJ* **2018**, *6*, e5280. [CrossRef]
14. Assimakopoulou, A.; Salmas, I.; Kounavis, N.; Bastas, A.I.; Michopoulou, V.; Michail, E. The Impact of Ammonium to Nitrate Ratio on the Growth and Nutritional Status of Kale. *Not. Bot. Horti Agrobot. Cluj-Napoca* **2019**, *47*, 848–859. [CrossRef]
15. Agrios, N.G. *Plant Pathology*, 5th ed.; Elsevier-Academic Press: Cambridge, MA, USA, 2005.
16. Torshiz, A.O.; Goldansaz, S.H.; Motesharezadeh, B.; Askari, M.A.; Zarei, A. The Influence of Fertilization on Pomegranate Susceptibility to Infestation by Ectomyelois ceratoniae. *Int. J. Fruit Sci.* **2020**, *20*, S1156–S1173. [CrossRef]
17. Kashyap, P.; Pramanick, K.K.; Meena, K.K.; Meena, V. Effect of N and K application on yield and quality of pomegranate cv. Ganesh under rainfed conditions. *Indian J. Hortic.* **2012**, *69*, 322–327.
18. Korkmaz, N.; Aşkın, M. Effects of calcium and boron foliar application on pomegranate (*punica granatum* L.) Fruit quality, yield, and seasonal changes of leaf mineral nutrition. *Acta Hortic.* **2015**, *2015*, 413–422. [CrossRef]
19. Davarpanah, S.; Tehranifar, A.; Davarynejad, G.; Aran, M.; Abadia, J.; Khorassani, R. Effects of Foliar Nano-nitrogen and Urea Fertilizers on the Physical and Chemical Properties of Pomegranate (*Punica granatum* cv. Ardestani) Fruits. *HortScience* **2017**, *52*, 288–294. [CrossRef]
20. Lyu, Y.; Porat, R.; Yermiyahu, U.; Heler, Y.; Holland, D.; Dag, A. Effects of nitrogen fertilization on pomegranate fruit, aril and juice quality. *J. Sci. Food Agric.* **2019**, *100*, 1678–1686. [CrossRef]
21. Abd El-Rhman, I.E.; Shadia, A.A. Effect of foliar sprays of urea and zinc on yield and physico chemical composition on jujube (Ziziphus mauritiana). *Middle East J. Agric. Res.* **2012**, *1*, 52–57.
22. Obaid, E.A.; Al-Hadethi, M.E.A. Effect of foliar application with manganese and zinc on pomegranate growth, yield and fruit quality. *J. Hortic. Sci. Ornam. Plants* **2013**, *5*, 41–45.
23. Neilsen, G.; Neilsen, D.; Peryea, F. Response of Soil and Irrigated Fruit Trees to Fertigation or Broadcast Application of Nitrogen, Phosphorus, and Potassium. *HortTechnology* **1999**, *9*, 393–401. [CrossRef]
24. Amiri, M.E.; Fallahi, E.; Golchin, A. Influence of Foliar and Ground Fertilization on Yield, Fruit Quality, and Soil, Leaf, and Fruit Mineral Nutrients in Apple. *J. Plant Nutr.* **2008**, *31*, 515–525. [CrossRef]

25. Tanari, N.; Ramegowda, S.; Thottan, A.; Girigowda, M. Effect of fertigation of primary nutrients on pomegranate (*Punica granatum* L.) fruit productivity and quality. *Trop. Plant Res.* **2019**, *6*, 424–432. [CrossRef]
26. Bernardi, A.C.D.C.; Carmello, Q.A.D.C.; De Carvalho, S.A.; Machado, E.C.; Medina, C.L.; Gomes, M.D.M.D.A.; Lima, D.M. Nitrogen, Phosphorus and Potassium Fertilization Interactions on the Photosynthesis of Containerized Citrus Nursery Trees. *J. Plant Nutr.* **2015**, *38*, 1902–1912. [CrossRef]
27. Bonner, J.; Varner, J.E. *Plant Biochemistry*; Academic Press: New York, NY, USA, 2012.
28. Lea, P.J.; Morot-Gaudry, J.F. *Plant Nitrogen*; Springer Science & Business Media and INRA: Paris, France, 2013.
29. Lin, Y.-L.; Tsay, Y.-F. Influence of differing nitrate and nitrogen availability on flowering control in Arabidopsis. *J. Exp. Bot.* **2017**, *68*, 2603–2609. [CrossRef] [PubMed]
30. El-Masry, S.E.M. Physiological Studies to Control Pomegranate Fruit Disorders. Master's Thesis, Faculty of Agriculture, Assiut University, Assiut, Egypt, 1995. Unpublished.
