Article

Conventional versus Nano Calcium Forms on Peanut Production under Sandy Soil Conditions

Mohamed Hamza ^{1,2}, Mohamed Abbas ³ , Asmaa Abd Elrahman ⁴, Mohamed Helal ⁵ and Mohamed Shahba ^{3,*}

¹ Biology Department, College of Science, Jouf University, Jouf 72388, Saudi Arabia; mohamedhamza@agr.cu.edu.eg

² Agronomy Department, Faculty of Agriculture, Cairo University, Cairo 12613, Egypt

³ Natural Resources Department, Faculty of African Postgraduate Studies, Cairo University, Cairo 12613, Egypt; msaelsarawy@cu.edu.eg

⁴ Soil Laboratory, Cairo University Research Park, Faculty of Agriculture, Cairo University, Cairo 12613, Egypt; eng.asmaaabdelrahim@gmail.com

⁵ Soil Science Department, Faculty of Agriculture, Cairo University, Cairo 12613, Egypt; mohdesoky206@gmail.com

* Correspondence: shahbam@cu.edu.eg; Tel.: +20-1099-415-131

Abstract: Abiotic stresses in sandy soil, which include saline water, saline soil, and lack of nutrients, affect the productivity and quality traits of peanuts (*Arachis hypogaea* L.). Elemental calcium (Ca^{2+}) is necessary for the proper development of peanut pods. This work aimed at comparing conventional Ca and nano-Ca form effects on peanut production and quality traits. Two randomized complete block field experiments were conducted in the 2015 and 2016 seasons. Treatments were control, gypsum plus calcium nitrate $\text{Ca}(\text{NO}_3)_2$, $\text{Ca}(\text{NO}_3)_2$, and chelated calcium, as well as 100%, 75%, 50%, 25%, and 12.5% of $\text{Ca}(\text{NO}_3)_2$ doses in a nano form. The results indicated that the treatment of gypsum plus conventional CaNO_3 achieved the highest yield and best quality traits, followed by the $\text{Ca}(\text{NO}_3)_2$ and 100% nano $\text{Ca}(\text{NO}_3)_2$ treatments. The treatments of the control, gypsum, and 12.5% nano $\text{Ca}(\text{NO}_3)_2$ had the lowest effect on peanut performance. The conventional treatment of gypsum plus $\text{Ca}(\text{NO}_3)_2$ resulted in the greatest seed yield (1.6 ton ha^{-1}), oil yield (700.3 kg ha^{-1}), and protein yield (380.1 kg ha^{-1}). Peanuts may benefit from Ca^{2+} better by using gypsum as the soil application and calcium nitrate as the foliar application to prevent disorders of Ca^{2+} deficiency under sandy soil conditions.

Keywords: calcium; gypsum; oil; pod; protein; yield

Citation: Hamza, M.; Abbas, M.; Abd Elrahman, A.; Helal, M.; Shahba, M. Conventional versus Nano Calcium Forms on Peanut Production under Sandy Soil Conditions.

Agriculture **2021**, *11*, 767. <https://doi.org/10.3390/agriculture11080767>

Academic Editor: Xingmao Ma

Received: 9 July 2021

Accepted: 4 August 2021

Published: 12 August 2021

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1. Introduction

Peanuts (*Arachis hypogaea* L.) are grown in many countries as oil, food, and feed crops. Its kernels are rich in oil (48–50%), protein (25–28%), vitamins, minerals, antioxidants, polyphenols, and flavonoids [1,2].

Nano-technology is a novel beneficial discovery; it may provide keener solutions for current agriculture problems [3]. These materials have unique properties of a very small size, ranging from 8 μm to 10 nm [4]. Nano-technology has been implemented in developing fertilizers as nanomaterials that improve the fertility and productivity of soil [5,6]. The advantages of nano-technology include less toxicity, low cost, improvement in soil fertility, and enhancement in crop yield [7,8]. Zulfiqar et al. [9] mentioned that nano-fertilizers offer benefits for nutrition management through their strong potential to increase nutrient use efficiency. Nano-technology has the potential to improve food quality, increase global food production, protect plants, and detect plant and animal diseases [10]. Nanotechnology also has a high potential for achieving sustainable agriculture, especially in developing countries [11].

