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Impact of Different Fertilization Levels on the Growth, Leaf Mineral Content, Yield and Fruit Quality of Pummelo (*Citrus maxima*) Trees

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Abstract

This study was conducted on six-year-old ‘Moneiby’ pummelo trees grown at the experimental farm, Faculty of Agriculture, Kafrelsheikh University, Kafr El-Sheikh, Governorate, Egypt during the 2019 and 2020 seasons. The aim was to evaluate the effect of different levels of fertilization with nitrogen (N), phosphorus (P), potassium (K) and magnesium (Mg) on the vegetative growth, leaf mineral contents, yield and fruit quality of ‘Moneiby’ pummelo trees. Nutrients were applied at the following five different levels: 60:15:60:1 (T_1), 85:20:80:1.25 (T_2), 105:25:100:1.5 (T_3), 125:30:120:1.75 (T_4) and 145:35:140:2 (T_5) unit/feddan/year, respectively. The obtained results indicate that fertilization with NPK and Mg at 125:30:120:1.75 and 145:35:140:2 unit/feddan/year (T_4 and T_5), respectively improved tree growth in terms of shoot length, diameter, leaf area, the annual increase of tree height, trunk circumference and canopy volume as well as leaf N, P, K, Ca, Mg, Fe, Mn and Zn contents during both seasons. Thereby, the best fruit set, and lowest June and preharvest fruit drops percentages were also achieved with both treatments. All treatments effectively improved fruit yield and quality compared to control during both seasons. Overall, the best results were achieved with T_4 under the clay soil conditions.

Keywords: *Shaddock*, *Citrus maxima*, fertilization, quality.

Introduction

Pummelo or Shaddock (*Citrus maxima* (Burm.) Merrill.) is a medium-size and high-yield tree. Fruit is the largest compared to all other citrus species; 10-20 cm in diameter with a reltaively sweet flavour **(Bhende and Pavithra 2020)**. The peel is too thick, thereby fruit has a long shelf life, with high resistance to pests and diseases and possibility of safe transportation to distant markets **(Ahmed *et al.*, 2015)**. Fruit has high nutritional value, in terms of high carbohydrates and fibers, low protein and fat, excellent source of calcium (Ca), phosphorus (P), iron (Fe), potassium (K) and vitamins A, C, and B complex (i.e., B_1, B_2, B_3) **(Vijaylakshmi and Radha 2015)**. Despite the trees are growing well under the Egyptian environmental conditions, the fruit is still not widely known for both growers and consumers, compared to all other citrus crops (**El-Hamady *et al.*, 2009)**. However, the popularity of the fruit may increase on the future due to people’s increased health awareness. In general, pummelo tree requires a large amount of nutrients in order to grow and produce well with high fruit quality under the Egyptian conditions. Adequate supply of N, P, K, Mg, S and micronutrients is important to improve growth and productivity. In this respect, **Thamrin *et al.*, (2015)** revealed that NPK complex (450: 582: 496 g/tree) resulted in the highest yield and average fruit weight per tree. **Fernandez and Guzman (2019a)** concluded that K level from 150 to 225 g/tree increased the number of flowers and fruit set, and eventually the total yield. Also, **Fernandez and Guzman (2019b)** reported that increasing K_2O level from 150 to 225 g/tree/year resulted in the highest tree height and canopy volume with enhanced fruit yield and characteristics of ‘Magallanes’ pummelo. **Jian-Ping *et al.*, (2014)** showed that pummelo trees fertilized with N: P_2O_5: K_2O: CaO: MgO at 1: 0.5: 1: 1.1: 0.4, respectively showed the highest yield and good fruit quality with reduced cracking percentage. In this regard, there is no current known fertilization treatments for pummelo production in Egypt. Therefore, this study aims to evaluate the effect of N, P, K and Mg fertilization on growth and productivity of ‘Moneiby’ pummelo trees under the Egyptian conditions.

Materials and Methods

The present study was carried out on six-year-old 'Moneiby'pummelo (*Citrus maxima*, Merr.) trees budded on volkamer lemon (*Citrus volkameriana* Ten & Pasq) rootstock, planted at 5×5 m spacing in clay soil under flood irrigation system at the experimental farm of the faculty of Agriculture, Kafrelsheikh University, Kafr El-Sheikh, Governorate, Egypt, during the 2019 and 2020 seasons. Soil samples were collected at 0-60 cm depth using Auger (10 cm diameter and 30 cm length), analyzed according to **Page *et al.* (1982)**, and displayed in Table (1). Five treatments were arranged in a randomized complete block design (RCBD) of three replicates with three trees per each, as shown in Table (2).