31. Lazare, S.; Lyu, Y.; Yermiyahu, U.; Heler, Y.; Ben-Gal, A.; Holland, D.; Dag, A. Optimizing Nitrogen Application for Growth and Productivity of Pomegranates. *Agronomy* **2020**, *10*, 366. [CrossRef]
32. Elmer, P.; Spiers, M.; Wood, P. Effects of pre-harvest foliar calcium sprays on fruit calcium levels and brown rot of peaches. *Crop Prot.* **2007**, *26*, 11–18. [CrossRef]
33. Faust, M. *Physiology of Temperate Zone Fruit Trees*; Wiley-Interscience: Hoboken, NJ, USA, 1989.
34. Hernández-Muñoz, P.; Almenar, E.; Ocio, M.J.; Gavara, R. Effect of calcium dips and chitosan coatings on postharvest life of strawberries (*Fragaria* × *ananassa*). *Postharvest Biol. Technol.* **2006**, *39*, 247–253. [CrossRef]
35. Lanauskas, J.; Kvikliene, N. Effect of calcium foliar application on some fruit quality characteristics of Sinap Orlovskij apple. *Agron. Res.* **2006**, *4*, 31–36.
36. Bonomelli, C.; Ruiz, R. Effects of foliar and soil calcium application on yield and quality of table grape cv. 'thompson seedless'. *J. Plant Nutr.* **2010**, *33*, 299–314. [CrossRef]
37. Chen, F.; Liu, H.; Yang, B.; Hou, H.; Yao, Y.; Zhang, S.; Bu, G.; Deng, Y. Quality attributes and cell wall properties of Strawberries (*Fragaria* × *Ananasa* Duch.) under calcium chloride treatment. *Food Chem.* **2011**, *1260*, 450–459. [CrossRef]
38. Irfan, P.; Vanjakshi, V.; Prakash, M.K.; Ravi, R.; Kudachikar, V. Calcium chloride extends the keeping quality of fig fruit (*Ficus carica* L.) during storage and shelf-life. *Postharvest Biol. Technol.* **2013**, *82*, 70–75. [CrossRef]
39. Lal, S.; Ahmed, N.; Mir, J.I. Effect of different chemicals on fruit cracking in pomegranate under Karewa condition of Kashmir valley. *Indian J. Plant Physiol.* **2011**, *16*, 326–330.
40. EL-Akkad, M.M.; EL-Zaharaa, F.; Guda, M.A.; Ibrahim, R.A. Effect of GA3, calcium chloride and vaporguard spraying on yield and fruit quality of Manfalouty pomegranate trees. *Assiut J. Agric. Sci.* **2016**, *47*, 181–195.
41. Masoud, A.A.B.; Radwan, E.M.A.; Abou-Zaid, E.A.A. Effect of some micronutrients, silicon and GA3 spraying on yield and fruit quality of pomegranate. *Assiut J. Agric. Sci.* **2018**, *49*, 97–106.
42. Mastrangelo, M.M.; Rojas, A.M.; Castro, M.A.; Gerschenson, L.N.; Alzamora, S.M. Texture and structure of glucose-infused melon. *J. Sci. Food Agric.* **2000**, *80*, 769–776. [CrossRef]
43. Picchioni, G.; Weinbaum, S.; Brown, P. Retention and the Kinetics of Uptake and Export of Foliage-applied, Labeled Boron by Apple, Pear, Prune, and Sweet Cherry Leaves. *J. Am. Soc. Hortic. Sci.* **1995**, *120*, 28–35. [CrossRef]
44. Lanauskas, J.; Uselis, N.; Valiuskaite, A.; Viskelis, P. Effect of foliar and soil applied fertilizers on strawberry healthiness, yield and berry quality. *Agron. Res.* **2006**, *4*, 247–250.