Nanotechnology provides new agrochemicals and delivers tools for the improvement of crop productivity [10]. One of the most important uses of nanotechnology is in the field

of plant fertilization [12–14]. Nano-fertilizers are a new generation of synthetic fertilizers that contain readily available nutrients in a nano scale range [15]. However, Tavan et al. [16] reported that the use of nano-fertilizers to precisely control nutrient release is an effective step for achieving sustainable and environmentally sound agriculture. Nano-fertilizers are being studied as a way to increase nutrient efficiency and improve plant nutrition, compared with traditional fertilizers [17]. On the other hand, Nel et al. [18] demonstrated that the environmental and public health impacts of any new nano-fertilizer must be determined, validated, and diminished through the regulation and re-design of the product before marketing. In addition, Pullagurala et al. [19] highlighted that nano-materials have negative effects on plants after exposure to higher concentrations. However, the main problem of contamination and toxicity result from using high doses [18].

Calcium is a critical element that plays key structural and signaling roles in plant growth. In addition to its role in the cell wall structure and function, it helps in cell wall strengthening, cell extension, cell division, osmoregulation, and the modulation of certain enzymes [20–22]. The peanut is unique, as the pods directly absorb most of the calcium, and therefore calcium fertilizers are applied in the pod zone at the peak flowering stage to ensure its availability to the pods [2]. The availability of calcium in the peanut pod zone is one of the most significant soil fertility factors affecting the success of reproductive growth of peanuts and, as a result, pod and kernel yields [23–25]. Different forms of Ca^{2+} fertilizers, such as gypsum (CaSO_4), limestone (CaCO_3), and nano calcium forms are available for soil amendment to supplement soil Ca^{2+} . Several authors have shown the importance of different calcium forms in the growth and productivity of peanuts [26–28]. Thilakarathna et al. [29] found that the addition of 250 kg ha^{-1} of gypsum increased the pod dry weight of peanuts by 39%. Furthermore, the application of gypsum at 200 kg ha^{-1} significantly increased peanut growth parameters and yield, as reported by Yadav et al. [30]. Arnold et al. [31] also indicated that the peanut cultivar and gypsum application rate had effects on seed Ca^{2+} concentration, which increased as the field gypsum application rate increased. Xiumei et al. [32] found that adding nano- CaNO_3 amended with humic acid and manures significantly enhanced peanut growth and development.

Calcium deficiency is recognized as an important problem in peanut production, being associated with pod rot and poorly filled pods [23,24,33]. Peanuts reproduce via geocarpic [34]. However, the Ca^{2+} nutrition of peanuts is complicated by the geocarpic nature of the plant and by the immobility of Ca^{2+} in the phloem, which restricts the redistribution of Ca^{2+} from older to younger tissues within the plant via the phloem [20]. Peanuts lacking Ca^{2+} may form undeveloped pods called “pops”, or have poor germination and vigor. Pods must obtain Ca^{2+} from the surrounding soil, because Ca^{2+} is generally immobile in the phloem. Adequate Ca^{2+} in the pegging zone is essential for proper peanut development [35,36]. During the development of peanut pods, more than 90% of the total required Ca^{2+} is absorbed [37]. The insufficient Ca^{2+} supply may result in a large number of empty pods, undeveloped pods, final low yield, poor quality seeds, and darkened plumule or black hearts, which can adversely affect seed viability and germination rates [23,24,36]. However, Yang et al. [38] reported that Ca^{2+} deficiency is the main cause of empty pods in peanuts. In addition, the lack of calcium can lead to embryo abortion, empty pod formation, and massive reductions in yields. Therefore, the current investigation was designed to compare the effect of conventional Ca^{2+} and nano- Ca^{2+} forms on peanut production and quality traits under sandy soil conditions. Given the fact that different forms of Ca^{2+} fertilizers, such as gypsum (CaSO_4), limestone (CaCO_3), and nano calcium forms are available for soil amendment to provide the soil with Ca^{2+} , we hypothesized a difference in both regular and nano-calcium forms in their effect on peanut growth and quality, as nano-fertilizers are new generation of the synthetic fertilizers that contain readily available nutrients in a nano scale range.

2. Materials and Methods

2.1. Field Experiment

Two field experiments were carried out during two successive summer seasons of 2015 and 2016 at the Desert Experimental Station, Faculty of Agriculture, Cairo University, Wadi El-Natroon, El-Beheira Governorate, Egypt (30°32'30" and 30°33'0" N, 29°57'15" and 29°58'15" E. Altitude: 31 and 59 m above sea level) under drip irrigation. Ismailia-1 peanut cultivar was used. It was chosen because it was a new cultivar in Egypt. It is the commercial and common cultivar, which is disseminated for farms and farmers especially under reclaimed sandy soils conditions. It is well adapted to sandy soil conditions. The seeds were obtained from the Field Crops Research Institute, Agricultural Research Center (ARC), Egyptian Ministry of Agriculture. The monthly mean temperature, monthly relative humidity, and rainfall were recorded (Table 1). The monthly mean temperature values increased gradually from 22.3 and 23.7 °C in May to 26.7 and 27.6 °C in July in the 2015 and 2016 seasons, respectively. The maximum relative humidity was 67 and 61.3% during July in the both seasons, respectively. There was no rain in the two seasons.