The fertilizers were added annually to the soil under the canopy at 50 cm apart from the tree trunk. The following fertilizers were added: 1) ammonium nitrate (NH_4NO_3, 33.5% N) was divided in three equal doses and applied at the first week of March, June and August; 2) Calcium super phosphate ($Ca(H_2PO_4)_2$, 15.5% P_2O_5) was applied once in December during the winter cultural practices; 3) potassium sulphate (K_2SO_4, 48% K_2O) was applied at two equal doses on March and late June; and 4) magnesium sulphate ($MgSO_4$, 14% MgO) was applied at two equal doses by mid-February and mid-July. In addition, all trees annually received sulphur as gypsum ($CaSO_4.2H_2O$) during the winter cultural practices in late December. Trees also sprayed three times in March, July and August of each season with a micronutrient mixture of chelated Fe, Mn, Zn and Cu at 300, 150, 100, 50 and 50 mg/L, respectively.

Table 1. Soil analysis at the experimental site

Soil depth (0– 60 cm)			
Parameters	Value	Parameters	Value
Sand (%)	6.88	Mg^{2+} (meq/L)	2.25
Silt (%)	32.31	Na^{+} (meq/L)	1.50
Clay (%)	60.81	HCO_3^{-} (meq/L)	1.35
Texture grade	Clay	Cl^{-} (meq/L)	0.65
pH (1:2.5 solution)	8.08	SO_4^{2-} (meq/L)	4.15
EC dSm^{-1} (1:5 solution)	0.60	CO_3^{2-}	0.00
Organic matter (%)	1.15	Total N (%)	0.129
K^{+} (meq/L)	0.35	Available P (mg/kg soil)	11.45
Ca^{2+} (meq/L)	2.05	Available K (mg/kg soil)	750

Table 2. Used fertilizers and rates

Treatment (N: P: K: Mg unit/feddan/season)	kg/feddan/season			
	NH_4NO_3 (33.5% N)	$Ca(H_2PO_4)_2$ (15.5% P_2O_5)	K_2SO_4 (48% K_2O)	$MgSO_4$ (14% MgO)
T_1: 65: 15: 60: 1 (Control)	194.0	96.7	125.0	7.1
T_2: 85: 20: 80: 1.25	253.7	129.0	166.6	8.9
T_3:105: 25: 100: 1.50	313.4	161.2	208.3	10.7
T_4:125: 30: 120: 1.75	373.1	193.5	250.0	12.5
T_5:145: 35: 140: 2	432.8	225.8	291.6	14.2

Four 2-inch-diameter branches per tree were selected and tagged at four different directions to determine the following variables:

1. Vegetative growth and tree size:

The percentage of increase in tree height (cm), trunk circumference (cm) and canopy volume (m^3) were calculated according to the following equation: Percentage of increase in each variable = $[(X_1 – X_0)/X_0] \times 100$. Where X_1 = final tree height, trunk circumference or canopy volume in December; X_0 = initial tree height, trunk circumference or canopy volume in January. Canopy volume was calculated as follow: Canopy volume = 0.5238 x H x D^2 Where H = tree height and D = tree diameter, according to **Turrell, (1946).** Shoot length (cm), diameter (cm) and leaf area (cm^2) were measured in both seasons.

2. Leaf mineral contents:

Twenty mature leaves were collected from non-fruiting spring shoots in September of each season to determined leaf mineral contents. Leaf samples were dried at 70°C using a heat-dry oven to a constant weight, and then ground and digested using H_2SO_4 and H_2O_2 to determine N, P, K, Ca, Mg, Fe, Mn and Zn contents **(Evenhuis and DeWaard, 1980)**. The contents of N, P and K were determined using the micro-Kjeldahl, spectrophotometer, and flame photometer methods **(A.O.A.C., 1990)**. The atomic absorption spectrophotometer (Unican SP 1900) was used to determine Ca, Mg, Fe, Mn and Zn according to **Chapman and Pratt (1978)**.

3. Fruit set and drop percentages:

- Initial and final fruit set (%) were calculated as follow:

Initial fruit set (%)

$$= \frac{\text{total number of fruits}}{\text{total number of flowers}} \times 100$$

Final fruit set (%)

$$= \frac{\text{total number of fruits after June drop}}{\text{total number of fruits}} \times 100$$

- June and preharvest fruit drop (%) were calculated as follow:

June drop (%)

$$= \frac{\text{total number of fruits} - \text{total number of fruits after June drop}}{\text{total number of flowers}} \times 100$$

Preharvest drop (%)

$$= \frac{\text{total number of fruits} - \text{total number of mature fruits}}{\text{total number of fruits}} \times 100$$

4. Total yield:

Fruits were harvested at December 21th and 17th in 2019 and 2020 seasons, respectively. The yield of each replicate was determined as kg/tree, then total yield as ton/feddan was calculated. The fruit of each tree were divided into three groups according to their diameter; large (>13.5 cm), medium (9.5–13.5 cm), and small (< 9.5 cm).

5. Fruit quality:

Twelve fruits were randomly collected from each treatment (4 fruit/replicate) to determine fruit length, diameter (cm), weight (kg) and size (liter), and peel thickness (cm). The percentage of peel, juice and rag per fruit were determined and calculated as follow:

$$\text{Peel, juice or rag (\%)} = \frac{\text{Weight of peel,juice or rag (g)}}{\text{Fruit weight (g)}} \times 100$$

Fruit soluble solid contents (SSC %) was determined using a hand-held refractometer. Titratable acidity (TA %) was determined as citric acid, and then SSC: acid ratio was calculated. Ascorbic acid (mg/100 ml juice) was determined using 2, 6 dichlorophenol indophenol, according to **(A.O.A.C., 1990)**. In addition, chlorophyll and carotene pigments were calculated as mg/100 g fresh weight of fruit peel using the following equations according **to Wettstein (1957):**

Chlorophyll a = (9.784) x extinction on 662 nm-(0.99) x extinction on 644 nm = mg/100 g.