45. Badawy, I.F.M.; Abou-Zaid, E.A.A.; Hussein, E.M.E. Cracking and fruit quality of Manfalouty pomegranate as affected by pre-harvest of Chitosan, Calcium chloride and Gibbrellic acid spraying. *Middle East J. Agric. Res.* **2019**, *8*, 873–882.
46. Swietlik, D. The interaction between $CaCl_2$ and ammonium-nitrogen on growth, N uptake and translocation in apple and sour orange. *Acta Hortic.* **2006**, *721*, 159–164. [CrossRef]
47. Lea-Cox, J.; Syvertsen, J. Salinity reduces water use and nitrate use efficiency of citrus. *Ann. Bot.* **1993**, *72*, 47–54. [CrossRef]
48. Cushman, J. Osmoregulation in plants: Implications for agriculture. *Am. Zool.* **2001**, *41*, 758–769. [CrossRef]
49. Sima, N.A.K.; Khalvati, M.A.; Hu, Y. Response of Plant Growth to Different Salinization in Root Zone. *J. Plant Nutr.* **2008**, *31*, 411–425. [CrossRef]
50. Yadava, U.L. A rapid and non-destructive method to determine chlorophyll in intact leaves. *HortScience* **1986**, *21*, 1449–1450.
51. Reisenauer, H.M. *Soil and Plant Tissue Testing in California*; Bulletin 1879; University of California Agriculture and Natural Resources (UC ANR): Singapore, 1976.
52. Evenhuis, B.; De Waard, P.W. Principles and practices in plant analysis. *FAO Soils Bull.* **1980**, *38*, 152–163.
53. Chapman, H.D.; Pratt, P.F. Methods of analysis for soils, plants and waters. *Soil Sci.* **1962**, *93*, 68. [CrossRef]
54. Evenhuis, B. *Nitrogen Determination*; Department of Agricultural Research Royal Tropical Inst.: Amsterdam, The Netherlands, 1976.
55. Murphy, J.A.; Riley, J.P. A modified single solution method for the determination of phosphate in natural waters. *Anal. Chim. Acta* **1962**, *27*, 31–36. [CrossRef]
56. Jackson, N.L. *Soil Chemical Analysis*; Prentice-Hall Inc.: Englewood Cliffs, NS, USA, 1967.
57. Carter, M.R. (Ed.) *Soil Sampling and Methods of Analysis*; Canadian Society of Soil Science, Lewis Publishers: London, UK; Tokyo, Japan, 1993.
58. Abdel-Sattar, M.; Mohamed, Y.I. Pomegranate Trees Productivity in Response to Three Levels of Irrigation and Slow or Fast Nitrogen Release Fertilizer as Well as their Combinations. *J. Plant Prod.* **2017**, *8*, 813–820. [CrossRef]

59. Gomez, K.A.; Gomez, A.A. *Statistical Procedures for Agricultural Research*, 2nd ed.; John Wiley & Sons: New York, NY, USA, 1984.
60. SAS Statistical Package. *The SAS System for Windows*; Version 9.13; SAS Institute Inc.: Cary, NC, USA, 2008.
61. Urlić, B.; Špika, M.J.; Becker, C.; Kläring, H.-P.; Krumbein, A.; Ban, S.G.; Schwarz, D. Effect of NO_3 and NH_4 concentrations in nutrient solution on yield and nitrate concentration in seasonally grown leaf lettuce. *Acta Agric. Scand. Sect. B—Soil Plant Sci.* **2017**, *67*, 748–757. [CrossRef]
62. Zhang, J.; Lv, J.; Dawuda, M.M.; Xie, J.; Yu, J.; Li, J.; Zhang, X.; Tang, C.; Wang, C.; Gan, Y. Appropriate Ammonium-Nitrate Ratio Improves Nutrient Accumulation and Fruit Quality in Pepper (*Capsicum annuum* L.). *Agronomy* **2019**, *9*, 683. [CrossRef]