Table 1. Mean monthly climatic data from the nearest weather station (longitude: 29°57'; latitude: 31°12'; elevation: 3.4 m) at the experimental location for 2015 and 2016.

Month	2015			2016		
	Temperature (°C)	Relative Humidity (%)	Rainfall (mm)	Temperature (°C)	Relative Humidity (%)	Rainfall (mm)
May	22.3	63.7	0	23.7	63.0	0
June	24.6	64.7	0	26.9	59.0	0
July	26.7	67.0	0	27.6	61.3	0
August	19.4	43.0	0	18.8	43.7	0
September	28.2	56.0	2	26.0	58.0	0

Note: data obtained by the Central Laboratory for Agricultural Climate (CLAC), Agricultural Research Center (ARC), Egypt.

The soil and irrigation water properties are listed in Tables 2 and 3, respectively. Soil physical and chemical analyses were conducted according to Klute [39] and Page et al. [40]. Sandy soil was the prevailing type in the experimental station. The soil was saline (the electrical conductivity "EC" of soil was 4.73 and 4.46 dS m⁻¹ in the two seasons, respectively), and was found to be poor in macronutrients, as the soil nutritional concentrations of N, P, and K were 0.67, 2.54, and 190 mg kg⁻¹ in first season and 0.87, 2.45, and 178 mg kg⁻¹ in the second season, respectively. Organic matter was low and ranged from 0.28% in the first season to 0.30% in the second season. Saline irrigation water with an EC of 4.02 and 3.82 dS m⁻¹ in the first and second seasons, respectively, was used.

Table 2. Soil properties of the study site in the 2015 and 2016 seasons.

Properties	Season	
	2015	2016
Physical Properties		
Sand %	91.84	93.61
Silt %	3.64	2.84
Clay %	4.52	3.55
Texture	Sandy	Sandy
Chemical Properties		
Soil pH (1:1)	7.31	7.53
EC (1:1, dS m ⁻¹)	4.73	4.46
Soluble anions (meq L ⁻¹)		
Cl ⁻	28.50	32.60
SO ₄ ²⁻	10.28	11.02
HCO ₃ ⁻	1.80	1.93

Table 2. *Cont.*

Properties	Season	
	2015	2016
Soluble cations (meq L ⁻¹)		
K ⁺	2.26	2.62
Ca ²⁺	6.62	7.00
Mg ²⁺	8.44	8.62
Na ⁺	23.60	26.88
Organic Matter (%)	0.28	0.30
Total carbonate content	2.75	3.10
Available N (mg kg ⁻¹)	0.67	0.87
Available P (mg kg ⁻¹)	2.54	2.45
Available K (mg kg ⁻¹)	190	178

Table 3. Chemical properties of the irrigation water during the 2015 and 2016 seasons.

Season	pH	EC (dS m ⁻¹)	Soluble Ions (meq L ⁻¹)						
			HCO ₃ ⁻	Cl ⁻	SO ₄ ²⁻	Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺
2015	7.09	4.02	1.9	31.0	8.0	4.7	3.8	30.8	1.52
2016	7.10	3.82	2.2	29.4	7.7	4.5	3.2	31.2	0.44

2.2. Calcium Nitrate Ca(NO₃)₂ Nanoparticles Preparation

Nano calcium nitrate Ca(NO₃)₂ was prepared physically in the lab by ball-milling (Photon Company, Egypt). Portions of 80 g of Ca(NO₃)₂ were placed in four stainless steel canisters with metal balls of different sizes, namely, large, medium, and small. The canisters were placed on the ball-milling machine and stirred for 30 h at speed of 1000 rpm/minute, then part of the milled Ca(NO₃)₂ was collected and submitted for transmission electron microscopy (TEM, Jeol-1400), Tokyo, Japan, for determining the size of the Ca(NO₃)₂ particle measurements (Figure 1).

Figure 1. Transmission electron microscopy (TEM) of nano calcium nitrate particles using 80,000× magnification.