Chlorophyll b = (21.426) x extinction on 644 nm - (4.65) x extinction on 662 nm = mg/100 g.

Carotene = (4.695) x extinction on 440 nm-(0.268) x extinction of (a + b) = mg/100 g.

Statistical analysis was conducted as analysis of variance (ANOVA), and the least significant differences (LSD) at $p \leq 5\%$ was used for mean comparisons **(Snedecor and Cochran, 1990)**.

Results and Discussion

1. Vegetative growth and Tree size:

The annual increase in tree height, trunk circumference and canopy volume were a result of the significant increase in shoot length and diameter, as well as leaf area of 'Moneiby' pummelo trees in response of N, P, K and Mg fertilization during both seasons (Table 3).

Table 3. Effect of different fertilization treatments on some vegetative growth parameters of 'Moneiby' pummelo trees during the 2019 and 2020 seasons.

Treatment (N: P: K: Mg unit/feddan/season)	Annual increment of tree height (cm)		Annual increment of tree trunk circumference (cm)		Annual increment of tree canopy volume (m^3)	
	2019	2020	2019	2020	2019	2020
T^1: 65: 15: 60: 1 (Control)	33.91	40.87	4.18	4.39	6.19	7.57
T_2: 85: 20: 80: 1.25	35.84	47.95	4.33	4.60	6.29	7.88
T_3:105: 25: 100: 1.50	46.58	54.96	4.49	5.29	6.63	8.82
T_4:125: 30: 120: 1.75	57.23	67.10	4.50	5.63	8.20	8.96
T_5:145: 35: 140: 2	61.12	69.36	4.71	5.21	7.37	8.80
L.S.D. ($p \leq 5\%$)	2.46	3.47	0.05	0.09	0.08	0.16
Treatment (N: P: K: Mg unit/feddan/season)	Shoot length (cm)		Shoot diameter (cm)		Leaf area (cm^2)	
	2019	2020	2019	2019	2020	2019
T_1: 65: 15: 60: 1 (Control)	25.23	31.63	4.51	7.45	33.40	35.58
T_2: 85: 20: 80: 1.25	27.21	32.58	5.50	7.62	34.00	37.07
T_3:105: 25: 100: 1.50	27.45	34.97	6.09	8.15	34.48	37.65
T_4:125: 30: 120: 1.75	30.17	40.55	7.20	8.81	35.36	39.16
T_5:145: 35: 140: 2	28.94	36.44	6.12	8.37	34.69	38.71
L.S.D. ($p \leq 5\%$)	0.28	1.81	0.11	0.08	0.38	0.18

Trees fertilized with T_4 and T_5 recorded the highest values of vegetative growth and tree size parameters in both seasons. These results agree with those of **Habasy (2017)** and **Ennab *et al.*, (2019)** on navel orange. **Fernandez and Guzman (2019b)** reported that application of 225g K_2O significantly increased pummelo tree size. Similar results were reported on Valencia orange **(El-Sayed and Ennab, 2013)**. **Ismaiel and Habasy (2021)** stated that Balady lime trees budded on volkamer lemon rootstock and fertilized with NPK at 750:500:500 units, respectively showed a significant improvement in shoot length, leaf number per shoot and leaf area, compared to other rates (e.g., 500:250:250 and 1000:750:750, respectively). The positive role of T_4, and T_5 treatments maybe due to the high available nutrient contents in root zone, which reflected on the uptake of available nutrients, and hence improved cell division and elongation; resulted in increased the tree growth and size **(Ennab, 2016 & Fayaz *et al.*, 2020)**.

2. Leaf mineral contents:

Data presented in Table 4 showed that in most cases N, P, K and Mg fertilization improved leaf N, P, K, Ca, Mg, Fe, Mn, and Zn contents of 'Moneiby'pummelo trees compared to the control during both seasons. The most conspicuous effect on N, K, and Ca contents was recorded for both T_5 followed by T_4 treatments with no significant differences between both treatments in both seasons. On the other hand, there were no significant differences on leaf P and Mg contents in both seasons. These results are in consistence with previously reported findings on pummelo trees (**Nguyen *et al.*, 2017; Fernandez and Guzman, 2013**). It was reported that leaf N, P, K, Mg, Fe, Zn, and B contents were significantly improved in pummelo trees received NPK fertilization at 450 N: 247.5 P: 438 K kg/hectare. These results could be attributed to the balanced fertilization of NPK in root zone, which led to better uptake of available nutrients that eventually improved leaf nutrient contents **(Li *et al.*, 2017)**. Results also indicated that application of T_5 or T_4 has resulted in a significant increase in leaf Fe, Mn, and Zn contents in both seasons (Table 4). **Nguyen *et al.*, (2016)** reported that soil application of ammonium sulphate $(NH_4)_2SO_4$, potassium chloride KCl and magnesium sulphate $MgSO_4$ fertilizers increased Mn and Fe, but decreased Zn contents in pummelo leaves. Also, **Karuna *et al.*, (2017)** found that increasing the rates of NPK from 40 to 120% from recommended doses 300:90:90 g/tree/year improved leaf Fe, Mn, and Zn contents in Kinnow mandarin. So, it could be concluded from Tables (3 and 4) that T_5 and T_4 treatments improved nutrient uptake by roots, and hence overall vegetative growth and tree size.