63. Marschner, H. *Marschner's Mineral Nutrition of Higher Plants*, 3rd ed.; Academic Press: Cambridge, MA, USA, 2012.
64. Guo, S.; Zhou, Y.; Shen, Q.; Zhang, F. Effect of Ammonium and Nitrate Nutrition On Some Physiological Processes in Higher Plants—Growth, Photosynthesis, Photorespiration, and Water Relations. *Plant Biol.* **2007**, *9*, 21–29. [CrossRef]
65. Li, S.-X.; Wang, Z.-H.; Stewart, B. Responses of Crop Plants to Ammonium and Nitrate N. *Adv. Agron.* **2013**, *118*, 205–397. [CrossRef]
66. Marschner, P.; Rengel, Z. Nutrient Availability in Soils. In *Marschner's Mineral Nutrition of Higher Plants*, 3rd ed.; Marshner, P., Ed.; Academic Press: San Diego, CA, USA, 2012; pp. 315–330.
67. Mendoza-Villarreal, R.; Valdez-Aguilar, L.A.; Sandoval-Rangel, A.; Robledo-Torres, V.; Benavides-Mendoza, A. Tolerance of Lisianthus to High Ammonium Levels in Rockwool Culture. *J. Plant Nutr.* **2014**, *38*, 73–82. [CrossRef]
68. Assunção, N.S.; Fernandes, E.S.; Aquino, L.A.; Fernandes, F.L.; Silva, N.O. Nutritional quality of tomatoes as a function of nitrogen sources and doses. *Afr. J. Agric. Res.* **2018**, *13*, 996–1000.
69. Serna, M.D.; Borrás, R.; Legaz, F.; Primo-Millo, E. The influence of nitrogen concentration and ammonium/nitrate ratio on N-uptake, mineral composition and yield of citrus. *Plant Soil* **1992**, *147*, 13–23. [CrossRef]
70. Geisseler, D.; Ortiz, R.S.; Diaz, J. Nitrogen nutrition and fertilization of onions (*Allium cepa* L—A literature review. *Sci. Hortic.* **2021**, *291*, 110591. [CrossRef]
71. Kaur, M.; Sharma, S.; Verma, M.L. Leaf nutrient status of pomegranate (*Punica granatum*) orchards in district Kullu of Himachal Pradesh. *Int. J. Chem. Stud.* **2018**, *6*, 1401–1404.
72. Kolekar, P.B.; Bhagyaresha, G. Studies on macro and micro nutrient status in leaf tissue of pomegranate (*Punica granatum*) orchards of Latur district. *Int. J. Curr. Microbiol. Appl. Sci.* **2018**, *6*, 112–119.
73. Tabatabaei, S.J.; Fatemi, L.S.; Fallahi, E. Effect of Ammonium: Nitrate Ratio on Yield, Calcium Concentration, and Photosynthesis Rate in Strawberry. *J. Plant Nutr.* **2006**, *29*, 1273–1285. [CrossRef]
74. Britto, D.T.; Kronzucker, H. NH4+ toxicity in higher plants: A critical review. *J. Plant Physiol.* **2002**, *159*, 567–584. [CrossRef]
75. Liu, Y.; Lai, N.; Gao, K.; Chen, F.; Yuan, L.; Mi, G. Ammonium Inhibits Primary Root Growth by Reducing the Length of Meristem and Elongation Zone and Decreasing Elemental Expansion Rate in the Root Apex in Arabidopsis thaliana. *PLoS ONE* **2013**, *8*, e61031. [CrossRef]
76. Na, L.; Li, Z.; Xiangxiang, M.; Ara, N.; Jinghua, Y.; Mingfang, Z. Effect of Nitrate/Ammonium Ratios on Growth, Root Morphology and Nutrient Elements Uptake of Watermelon (*Citrullus lanatus*) Seedlings. *J. Plant Nutr.* **2014**, *37*, 1859–1872. [CrossRef]
77. Borrero, C.; Trillas, M.; Delgado, A.; Avilés, M. Effect of ammonium/nitrate ratio in nutrient solution on control of Fusarium wilt of tomato by Trichoderma asperellum T34. *Plant Pathol.* **2012**, *61*, 132–139. [CrossRef]
78. Khorsandi, F.; Yazdi, F.A.; Vazifehshenas, M.R. Foliar zinc fertilization improves marketable fruit yield and quality attributes of pomegranate. *Int. J. Agric. Biol.* **2009**, *11*, 766–770.