2.3. Cultural Practices

Seedbed was prepared by harrowing, compacting, and leveling. The preceding crop was eggplant (*Solanum melongena* L.) in both seasons. Sowing dates were on 2 and 7 May in the 2015 and 2016 seasons, respectively. Harvesting dates were on 12 and 17 September in the first and second seasons, respectively. Each experimental plot consisted of five ridges 60 cm apart and 4 m long. The plot area was 12 m² (3.0 × 4.0 m). Seeds were sown by hand on hills, and the plots were irrigated immediately after seeding. Seedlings were thinned to two plants/hill two weeks after sowing (168,000 plant ha⁻¹) to avoid competition. The seeds of the peanuts were directly inoculated before planting with *Bradyrhizobium* spp. Phosphorus fertilizer in the form of super phosphate (15.5% P₂O₅) was added at a rate of 360 kg ha⁻¹ during the seedbed preparation. Potassium fertilizer in the form of potassium sulphate (48% K₂O) at a rate of 240 kg ha⁻¹ was added directly before flowering. Nitrogen fertilizer was also added to the soil in the form of calcium nitrate (15.5% N) at a rate of 240 kg ha⁻¹ in two equal doses, one at sowing and the second 15 days after sowing. A drip irrigation system was used. It was composed of polyethylene pipes GR (4 L h⁻¹) of 16 mm in diameter. Irrigation was applied daily until the emergence stage. After emergence, irrigation was applied at 7-day intervals during vegetative growth. At the flowering stage, daily irrigation was applied. Cultural practices were done according to the recommendation of ARC, Ministry of Agriculture, Egypt.

2.4. Experimental Design and Treatments

The experimental design was a completely randomized block design (RCBD) with three replications. We chose to use the RCBD as it is the standard design for agricultural experiments, where similar experimental units are grouped into blocks or replicates (Figure S1). This helped us to control the variations that may have resulted from the spatial effects in field such as local variation in fertility or soil moisture content due to drainage differences, so that the observed differences were largely due to the true differences among the treatments that were randomly assigned. Treatments included control (distilled water); gypsum (CaSO₄ · 2H₂O; 19.5% Ca) plus calcium nitrate (Ca (NO₃)₂ · 4H₂O 23% Ca); Ca (NO₃)₂; 12.5%, 25%, 50%, 75%, and 100% of calcium nitrate (Ca (NO₃)₂ · 4H₂O 23% Ca) in nano form; and chelated calcium (Ca-EDTA; 14%). Gypsum was added at a rate of 3.57 ton ha⁻¹ in one dose during the seedbed preparation. Both conventional and nano calcium nitrate forms were added through foliar application at a rate of 714.28 mg ha⁻¹ divided into three applications at 30, 45, and 60 days after sowing. Chelated calcium was added at a rate of 3 g L⁻¹ (1440 g ha⁻¹), divided into three applications at 30, 45, and 60 days after sowing. The foliar application doses were sprayed at morning time (08:00–10:00 a.m.) on a sunny and dry day.

2.5. Traits and Measurements

Data on growth and yield were collected by randomly selecting ten plants from the three inner ridges of each plot at harvest time by hand in order to record plant height (cm), the number of branches per plant, the number of pods per plant, the number of immature pods per plant, the weight of pods per plant, and the weight of the seeds per plant in grams. The quality traits of the pods and seeds were measured by determining the seed index (the weight of 100 seeds in grams), pod index (the weight of 100 pods in grams), pops percentage (%), and shelling percentage (the dried pods were hand-shelled), as follows:

$$\text{Pops percentage} = \frac{\text{number of pops}}{\text{number of pods}} \times 100$$

$$\text{Shelling percentage} = \frac{\text{weight of pods} - \text{weight of their shell}}{\text{weight of pods}} \times 100$$

The biological yield (ton ha⁻¹) was calculated as the total mass (above ground) at harvest and was dried to 15% moisture content after sun drying, after which the pod yield

(kg ha⁻¹), seed yield (kg ha⁻¹), and oil yield (kg ha⁻¹) were assessed. Oilseed and protein percentages were determined according to AOAC [41].

2.6. Statistical Analysis

Data were checked for normal distribution in each trait with the Shapiro–Wilk method [42], using the SPSS v. 17.0 [43] computer package. Furthermore, data were tested for violations of assumptions underlying the combined analysis of variance by separately analyzing the data of each season and then running a combined analysis across the two seasons according to Steel et al. [44]. Mean separations were done using the least significant difference (LSD) test at a 5% significance level using MSTAT-C [45].

3. Results and Discussion

3.1. Analysis of Variance, Growth and Yield Components

Analysis of variance indicated no significant differences between the two seasons of the study, nor for the interaction between years and cultivars (Table 4). Data for the two seasons were pooled together. Significant differences were found among the Ca²⁺ treatments' variance with mean squares and coefficient of variation for all of the tested traits under calcium treatments (combined data of 2015 and 2016 season).