Table 4. Effect of different fertilization treatments on leaf nutrient contents of 'Moneiby'pummelo trees during the 2019 and 2020 seasons.

Treatment (N: P: K: Mg unit/feddan/season)	N (%)		P (%)		K (%)		Ca (%)	
	2019	2020	2019	2020	2019	2020	2019	2020
T_1: 65: 15: 60: 1 (Control)	2.52	2.59	0.26	0.24	1.64	1.70	2.81	2.90
T_2: 85: 20: 80: 1.25	2.56	2.62	0.24	0.25	1.69	1.76	2.97	3.07
T_3:105: 25: 100: 1.50	2.59	2.66	0.25	0.25	1.79	1.89	3.93	4.00
T_4:125: 30: 120: 1.75	2.65	2.68	0.26	0.26	1.83	1.84	3.80	3.87
T_5:145: 35: 140: 2	2.69	2.74	0.27	0.27	1.86	1.96	4.03	4.16
L.S.D. ($p \leq 5\%$)	0.10	0.08	ns	ns	0.06	0.20	0.11	0.08
Treatments of N, P, K and Mg units/feddan/year	**Mg (%)**		**Fe (mg/L)**		**Mn (mg/L)**		**Zn (mg/L)**	
	2019	2020	2019	2020	2019	2020	2019	2020
T_1: 65: 15: 60: 1 (Control)	0.45	0.46	65.90	76.60	39.7	41.0	42.3	38.0
T_2: 85: 20: 80: 1.25	0.45	0.46	65.50	77.40	39.1	41.6	42.6	38.9
T_3:105: 25: 100: 1.50	0.46	0.46	67.40	79.60	40.2	42.8	43.2	39.9
T_4:125: 30: 120: 1.75	0.47	0.47	68.00	82.00	41.1	43.7	44.0	40.7
T_5:145: 35: 140: 2	0.47	0.48	68.70	84.00	41.5	44.7	44.4	41.7
L.S.D. ($p \leq 5\%$)	ns	ns	1.14	3.40	0.87	0.33	0.59	0.45

3. Fruit set and drop percentages:

Fruit set and drop percentages were positively affected with fertilization treatments as compared with the control treatment in both seasons (Table 5). Both T_4 and T_5 treatments recorded the highest initial and final fruit sets, as well as the lowest June and preharvest fruit drops in both seasons. Similar results were reported by **El-Sayed and Ennab (2013)** where the initial and final fruit sets of Valencia orange trees were positively increased by N fertilization at 900 g/tree/year, with decreased June and preharvest fruit drops. **Nartvaranant, (2020)** stated that higher N fertilization rate at 900 g/tree/year improved fruit set percentage of pummelo trees. In this respect, **Fernandez and Guzman `(2019a)** revealed that K fertilization at 0, 150, and 225 g/tree/year had a positive effect on fruit set percentage of pummelo. **El-Saady and El-Abd, (2012)** stated that application of NPK fertilizer mixture significantly decreased the percentages of June and preharvest fruit drops in navel orange. Also, **Ennab (2016)** revealed that application of moderate rate of NPK fertilizer mixture (750:250:500) led to increased percentages of initial and final fruit sets, but reduced percentages of June and preharvest fruit drops of Eureka lemon trees.

The current results could be attributed to the balanced levels of soil nutrients that led to improved nutrient uptake, and consequently improved vegetative growth, fruit set and reduced fruit drop, which eventually increased total yield**.** **Nartvaranant (2012)** and **Ennab *et al.*, (2019)** reported that balanced fertilization maintained adequate leaf nutrient contents during the vegetative growth cycles of pummelo and navel orange trees. This was also reflected on improved levels of proteins and hormones that improved fruit set and reduced fruit drop waves **(Ennab et al., 2018)**.