79. Hasani, M.; Zamani, Z.; Savaghebi, G.; Fatahi, R. Effects of zinc and manganese as foliar spray on pomegranate yield, fruit quality and leaf minerals. *J. Soil Sci. Plant Nutr.* **2012**, *12*, 471–480. [CrossRef]
80. Davarpanah, S.; Tehranifar, A.; Davarynejad, G.; Abadía, J.; Khorasani, R. Effects of foliar applications of zinc and boron nano-fertilizers on pomegranate (*Punica granatum* cv. Ardestani) fruit yield and quality. *Sci. Hortic.* **2016**, *210*, 57–64. [CrossRef]
81. Chater, J.M.; Garner, L.C. Foliar nutrient applications to 'Wonderful' pomegranate (*Punica granatum* L.). II. Effects on leaf nutrient status and fruit split, yield and size. *Sci. Hortic.* **2018**, *242*, 207–213. [CrossRef]
82. Ibrahim, R.; El-Mahdy, M.; Taha, M.; Shaaban, M. Improving the quantitative and qualitative of Manfalouty pomegranate cultivar. *SVU-Int. J. Agric. Sci.* **2021**, *3*, 31–52. [CrossRef]
83. Hamouda, H.A.; Elham, Z.A.M.; Zahran, N.G. Nutritional status and improving fruit quality by potassium, magnesium and manganese foliar application in pomegranate shrubs. *Int. J. ChemTech Res.* **2015**, *8*, 858–867.
84. Holland, D.; Hatib, K.; Bar-Ya'Akov, I. Pomegranate: Botany, Horticulture, Breeding. In *Horticultural Review*; Janick, J., Ed.; John Wiley & Sons: Hoboken, NJ, USA, 2009; pp. 127–191. [CrossRef]
85. Ruamrungsri, S.; Khuankaew, T.; Ohyama, T.; Sato, T. Nitrogen Sources and Its Uptake in Dendrobium Orchid by 15n Tracer Study. *Acta Hortic.* **2014**, *1025*, 207–211. [CrossRef]
86. Pal, R.; Laloraya, M. Effect of Calcium Levels on Chlorophyll Synthesis in Peanut and Linseed Plants. *Biochem. Und Physiol. Der Pflanz.* **1972**, *163*, 443–449. [CrossRef]
87. Eticha, D.; Kwast, A.; Chiachia, T.R.D.S.; Horowitz, N.; Stützel, H. Calcium Nutrition of Orange and Its Impact on Growth, Nutrient Uptake and Leaf Cell Wall. *Citrus Res. Technol.* **2017**, *38*, 62–70. [CrossRef]
88. Yang, H.; Yang, J.; Lv, Y.; He, J. SPAD Values and Nitrogen Nutrition Index for the Evaluation of Rice Nitrogen Status. *Plant Prod. Sci.* **2014**, *17*, 81–92. [CrossRef]

89. Bonasia, A.; Conversa, G.; Gonnella, M.; Serio, F.; Santamaria, P. Effects of ammonium and nitrate nutrition on yield and quality in endive. *J. Hortic. Sci. Biotechnol.* **2008**, *83*, 64–70. [CrossRef]
90. De Oliveira, M.O.A.; Alves, S.M.F.; Freitas, E.F.M.; Faria, H.F.L.; Lisboa, C.F. Relative chlorophyll index on doses of nitrogen fertilization for cherry tomato culture. *Afr. J. Agric. Res.* **2017**, *12*, 2946–2953. [CrossRef]
91. Barickman, T.C.; Kopsell, D. Nitrogen form and ratio impact Swiss chard (*Beta vulgaris* subsp. cicla) shoot tissue carotenoid and chlorophyll concentrations. *Sci. Hortic.* **2016**, *204*, 99–105. [CrossRef]
92. Yang, J.; Zhu, B.; Ni, X.; He, Y. Ammonium/nitrate ratio affects the growth and glucosinolates content of pakchoi. *Hortic. Bras.* **2020**, *38*, 246–253. [CrossRef]