Table 4. Analysis of variance with mean squares and coefficient of variation for all of the tested traits under calcium treatments (combined data of 2015 and 2016 season).

SOV	Growth and Yield Components					
	Plant Height, cm	Branches Number Plant ⁻¹	Pods Number Plant ⁻¹	Immature Pods Number Plant ⁻¹	Pods weight Plant ⁻¹ , g	Seeds Weight Plant ⁻¹ , g
Year (Y)	**	**	**	**	NS	**
Treatment (T)	**	**	**	**	**	**
T × Y	**	NS	**	**	**	**
SOV	Quality Characteristics					
	Pod Index, g	Seed Index, g	Shelling, %	Pops, %	Oil, %	Protein, %
Year (Y)	*	*	*	NS	NS	NS
Treatment (T)	**	**	**	**	**	**
T × Y	NS	**	NS	NS	NS	NS
SOV	Yields					
	Biological Yield, ton ha ⁻¹	Pods Yield, ton ha ⁻¹	Seed Yield, ton ha ⁻¹	Oil Yield, kg ha ⁻¹	Protein Yield, kg ha ⁻¹	
Year (Y)	**	*	NS	NS	NS	
Treatment (T)	**	**	**	**	**	
T × Y	NS	**	**	*	*	

NS (non-significant), *, ** for $p < 0.05$, $p < 0.01$ and $p < 0.001$.

Significant differences among the treatments in all of the tested parameters were found. The conventional treatment of gypsum plus Ca(NO₃)₂, Ca(NO₃)₂, 100%, 75%, and 50% nano CaNO₃ achieved a higher plant height (51.3, 49.8, 49.8, 49.1, and 48.9 cm, respectively). There was no significant difference among Ca(NO₃)₂, chelated Ca, and 12.5% and 25% nano Ca(NO₃)₂. The treatment of gypsum plus Ca(NO₃)₂ achieved the largest number of branches per plant (25.68), the largest number of pods per plant (32.9), the highest pods weight plant (45.1 g), the highest seed weight per plant (31.5 g), and the lowest number of immature pods per plant (8.7) (Table 5 and Table S1).

The treatment of gypsum as a soil application plus calcium nitrate as a foliar application improved the Ca²⁺ availability for peanuts. Gypsum delivers Ca²⁺ to the fruiting zone, which makes Ca available during kernel and pod development. In addition, gypsum reduced the soil EC and as a result improved the Ca²⁺ absorption through peanut roots. In agreement with our findings, Wiatrak et al. [26] indicated that gypsum applications may help with increasing the peanut yields by enhancing the availability of Ca²⁺ in the fruiting zone. In addition,

Clark et al. [46], Elrashicli et al. [47], Florence [48], and Yang [36] reported that gypsum and calcium applied through foliar had many benefits for peanut growth. Gypsum does not increase the rhizosphere pH and has a high solubility in water, which helps to improve the flow of Ca^{2+} to the peanut. Gypsum had a vital role of enhancing the physical and chemical properties of soil. Soils with added gypsum are characterized by less surface crusting and compaction, higher infiltration rates, and a higher water holding capacity. Gypsum also increases the aggregates stability in amended soils. Gypsum is effective at reducing the soil EC and enhancing plant growth [49,50]. This suggestion is similar to that of Arnold [51], who reported that plant available water and soil calcium availability are the most important factors that influence the seed quality of peanuts. Tillman et al. [52] indicated that higher soil Ca^{2+} levels are needed for a high seed quality rather than optimum yield. Furthermore, using different forms of Ca^{2+} fertilizers give peanut producers more flexibility.

Table 5. Means of growth, yield components, and coefficient of variation (CV) of the peanut tested under calcium treatments in field experiments in Wadi El-Natroon, Egypt (combined data of the 2015 and 2016 seasons).