Table 5. Effect of different fertilization treatments on fruit set and drop percentages of Pummelo trees during the 2019 and 2020 seasons

Treatment (N: P: K: Mg unit/feddan/season)	Fruit set (%)				Fruit drop (%)			
	Initial		Final		June		Pre-harvest	
	2019	2020	2019	2020	2019	2020	2019	2020
T_1: 65: 15: 60: 1 (Control)	18.1	21.4	3.9	3.5	10.0	10.1	6.2	7.0
T_2: 85: 20: 80: 1.25	19.3	22.5	4.7	4.5	10.0	9.2	5.6	5.8
T_3:105: 25: 100: 1.50	20.0	22.5	4.5	5.1	9.3	9.0	5.2	5.4
T_4:125: 30: 120: 1.75	22.1	23.9	4.7	6.3	8.0	7.7	4.2	3.6
T_5:145: 35: 140: 2	20.0	23.7	5.5	5.8	8.7	7.3	4.3	4.5
L.S.D. ($p \leq 5\%$)	1.15	0.48	0.34	0.20	0.36	0.54	0.18	0.33

4. Total yield:

Results in Figures 1 and 2 showed that the application of N, P, K, and Mg fertilizers have significantly increased fruit yield of 'Moneiby'pummelo trees expressed as kg/tree or ton/feddan in both seasons. Treatments of T_4 (125:30:120:1.75) and T_5 (145:35:140:2) were the most effective in this regard, without significant differences between them in both seasons. These results are in consistence with the findings of **Thamrin *et al.*, (2014)** and **Fernandez and Guzman (2019 a, b)** on pummelo trees. In this respect, **Jian-Ping *et al.*, (2014)** reported that pummelo trees fertilized with N: P_2O_5: K_2O: CaO: MgO at 1: 0.5: 1: 1.1: 0.4 had high yield as fruit number/tree or kg/tree. **Li *et al.*, (2017)** also reported that the number of pummelo fruit per tree and kg/tree were significantly increased with the application of N, P and K at 450, 247.5 and 438 kg/ hectare. The beneficial effect of N, P, K and Mg fertilization on total yield of pummelo maybe due to the positive effect on nutrient uptakes (Tables 4), which reflected on active vegetative growth parameters (Table 3). Also, yield was increase as a result of increased fruit set and decreased fruit drop (Table 5), and these results were in consistence with a previous report by **Fernandez and Guzman (2019b**). Moreover, results in Table 4 also indicated that leaf content of N, P, K, Ca, Mg, Fe, Mn, and Zn in the range for optimum fruit yield in pummelo trees. These results support the previous findings of **Thamrin *et al.*, (2014), Li *et al.*, (2015)** and **Da *et al.*, (2020).**

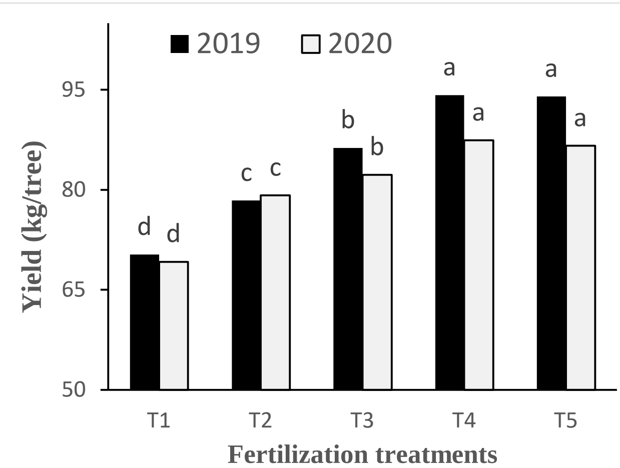

Fig. 1: Effect of different fertilization treatments on yield (kg/tree) of 'Moneiby' pummelo tree

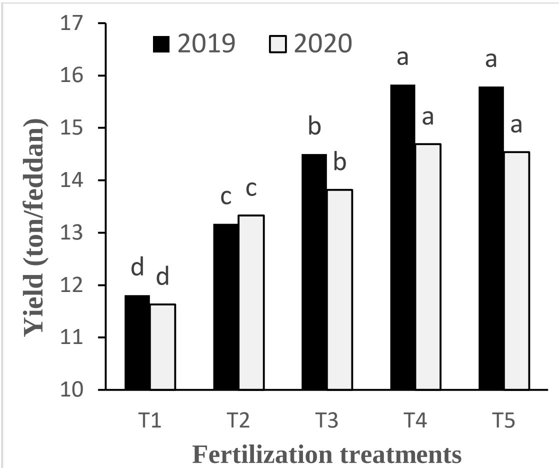

Fig. 2: Effect of different fertilization treatments on total yield (ton/feddan) of 'Moneiby' pummelo tree.

T_1: 65:15:60:1.00 N, P, K, Mg, **T_2:** 85:20:80:1.25 N, P, K, Mg, **T_3:**105:25: 100:1.50 N, P, K, Mg, **T_4:**125:30: 120:1.75 N, P, K, Mg, **T_5:**145:35: 140:2.00 N, P, K, Mg

