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Potassium Fertilization for Higher Flowering and Fruit Yield in ‘Magallanes’ Pummelo (*Citrus maxima*)

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Authors’ contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

This study aimed to determine the influence of Potassium (K) fertilization on the flowering and fruit yield of 13-year old ‘Magallanes' pummelo [*Citrus maxima* (Burm. ex Rumph.) Merr.] trees. The experiment was conducted at South Davao Corporation (SODACO) farm, Davao City, Philippines for 12-month duration. Five treatments with increasing K levels were applied per tree: control, no K, 150 g K basal, 225 g K basal, and 225 g K basal + foliar application. Flowering, fruit set and yield of pummelo were enhanced by higher K rates. Flowering was increased by 4 times while fruit set by 86-100%. Fruit number was increased by 7 times, weight per fruit by 22-26%, and yields up to 9 times with 100% (return of investment) ROI on trees applied with 225 g K rates. The results of the study indicated the important role of K in improving the flowering, fruit yield and income of ‘Magallanes' pummelo.

Keywords: Flowering; fruit yield; potassium; pummelo; foliar; fertilization.

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1. INTRODUCTION

'Magallanes' pummelo is one of the best pink varieties originated in Davao City growing as large as 16 cm in diameter and weighing as much as 1.4 kg. For trees over ten years old, the yield of 20 t/ha is considered economically beneficial [1].

At present, there is much interest in citrus fruits because they are one of the major sources of antioxidants called flavonoids in the human diet. Pummelo is an excellent source of antioxidant flavonoids [2] and about twice the daily recommended amount of vitamin C [3]. It also contains vitamins A, B1, B2, B6 and B12, protein, Ca, fiber, folate, K, and Fe. Hence, pummelo is considered a functional food and potent dietary option for preventing diseases such as cancer, heart disease, hypertension, cholesterol, diabetes, asthma, common colds, inflammation and diverticular diseases [4-6].

Pummelo peel also contains essential oils with applications in the food and flavor industries, cosmetics industry, and medicinal purposes in Oriental cultures [7,8].

As a healthy food with industrial use, there is a big demand for pummelo in both domestic and export market [9]. However, production of pummelo is limited by problems like nutritional disorders and some pests and diseases. Based on the Philippine Statistics Authority, the area devoted to pummelo production in the Philippines, historically (2004-2013) has decreased from 5,211 to 5,164 has. Moreover, the production volume decreased from 35,488 m.t. to 29,940 m.t. from 2004-2013 while no further recent data was available [10].

Thus, there is a need to improve the production of pummelo to cater to the increasing demands of health conscious consumers for both local and export markets. To obtain optimum yields of pummelo growers, it is important to provide an efficient fertilizer program.

Potassium (K) is a macronutrient in plants that has multiple enzymatic and catalytic functions used in many photosynthetic and metabolic processes in plants. Among the important elements in plant nutrition, K is the most abundant element found in fruits and the highest nutrient removed in the soil. Thus, K is considered a key element in fruit production and quality worldwide [11].

Studies on different rates of K fertilizers have been shown to increase the growth and yield of several plants such as 'Shatian' pomelo, orange, grapefruit, lemon, papaya, avocado, watermelon, plum, and peach. The potential effect of K on the flowering, fruit set and fruit yield of pummelo has not been investigated yet; hence, this particular study was conducted.

2. MATERIALS AND METHODS

A field experiment was conducted at South Davao Corporation (SODACO), Calinan, Davao City, Philippines for 12-month duration to evaluate the effect of K application on the flowering, fruit set, yield, and quality of 'Magallanes' pummelo cultivar. The area is located 7° latitudes and 125° longitudes with an elevation of 700 m Mean Sea Level (msl). Based on modified Coronas classification, Davao city belongs to the Type IV climate where rainfall is more or less evenly distributed throughout the year. Meteorological data of the area were taken within the duration of the study at the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) weather station at Sasa, Davao City. Temperature, amount of sunshine, relative humidity, rainfall and wind speed were favorable for the growth and development of pummel (Table 1).

The cultivar used in the study was 13-year old 'Magallanes' pummelo, the major variety grown in Davao region and one of the best pink varieties which originated in Davao City. The experiment was carried out in Randomized Complete Block Design (RCBD). Field experiment was composed of five treatments replicated three times. There were three sample trees per replication per treatment for a total of 45 pummelo trees with a planting distance of 7 x 8 m in a rectangular planting system. Fruits were sampled from middle trees to minimize the border effects. Data were analyzed using Analysis of variance (ANOVA) and means were compared using Honest Significant Difference Test (HSD).