	Plant Height, cm	Branches Number Plant ⁻¹	Pods Number Plant ⁻¹	Immature Pods Number Plant ⁻¹	Pods Weight Plant ⁻¹ , g	Seeds Weight Plant ⁻¹ , g
Control	36.9 ^{e†}	15.1 ^{de}	19.2 ^h	20.5 ^b	22.5 ^f	16.3 ^g
Gypsum + $\text{Ca}(\text{NO}_3)_2$	51.3 ^a	25.7 ^a	32.9 ^a	8.7 ^h	45.1 ^a	31.5 ^a
$\text{Ca}(\text{NO}_3)_2$	49.8 ^b	20.4 ^b	26.4 ^b	10.5 ^g	39.9 ^b	27.0 ^b
100% nano $\text{Ca}(\text{NO}_3)_2$	49.8 ^b	20.0 ^b	24.7 ^{cd}	10.9 ^{fg}	38.6 ^b	26.3 ^b
75% nano $\text{Ca}(\text{NO}_3)_2$	49.1 ^b	19.3 ^b	23.9 ^{de}	11.8 ^f	33.4 ^d	23.3 ^c
50% nano $\text{Ca}(\text{NO}_3)_2$	48.9 ^b	18.4 ^{bc}	23.4 ^{ef}	12.8 ^e	29.5 ^e	21.0 ^d
25% nano $\text{Ca}(\text{NO}_3)_2$	47.3 ^c	18.1 ^{bc}	21.7 ^g	16.7 ^d	28.2 ^e	18.7 ^{ef}
12.5% nano $\text{Ca}(\text{NO}_3)_2$	43.8 ^d	16.4 ^{cd}	22.3 ^{fg}	19.3 ^c	24.3 ^f	17.7 ^{fg}
Chelated Ca	30.9 ^f	12.7 ^e	25.3 ^{bc}	23.8 ^a	36.6 ^c	20.8 ^{de}
Mean	45.3	18.5	24.4	15.0	33.1	22.5
CV %	6.8	4.7	5.7	4.1	12.3	2.4
LSD 0.05	1.3	2.7	1.2	1.0	1.8	2.2

† Values followed by the same letters within a column are not significantly different ($p = 0.05$) based on a Fisher's LSD test.

3.2. Quality Traits

Significant differences were found among treatments in the seed index, pod index, shelling percentage, pops percentage, oil content percentage, and protein percentage due to the Ca^{2+} treatments. The conventional treatment of gypsum plus $\text{Ca}(\text{NO}_3)_2$ achieved the highest values of pod index (188.2 g), seed index (64.3 g), shelling percentage (65.2), oil percentage (42.9%), and protein percentage (23.2%), and the lowest value of pops percentage (12.2%), followed by $\text{Ca}(\text{NO}_3)_2$ and 100% nano $\text{Ca}(\text{NO}_3)_2$ (Table 6 and Table S2).

Table 6. Means of quality traits and coefficient of variation (CV) of peanuts tested under calcium treatments in field experiments in Wadi El-Natroon, Egypt (combined data of the 2015 and 2016 seasons).

	Pod Index, g	Seed Index, g	Shelling, %	Pops, %	Oil, %	Protein, %
Control	115.0 ^f	45.3 ^f	54.2 ^e	26.3 ^b	39.5 ^e	19.3 ^f
Gypsum + $\text{Ca}(\text{NO}_3)_2$	188.2 ^a	64.3 ^a	65.2 ^a	12.2 ^e	42.9 ^a	23.2 ^a
$\text{Ca}(\text{NO}_3)_2$	171.9 ^b	60.7 ^b	63.1 ^{ab}	15.2 ^d	41.8 ^b	22.1 ^b
100% nano $\text{Ca}(\text{NO}_3)_2$	168.2 ^{bc}	60.6 ^b	62.1 ^{bc}	15.7 ^d	41.4 ^{bc}	21.7 ^{bc}
75% nano $\text{Ca}(\text{NO}_3)_2$	165.2 ^c	59.7 ^{bc}	61.3 ^{bc}	17.5 ^{cd}	41.1 ^{bc}	21.5 ^{bcd}
50% nano $\text{Ca}(\text{NO}_3)_2$	155.1 ^d	52.2 ^d	60.7 ^c	19.0 ^c	40.8 ^{bcd}	21.3 ^{cd}
25% nano $\text{Ca}(\text{NO}_3)_2$	150.7 ^d	49.7 ^e	58.3 ^d	24.5 ^b	40.5 ^{cde}	20.8 ^{de}
12.5% nano $\text{Ca}(\text{NO}_3)_2$	117.0 ^f	46.8 ^f	57.2 ^d	25.5 ^b	39.7 ^{de}	20.2 ^e
Chelated Ca	124.1 ^e	57.5 ^c	58.0 ^d	30.2 ^a	40.8 ^{bc}	21.2 ^{cd}
Mean	150.6	55.2	60.0	20.7	40.9	21.3
CV %	2.9	2.2	9.8	3.0	3.8	3.5
LSD 0.05	6.2	2.7	2.1	2.4	1.0	0.7

Values followed by the same letters within a column are not significantly different ($p = 0.05$) based on a Fisher's LSD test.