5. Percentage of fruit size distribution:

Results presented in Table 6 show the effect of NPK and Mg fertilization on fruit size distribution of 'Moneiby' pummelo trees. Generally, it is clear from Table 6 that, fertilization with NPK and Mg produced the larger fruits by 26.6% followed by medium fruits with 51.4 percent compared to 22.0% small fruit. Moreover, all different fertilization levels of NPK and Mg led to produced higher medium fruits as compared with small and large fruits, and also all levels were found to be at par in medium fruits values in both seasons. Whereas, application of T_4 (125:30:120:1.75) and T_5 (145:35:140:2) significantly increased the percentage of large fruits and reduce small fruits. In contrary, application of T_1 (60:15:60:1) and T_2 (85:20:80:1.25) produced high percent of small fruits, but larger fruits were low. Thus, it is obvious from Figures 1, 2 and Table 6 that, 'Moneiby' pummelo trees fertilized with T_4 (125:30:120:1.75) and T_5 (145:35:140:2) obtained the best yield with high percent of medium and large fruits in both seasons. Similar results were reported by **Cerda *et al.*, (2012)** where the highest total and large fruit yield of grapefruit was achieved with NPK fertilizer mixture at 160-80-95 kg/hectare, respectively. **Fernandez and Guzman (2019a)** found that, K fertilization (225 g/tree/year) produced the optimum medium- and large-size fruit, and total yield in terms of kg/tree and kg/ha^{-1} at harvest.

Table 6. Effect of different fertilization treatments on fruit size distribution according to 'Moneiby' pummelo fruit diameter during the 2019 and 2020 seasons.

Treatment (N: P: K: Mg unit/feddan/season)	Fruit size distribution (%)					
	Small (< 9.5 cm)		Medium (9.5–13.5 cm)		Large (> 13.5 cm)	
	2019	2020	2019	2020	2019	2020
T_1: 65: 15: 60: 1 (Control)	30.41	32.73	54.83	51.13	14.76	16.14
T_2: 85: 20: 80: 1.25	28.94	30.79	50.00	49.70	26.31	25.80
T_3:105: 25: 100: 1.50	13.46	13.24	50.88	51.17	35.66	35.49
T_4:125: 30: 120: 1.75	15.58	15.47	52.04	52.35	29.33	28.65
T_5:145: 35: 140: 2	20.00	19.85	52.00	51.49	32.38	32.18
L.S.D. ($p \leq 5\%$)	0.41	0.29	0.17	0.39	2.13	0.91

6. Fruit quality:

6.1. Physical characteristics:

The soil application of N, P, K and Mg fertilizers has significantly improved fruit length, diameter, weight and size in both seasons (Table 7). The most pronounced effect was similarly recorded for the application of T_4 (125:30:120:1.75) and T_3 (105:25:100:1.5), followed by T_5 (145:35:140:2), in comparison to the control (60:15:60:1). Similar results were reported by **Nguyen *et al.*, (2017)** and **Nartvaranant (2020)** on pummelo trees. In this respect, **Li *et al.*, (2017)** stated that fertilization with NPK fertilizer mixture at 450: 247.5:438 kg/hectare, respectively improved fruit length, diameter, size and weight of pummelo trees. **Fernandez and Guzman (2019a)** observed that K fertilization improved fruit dimensions, size and weight of pummelo fruit.

'Moneiby' pummelo trees fertilized with T_3 (105:25:100:1.5) showed the highest juice percentage, followed by T_2 (85:20:80:1.25) in the first season and T_5 (145:35:140:2) in the second season, compared to the control. However, fruit rag weight percentage was the reported the highest with the application of T_1 (60:15:60:1, the control) and T_4 (125:30:120:1.75), whereas the lowest value was recorded for T_3 (105:25:100:1.5) in both seasons (Table 7). Application of T_5 (145:35:140:2) and T_4 (125:30:120:1.75) resulted in the highest values of peel percentage per fruit, while the lowest percentage was observed in T_3 (105:25:100:1.5) during both seasons. The highest peel thickness (cm) was recorded for T_5 (145:35:140:2), but the lowest was recorded for T_3 (105:25:100:1.5) in both seasons. **El-Zawily, (2016)** stated that fertilization with N, P, and K fertilizer mixture improved fruit physical structure (i.e., reduced fruit rag weight and peel weight, but increased juice percentages) of Washington navel orange fruit. **Ennab, (2017)** mentioned that N fertilization at 750 g/tree/year had significantly improved physical fruit characteristics, such as fruit length, diameter and weight, as well as peel and pulp percentages, and juice volume of mandarin fruit.

6.2. Chemical characteristics:

Data in Table 8 clearly indicated that the effect of N, P, K and Mg fertilization effectively improved fruit chemical characteristics that were characterized by increased levels of SSC and vitamin C, along with reduced levels of TA and SSC: TA ratio in both seasons (Table 8). The percentage of SSC was the highest in trees subjected to T_3 (105:25:100:1.5) and T_2 (85:20:80:1.25), while the lowest percentage was recorded in T_5 (145:35:140:2)-treated trees, which also recorded the highest fruit TA percentage and the lowest SSC: TA ratio with no significant differences compared to the control in both seasons. The highest SSC: TA ratio was related to the application of T_1 (60:15:60:1) and T_2 (85:20:80:1.25) in both seasons. In addition, both T_3 (105:25:100:1.5) and T_4 (125:30:120:1.75) similarly recorded the highest vitamin C content compared to the control (T_1 60:15:60:1) and other treatments in both seasons.