93. Da Silva, G.B.; Prado, R.D.M.; Silva, S.L.O.; Campos, C.N.S.; Castellanos, L.G.; Dos Santos, L.C.N.; Barreto, R.F.; Teodoro, P.E. Nitrogen concentrations and proportions of ammonium and nitrate in the nutrition and growth of yellow passion fruit seedlings. *J. Plant Nutr.* **2020**, *43*, 2533–2547. [CrossRef]
94. Podgórska, A.; Burian, M.; Rychter, A.M.; Rasmusson, A.G.; Szal, B. Short-term ammonium supply induces cellular defence to prevent oxidative stress in Arabidopsis leaves. *Physiol. Plant.* **2017**, *160*, 65–83. [CrossRef]
95. Jampeetong, A.; Brix, H.; Kantawanichkul, S. Effects of inorganic nitrogen forms on growth, morphology, nitrogen uptake capacity and nutrient allocation of four tropical aquatic macrophytes (*Salvinia cucullata, Ipomoea aquatica*, *Cyperus involucratus* and *Vetiveria zizanioides*). *Aquat. Bot.* **2012**, *97*, 10–16. [CrossRef]
96. Borgognone, D.; Colla, G.; Rouphael, Y.; Cardarelli, M.; Rea, E.; Schwarz, D. Effect of nitrogen form and nutrient solution pH on growth and mineral composition of self-grafted and grafted tomatoes. *Sci. Hortic.* **2012**, *149*, 61–69. [CrossRef]
97. Huang, L.; Lu, Y.; Gao, X.; Du, G.; Ma, X.; Liu, M.; Guo, J.; Chen, Y. Ammonium-induced oxidative stress on plant growth and antioxidative response of duckweed (*Lemna minor* L.). *Ecol. Eng.* **2013**, *58*, 355–362. [CrossRef]
98. Cid, N.S.C.; Renato, D.M.P.; Gustavo, C.; Antonio, J.A.O.D.L.N.; Bio, L.C.M.F.A.; Campos, C.N.S.; Prado, R.D.M.; Caione, G.; Neto, A.J.D.L.; Mingotte, F.L.C. Silicon and excess ammonium and nitrate in cucumber plants. *Afr. J. Agric. Res.* **2016**, *11*, 276–283. [CrossRef]
99. Zhang, Y.; Lin, X.; Zhang, Y.; Du, S. Effects of nitrogen forms on content and distribution of nitrate and oxalate forms in spinach plants. *Acta Hortic. Sin.* **2005**, *32*, 648–652.
100. Zhu, Y.; Qi, B.; Hao, Y.; Liu, H.; Sun, G.; Chen, R.; Song, S. Appropriate NH_4+/NO_3-Ratio triggers plant growth and nutrient uptake of flowering Chinese cabbage by optimizing the pH value of nutrient solution. *Front. Plant Sci.* **2021**, *12*, 656144. [CrossRef] [PubMed]
101. Wang, J.; Bingruia, L.I.; Xiaopenga, L.I.; Xudonga, Z.H.U.; Chuangenb, Z.H.U.; Haifeng, J.I.A. Evaluation of N fertilizers effects on grape based on the expression of N metabolic genes. *Hortic. Plant J.* **2016**, *2*, 261–271. [CrossRef]
102. Hashem, M.; Omran, Y.A.M.M.; Sallam, N.M.A. Efficacy of yeast extracts in the management of root-knot nematode (*Meloidogyne incognita*), in Flame Seedless grape vines and the consequent effect on the productivity of the vines. *Biocontrol. Sci. Technol.* **2008**, *18*, 357–375. [CrossRef]
103. El-Khawaga, A.S.; Zaeneldeen, E.M.A.; Yossef, M.A. Response of three pomegranate cultivars (*Punica granatum* L.) to salinity stress. *Middle East J. Agric. Res.* **2013**, *1*, 64–75.