Applying nano- $\text{Ca}(\text{NO}_3)_2$ with some organic fertilizer amendments could ameliorate the physiological situation and promote the peanut absorptivity for elemental nutrients [32]. The lower effect of nano-calcium forms on peanuts that was proven in this study may be due to the relatively higher salinity of the soil and irrigation water. In addition, it could be a result of the low mobility of Ca^{2+} in the phloem. The lower mobility of elements in the phloem limits the re-distribution of elements in the whole plant. Kiesling and Walker [33], Marschner [20], and Yang [36] concluded that the immobility of Ca^{2+} in the phloem restricts the redistribution of Ca^{2+} from older to younger tissues within the plant. Calcium does not move through the peg to the pod and the developing kernel [53]. Skelton and Shear [54] indicated that Ca^{2+} is poorly translocated through the phloem of the gynophores, and must be absorbed by the developing pod. As Ca^{2+} is generally immobile in the phloem, pods must obtain the needed Ca^{2+} from the rhizosphere zone, thus adequate Ca^{2+} supply in the pegging zone is more important than foliar application for proper peanut yield and quality. However, Ghosh et al. [55] recorded that the seed receiving gypsum and lime treatment showed a reduction in the number of immature pods plant⁻¹. Yang et al. [56] found that the mechanism of calcium regulation in peanut pod development when calcium is deficient in the soil induces early embryo abortion in peanuts, and this process produces empty pods.

3.3. Yield

Significant differences among the treatments in the biological, pods, seed, oil, and protein yields were found. Gypsum plus $\text{Ca}(\text{NO}_3)_2$ treatment achieved the highest biological yield (15.4 ton ha⁻¹), the highest pod yield (2.5 ton ha⁻¹), the highest seed yield (1.6 ton ha⁻¹), the highest oil yield (700.3 kg ha⁻¹), and the highest protein yield (380.1 kg ha⁻¹), followed by the treatments of CaNO_3 and 100% nano $\text{Ca}(\text{NO}_3)_2$ (Table 7, Table S3, Figures 2 and 3).

Table 7. Means of peanut yields and coefficient of variation (CV) tested under calcium treatments in the field experiments in Wadi El-Natroon, Egypt (combined data of the 2015 and 2016 seasons).

	Biological Yield, ton ha ⁻¹	Pods Yield, ton ha ⁻¹	Seed Yield, ton ha ⁻¹	Oil Yield, kg ha ⁻¹	Protein Yield, kg ha ⁻¹
Control	8.9 ^c	1.5 ^f	0.8 ^f	322.6 ^f	158.0 ^g
Gypsum + $\text{Ca}(\text{NO}_3)_2$	15.4 ^a	2.5 ^a	1.6 ^a	700.3 ^a	380.1 ^a
$\text{Ca}(\text{NO}_3)_2$	14.4 ^a	2.1 ^b	1.3 ^b	538.2 ^b	284.8 ^b
100% nano $\text{Ca}(\text{NO}_3)_2$	13.8 ^a	2.0 ^b	1.2 ^b	510.3 ^b	267.0 ^b
75% nano $\text{Ca}(\text{NO}_3)_2$	11.8 ^b	1.8 ^c	1.1 ^c	441.7 ^c	230.5 ^c
50% nano $\text{Ca}(\text{NO}_3)_2$	11.1 ^b	1.7 ^{de}	1.0 ^{cd}	407.5 ^d	212.9 ^{cd}
25% nano $\text{Ca}(\text{NO}_3)_2$	10.9 ^b	1.6 ^{def}	0.9 ^{de}	377.5 ^{de}	194.0 ^{ef}
12.5% nano $\text{Ca}(\text{NO}_3)_2$	10.6 ^b	1.8 ^{ef}	0.9 ^e	356.8 ^e	181.0 ^f
Chelated Ca	11.3 ^b	1.7 ^{cd}	1.0 ^{de}	395.5 ^d	205.9 ^{de}
Mean	12.0	1.9	1.1	450.0	234.9
CV %	6.8	6.2	5.7	4.5	11.5
LSD 0.05	1.6	0.1	0.1	32.6	18.8

Values followed by the same letters within a column are not significantly different ($p = 0.05$) based on a Fisher's LSD test.