The results of Figures 3 and 4 revealed that application of either T_5 (145:35:140:2) or T_4 (125:30:120:1.75) resulted in the highest significant increase in total chlorophyll content of fruit peel, compared to the lowest values recorded in T_3 (105:25:100:1.5) during both seasons. The highest values of carotene content in fruit peel were recorded in T_3 (105:25:100:1.5)-treated trees, compared to the lowest value in T_5 (145:35:140:2)-treated ones during both seasons. These results support the previous findings of **Jian-Ping *et al.*, (2014), Fernandez and Guzman (2013)** and **Li *et al.*, (2015)** on pummelo fruit.

Table 7. Effect of different fertilization treatments on 'Moneiby' pummelo physical fruit characteristics in 2019 and 2020 seasons

Treatment (N: P: K: Mg unit/feddan/season)	Fruit length (cm)		Fruit diameter (cm)		Fruit weight (kg)		Fruit size (liter)	
	2019	2020	2019	2020	2019	2020	2019	2020
T_1: 65: 15: 60: 1 (Control)	12.5	10.5	13.6	12.0	0.91	0.72	1.51	0.85
T_2: 85: 20: 80: 1.25	14.0	12.5	15.3	14.0	1.00	.84	1.71	1.74
T_3:105: 25: 100: 1.50	15.0	16.8	18.2	19.0	1.85	1.81	2.28	3.09
T_4:125: 30: 120: 1.75	16.0	17.4	17.3	18.4	1.45	1.44	2.39	2.52
T_5:145: 35: 140: 2	13.0	14.5	13.6	16.5	1.21	1.25	1.59	2.15
L.S.D. ($p \leq 5\%$)	1.22	1.54	1.42	1.22	0.24	0.07	0.12	0.10
Treatment (N: P: K: Mg unit/feddan/season)	**Fruit rag (%)**		**Peel (%)**		**Juice (%)**		**Peel thickness (cm)**	
	2019	2020	2019	2020	2019	2020	2019	2020
T_1: 65: 15: 60: 1 (Control)	38.35	36.94	24.11	26.17	37.54	36.89	1.60	1.64
T_2: 85: 20: 80: 1.25	31.78	31.11	25.09	28.26	43..13	40.63	1.58	1.62
T_3:105: 25: 100: 1.50	31.11	30.12	22.50	24.28	46.39	44.98	1.53	1.57
T_4:125: 30: 120: 1.75	34.24	31.29	27.08	28.18	38.68	40.53	1.62	1.66
T_5:145: 35: 140: 2	32.04	30.74	27.24	28.73	40.72	41.15	1.88	1.92
L.S.D. ($p \leq 5\%$)	1.47	0.21	0.39	0.14	0.11	0.15	0.17	0.05

Table 8. Effect of different fertilization treatments on 'Moneiby' pummelo fruit chemical characteristics during the 2019 and 2020 seasons.

Treatment (N: P: K: Mg (unit/feddan/season)	SSC (%)		Acidity (%)		SSC/acid ratio		Vitamin C (mg/100 ml juice)	
	2019	2020	2019	2020	2019	2020	2019	2020
T_1: 65: 15: 60: 1 (Control)	11.60	11.69	0.65	0.62	18.74	18.30	75.11	71.18
T_2: 85: 20: 80: 1.25	11.76	11.81	0.69	0.68	18.67	17.12	75.36	73.23
T_3:105: 25: 100: 1.50	12.49	12.21	0.78	0.78	16.71	16.34	75.88	76.38
T_4:125: 30: 120: 1.75	11.34	11.48	0.78	0.79	14.36	15.52	76.98	74.52
T_5:145: 35: 140: 2	09.59	10.2	0.94	0.93	10.31	10.85	75.19	74.45
L.S.D. ($p \leq 5\%$)	0.37	0.19	0.26	0.27	1.07	0.70	0.82	0.79

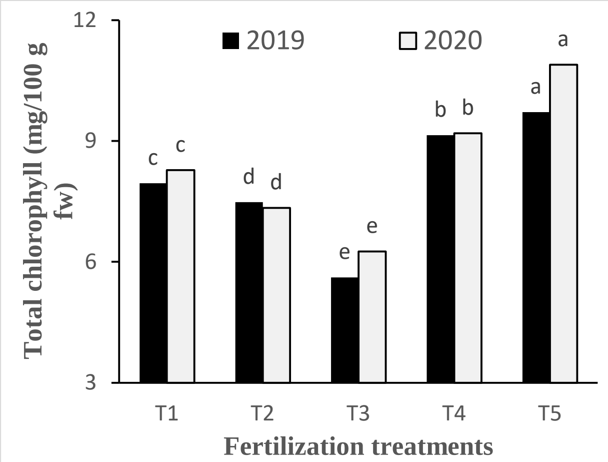

Fig. 3: Effect of different fertilization treatments on 'Moneiby' pummelo fruit peel's total chlorophyll content during the 2019 and 2020 seasons