104. Kumar, R.; Saroj, P.L.; Sharma, B.D.; Yadav, P.K. Studies on flowering induction, sex ratio and fruit set improvement in pomegranate. *Indian J. Hortic.* **2020**, *77*, 610–618. [CrossRef]
105. Miller, J.S.; Diggle, P.K. Correlated evolution of fruit size and sexual expression in andromonoecious Solanum sections Acanthophora and Lasiocarpa (Solanaceae). *Am. J. Bot.* **2007**, *94*, 1706–1715. [CrossRef]
106. Wetzstein, H.Y.; Ravid, N.; Wilkins, E.; Martinelli, A. A Morphological and Histological Characterization of Bisexual and Male Flower Types in Pomegranate. *J. Am. Soc. Hortic. Sci.* **2011**, *136*, 83–92. [CrossRef]
107. Chaudhari, S.M.; Desai, U.T. Effects of plant growth regulators on flower sex in pomegranate (*Punica granatum* L.). *Indian J. Agric. Sci.* **1993**, *63*, 34–35.
108. Mars, M. Pomegranate plant material: Genetic resources and breeding, a review. *Options Mediterr.* **2000**, *42*, 55–62.
109. Ramniwas; Kaushik, R.A.; Sarolia, D.K. Response of irrigation and fertigation scheduling on flowering, physiological parameters and fruit yield of guava *(Psidium guajava* L.) under high density planting. *Ann. Agric. Res.* **2012**, *33*, 115–120.
110. Bindraban, P.S.; Dimkpa, C.; Nagarajan, L.; Roy, A.; Rabbinge, R.R. Fertilizers and fertilization strategies for improved nutrient uptake by plants. *Biol. Fertil. Soils* **2015**, *51*, 897–911. [CrossRef]
111. Petrucio, M.M.; Esteves, F.A. Uptake rates of nitrogen and phosphorus in the water by Eichhornia crassipes and Salvinia auriculata. *Rev. Bras. De Biol.* **2000**, *60*, 229–236. [CrossRef]
112. Torshiz, A.O.; Goldansaz, S.H.; Motesharezadeh, B.; Sarcheshmeh, M.A.A.; Zarei, A. Effect of organic and biological fertilizers on pomegranate trees: Yield, cracking, sunburning and infestation to pomegranate fruit moth *Ectomyelois ceratoniae* (Lepidoptera: Pyralidae). *J. Crop Prot.* **2017**, *6*, 327–340.
113. Aziz, R.A.; Naira, A.; Moieza, A.; Abubakar, A.R.; Ashraf, N. Effect of plant biostimulants on fruit cracking and quality attributes of pomegranate cv. Kandharikabuli. *Sci. Res. Essays* **2013**, *8*, 2171–2175. [CrossRef]
114. Jackman, R.L.; Stanley, D.W. Perspectives in the textural evaluation of plant foods. *Trends Food Sci. Technol.* **1995**, *6*, 187–194. [CrossRef]
115. Asgharzade, A.; Babaeian, M. Foliar application of calcium borate and micronutrients effects on some characters of apple fruits in Shirvan Region. *Ann. Biol. Res.* **2012**, *3*, 527–533.

116. Davarpanah, S.; Tehranifar, A.; Abadia, J.; Val, J.; Davarynejad, G.; Aran, M.; Khorassani, R. Foliar calcium fertilization reduces fruit cracking in pomegranate (*Punica granatum* cv. Ardestani). *Sci. Hortic.* **2018**, *230*, 86–91. [CrossRef]
117. Khadivi-Khub, A. Physiological and genetic factors influencing fruit cracking. *Acta Physiol. Plant.* **2015**, *37*, 1718. [CrossRef]
118. Hegazi, A.; Samra, N.R.; El-Baz, E.E.T.; Khalil, B.M.; Gawish, M.S. Improving fruit quality of Manfaloty and Wonderful pomegranates by using bagging and some spray treatments with gibberellic acid, calcium chloride and kaolin. *J. Plant Prod. Mansoura Univ.* **2014**, *5*, 779–792.