Gypsum plus $\text{Ca}(\text{NO}_3)_2$, $\text{Ca}(\text{NO}_3)_2$, and 100% nano $\text{Ca}(\text{NO}_3)_2$ treatments significantly increased the biological yield by 77.2, 64.7, and 55.0%, respectively, compared with the control. The pod yield significantly increased by 66.2, 35.8, and 31.8% when the peanut plants were treated with gypsum plus $\text{Ca}(\text{NO}_3)_2$, $\text{Ca}(\text{NO}_3)_2$ and 100% nano $\text{Ca}(\text{NO}_3)_2$ treatments, respectively, compared with the control. However, the seed yield significantly increased by 100, 57.32, and 50% when the peanut plants were treated with gypsum plus $\text{Ca}(\text{NO}_3)_2$, $\text{Ca}(\text{NO}_3)_2$, and 100% nano $\text{Ca}(\text{NO}_3)_2$ treatments, respectively. In addition, the treatments of gypsum plus $\text{Ca}(\text{NO}_3)_2$, $\text{Ca}(\text{NO}_3)_2$, and 100% nano $\text{Ca}(\text{NO}_3)_2$ significantly increased the oil yield by 117.10, 66.85, and 58.21%, and the protein yield by 140.57%, 79.80%, and 68.99%, respectively.

Figure 2. Effect of conventional calcium and nano calcium forms on seed yield (kg ha^{-1}) in peanuts during the two seasons of 2015 and 2016 under sandy soil conditions. Columns labeled with different letters are significantly different at $p \leq 0.05$.

Figure 3. Effect of conventional calcium and nano calcium forms on oil yield (kg ha^{-1}) in peanuts during the two seasons of 2015 and 2016 under sandy soil conditions. Columns labeled with different letters are significantly different at $p \leq 0.05$.

Our data showed that calcium nitrate plus gypsum significantly increased the peanut yield under sandy soil conditions. In agreement with our findings, Gashti et al. [57], Yadav et al. [30], and Thilakarathna et al. [29] reported that the application of gypsum significantly increased peanut yield. In addition, the appropriate rate of Ca^{2+} was found to be critical to get the optimum pod yield of peanuts [58]. Moreover, Kamara [59] and Gashti et al. [57] found a positive effect for calcium on the pod, seed, and biological yield of peanuts. Rahman [60] reported that Ca^{2+} significantly affected all of the yield components with the increasing level of Ca^{2+} from 0–100 kg ha^{-1} . Zharare et al. [61] indicated that the pod-zone Ca^{2+} availability significantly affected peanut growth. In context, the application of gypsum significantly increased the weight of the pods plant^{-1} [57,62]. Thilakarathna et al. [29] concluded that gypsum significantly increased the seed weight and quality. Nobahar et al. [63] recommended the addition of Ca^{2+} and Zn fertilizers to improve

the peanut yield. However, Tillman et al. [52] and Chalwe et al. [64] found no clear effect for gypsum on pod yield, while Kamara et al. [65] indicated that calcium application improved the oil content and phosphorus application increased the protein content of the seeds. Howe et al. [66] found that the peanut yield was not increased by gypsum application if the soil Ca^{2+} levels were already sufficient. In addition, Vidya-Sagar et al. [67] indicated that the addition of gypsum increased the haulm yield and kernel yield of the peanut crop.

4. Conclusions

The present study indicated that the application of gypsum as a soil amendment and calcium nitrate as a foliar application is more favorable than other nano calcium treatments to improve the yield and quality parameters in peanuts. The conventional treatment of gypsum plus $\text{Ca}(\text{NO}_3)_2$ resulted in the greatest seed yield, the highest oil yield, and the highest protein yield. Peanuts may benefit from the calcium in a better way using gypsum as the soil application and calcium nitrate as a foliar application to prevent disorders of Ca^{2+} deficiency under sandy soil and saline irrigation water conditions.

Supplementary Materials: The following are available online at <https://www.mdpi.com/article/10.3390/agriculture11080767/s1>, Figure S1: Field Study layout at Cairo University Desert Research Site (Wadi El-Natroon, Egypt), Table S1: Effect of conventional calcium and nano calcium forms on growth and yield components of peanut during the two seasons of 2015 and 2016 under sandy soil conditions at field experiments Wadi El-Natroon, Egypt, Table S2: Effect of conventional calcium and nano calcium forms on quality traits of peanut during the two seasons of 2015 and 2016 under sandy soil conditions at field experiments Wadi El-Natroon, Egypt, Table S3: Effect of conventional calcium and nano calcium forms on yields of peanut during the two seasons of 2015 and 2016 under sandy soil conditions at field experiments Wadi El-Natroon, Egypt.

Author Contributions: Conceptualization, M.A.; data acquisition, M.H. (Mohamed Hamza) and A.A.E.; design of methodology M.H. (Mohamed Hamza), M.H. (Mohamed Helal) and A.A.E.; writing and editing, M.S. and M.A. All authors have read and agreed 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.

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

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