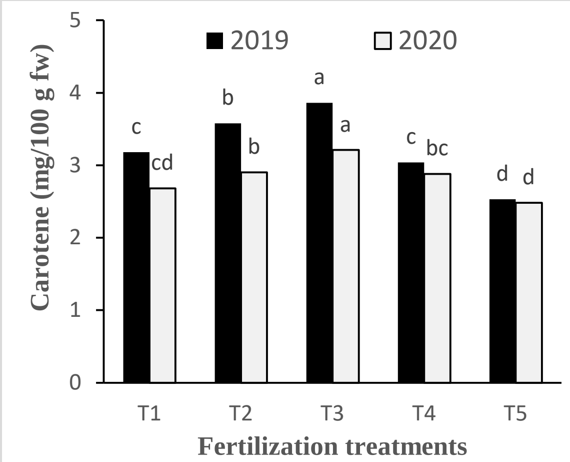

Fig. 4: Effect of different fertilization treatments on 'Moneiby' pummelo fruit peel's carotene content during the 2019 and 2020 seasons

T_1: 65:15:60:1.00 N, P, K, Mg, T_2: 85:20:80:1.25 N, P, K, Mg, T_3:105:25: 100:1.50 N, P, K, Mg, **T_4**:125:30: 120:1.75 N, P, K, Mg, T_5:145:35: 140:2.00 N, P, K, Mg

Generally, the physical and chemical characteristics of 'Moneiby' pummelo fruit were significantly improved with different N, P, K and Mg fertilization levels. The application of T_3 (105:25:100:1.5) and T_4 (125:30:120:1.75) has significantly improved fruit size, weight, length and diameter, and juice percentage. They also decreased fruit rag percentage, peel thickness and total chlorophyll content of fruit peel, compared to the all-other treatments. It could be suggested that applying N, P, K and Mg fertilization mixture at 125:30:120:1.75 units/feddan/year, respectively (T_4) is considered the best treatment to improve 'Moneiby' pummelo fruit quality.

Conclusions

The current findings indicated that soil N, P, K and Mg fertilization effectively improved nutrient levels in root zone of 'Moneiby' pummelo trees grown in clay soils, and consequently improved tree growth and nutritional status, and hence productivity and fruit quality. The most pronounced effect was recorded for the application of 125:30:120:1.75 N, P, K, Mg unit/feddan/year (T_4), respectively, in terms of improved fruit weight, size, SSC and vitamin C with reduced peel thickness and total chlorophyll content.

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تأثير التسميد بمستويات مختلفة على النمو و المحتوى المعدنى للأوراق و المحصول و جودة ثمار أشجار الشادوك

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أجريت تجربة حقلية خلال موسمى 2019 و 2020 على أشجار الشادوك صنف منيبى عمرها 6 سنوات مطعومة على أصل الفولكاماريانا و المزروعة على مسافة 5 × 5 متر فى مزرعة كلية الزراعة – جامعة كفر الشيخ – محافظة كفر الشيخ، مصر. تهدف الدراسة إلى تقييم تأثير التسميد بالنيتروجين و الفوسفور و البوتاسيوم و الماغنسيوم على النمو الخضري و المحتوى المعدنى للأوراق و المحصول و جودة ثمار أشجار الشادوك. إشتملت التجربة على خمس معاملات، المعاملة الأولى 1:60:15:60، المعاملة الثانية 1.25:80:20:85، المعاملة الثالثة 1.5:100:25:105، المعاملة الرابعة 1.75:120:30:125، المعاملة الخامسة 2:140:35:145 و حدة نيتروجين : فوسفور : بوتاسيوم : ماغنيسيوم فدان/سنة على التوالى.

أظهرت النتائج: أن التسميد بالمعاملة الرابعة 125: 30:120: 1.75 و المعاملة الخامسة 145: 35: 140: 2 وحدة / فدان / سنة أديا إلى تحسين النمو الخضرى من حيث طول و سمك النمو و المساحة الورقية و زيادة حجم الشجرة المتمثل فى الزيادة السنوية في إرتفاع الشجرة ومحيط الجذع لأشجار الشادوك في كلا الموسمين. كما أدى إستخدام أسمدة النيتروجين و الفوسفور و البوتاسيوم و الماغنسيوم فى كلا من المعاملة الرابعة و الخامسة إلى زيادة معنوية في محتوى الأوراق من N ، P، K، Mg، Ca، Feو Mn و Zn في كلا الموسمين. علاوة على تحسين النسبة المئوية لعقد الثمار وتقليل تساقط الثمار سواء تساقط يونيو أو تساقط ماقبل الجمع . أيضا زاد المحصول و تحسنت صفات جودة الثمار معنويا بكل معاملات التسميد و خاصة المعاملة الثالثة و الرابعة .

لذلك توصى هذة الدراسة باستخدام المعاملة الرابعة و هى إضافة عناصر النيتروجين و الفوسفور و البوتاسيوم و المغنسيوم إلى أشجار الشادوك بمعدل 125: 30: 120: 1.75 وحدة / فدان / سنة والتي أعطت أفضل نمو ومحصول وجودة ثمار لأشجار الشادوك المزروعة في بتربة طينية تحت ظروف محافظة كفر الشيخ