119. Abou El-Wafa, M. Effect of some treatments on reducing sunburn in Wonderful pomegranate fruit trees. *Egypt. J. Hortic.* **2015**, *42*, 795–806.
120. Harhash, M.M.; Aly, M.A.M.; Abd El-Megeed, N.A.; Ben Hifaa, A.B.S. Effect of some growth regulators, nutrient elements and kaolin on cracking and fruit quality of pomegranate 'Wonderful' cultivar. *J. Adv. Agric. Res.* **2019**, *24*, 280–297. [CrossRef]
121. Saad, F.A.; Shaheen, M.A.; Tawfik, H.A. Anatomical study of cracking in pomegranate fruit. *Alex. J. Agric. Res.* **1988**, *33*, 155–166.
122. Bakeer, S. Effect of ammonium nitrate fertilizer and calcium chloride foliar spray on fruit cracking and sunburn of *Manfalouty pomegranate* trees. *Sci. Hortic.* **2016**, *209*, 300–308. [CrossRef]
123. Melgarejo, P.; Martínez, J.; Hernández, F.; Martínez-Font, R.; Barrows, P.; Erez, A. Kaolin treatment to reduce pomegranate sunburn. *Sci. Hortic.* **2004**, *100*, 349–353. [CrossRef]
124. Parashar, A.; Ansari, A. A therapy to protect pomegranate (*Punica granatum* L.) from sunburn. *Int. J. Compr. Pharm.* **2012**, *3*, 1–3.
125. Ghorbani, M.; Dabbagh, G.R.; Yousefi, S.; Khademi, S.; Taki, M. The effect of application of different kinds of covers on the sunburn and internal qualities of pomegranate in Iran. *Biol. Forum—Int. J.* **2015**, *7*, 64–68.
126. Salama, A.S.; El Gammal, O.H.; Shaddad, A.M.G.E. Effect of Salicylic and Ascorbic Acids on Yield and Fruit Quality of Wonderful Pomegranate Trees. *Int. J. Adv. Res.* **2020**, *8*, 1059–1068. [CrossRef]
127. Hayat, S.; Ahmad, A. *Salicylic Acid: A Plant Hormone*; Springer Science and Business Media LLC: Berlin, Germany, 2007; pp. 1–14.
128. Taghavi, S.T.; Babalar, M.; Ebadi, A.; Ebrahimzadeh, H.; Asgari, A.M. Effects of nitrate to ammonium ratio on yield and nitrogen metabolism of strawberry (*Fragaria* × *ananassa* cv. Selva). *Int. J. Agric. Biol.* **2004**, *6*, 994–997.
129. Tanan, T.T.; da Silva, A.L.; de Oliveira, U.C.; Neto, L.P.G.; do Nascimento, M.N.D. Effect of nitrogen sources on fruit characteristics and seed physiological quality of *Physalis angulata* L. *Pesq. Agropec. Trop. Goiânia* **2019**, *49*, e55074. [CrossRef]
130. Khalil, N.H.; Agah, R.J. Effect of chemical, organic and bio fertilization on growth and yield of strawberry plant. *Int. J. Adv. Chem. Eng. Biol. Sci.* **2017**, *4*, 167–171.
131. Santamaría, P.; Elia, A.; Parente, A.; Serio, F. Fertilization strategies for lowering nitrate content in leafy vegetables: Chicory and rocket salad cases. *J. Plant Nutr.* **1998**, *21*, 1791–1803. [CrossRef]
132. Mengel, K.; Kirkby, E.A.; Kosegarten, H.; Appel, T. Nitrogen. In *Principles of Plant Nutrition*; Springer: Berlin, Germany, 2001; pp. 397–434.
133. Zhang, F.C.; Kang, S.Z.; Li, F.S.; Zhang, J.H. Growth and major nutrient concentrations in brassica campestris supplied with different NH_4+/NO_3-ratios. *J. Integr. Plant Biol.* **2007**, *49*, 455–462. [CrossRef]