Soil and tissue analyses were done before and after the conduct of the study to determine the nutrient requirement of the trees. Soil and leaf sampling methods were based on the standard procedure given by the Regional Soil Laboratory of the Department of Agriculture, Davao City, Philippines. Soil sample at 30 cm deep was air-dried, pulverized and placed in bags for analysis. Leaf samples using 4-6 months old leaves from

Table 1. Meteorological data of the experimental area during the conduct of the study. Data taken at the PAGASA Davao station, Sasa, Davao city

2010	Mean Temperature (°C)	Maximum Temperature (°C)	Rainfall (Mm)	Relative Humidity (%)	Sunshine (%)	Average Wind Speed (Km/Hr)
January	27.2	30.6	157.5	83	41.5	072
February	27.7	32.5	16.0	78	70.9	072
March	29.0	33.5	52.9	77	71.5	086
April	29.2	32.5	124.0	81	59.0	067
May	29.2	32.8	57.2	82	57.3	059
June	28.8	32.6	87.8	83	57.9	047
July	28.5	31.8	251.6	84	51.5	066
August	28.2	31.9	281.8	84	53.8	072
September	28.5	32.3	117.6	82	57.5	063

Table 2. Soil analysis before and after the conduct of the study

Treatments	Class	pH	OM (%)	OC (%)	N (%)	P (ppm)	K (ppm)
Initial	Clay	5.1	2.82	1.64	1.4	27	228
Control	Clay	4.7	4.75	2.76	2.5	52	300
no K	Clay	5.2	2.86	1.66	1.7	13	295
150 g K basal	Clay	5.4	3.54	2.06	2.3	8	388
225 g K basal	Clay	5.5	3.32	1.93	1.7	27	355
225 g K basal + foliar	Clay	6.0	3.47	2.02	2.1	16	325

All treatments were applied with recommended rate of NP except for the control (no fertilization)

Soil Analysis Legend:	Very low	Low	Medium	High	Very high
pH	<4.4	4.4-5.5	6.1-6.6	7.3-7.8	>9.0
			5.6-6.0	6.7-7.2	8.5-9.0
					7.9-8.4
Organic Matter (OM) Walkey Black (%)	<3.44	3.44-6.88	6.88-17.20	17.20-34.40	>34.40
Organic Carbon (%)	<2	2-4	4-10	10-20	>20
Nitrogen (%) OM (Wilde's Method)	**Low**		**Medium**		**Adequate**
	<1.5		1.6-3.0		>3.0
Olsen Phosphorus (ppm)	**Very low**	**Low**	**Medium**	**High**	**Very high**
	<10	10-20	20-30	30-50	>50
Extractable Potassium (ppm)	**Very deficient**	**Deficient**	**Possibly deficient**		**Adequate**
	<250	260-500	510-750		>750

non-fruiting terminals in the mid-region of the tree were collected and placed in bags for analysis. Result of the soil and leaf tissue analysis before and after the experiment is shown in Table 2. Based on soil and leaf tissue analysis, the treatments were: control, no K, 150 g K basal, 225 g K basal, and 225 g K basal + foliar application.

The area was applied with basal and foliar fertilizers following the recommendations of soil and leaf tissue analysis as practiced by the farm. The different rates of fertilizers were applied in 3 installments: at flushing or flower bud initiation, 30 and 60 days after flowering (DAF). All treatments were applied with recommended rate of NP except for the control (no fertilization). Urea (46-0-0), Complete (14-14-14) fertilizer, Solophos (0-18-0) and Muriate of Potash (0-0-60) were the sources of NPK fertilizers. Fertilizers were applied basally at 1.5-meter radius around the canopy. K foliar fertilizers were prepared by mixing the required amount of K fertilizer in water at the rate of 10 g L^{-1} and applied at 30 and 60 days after fruit set (DAFS) on target fruits and leaves. Adjuvant concentrate was also added to improve performance of the K foliar fertilizer. The pummelo trees were maintained by irrigating, weeding, pruning and applying pesticide and fungicide whenever necessary. The pummelo fruits were harvested after 156 days from fruit set when peel color changed from green to yellow or with 50% color change and produced a hollow sound when tapped. All mature fruits were harvested between 8:00 am and 3:00 pm (with sunlight) to reduce fruit injuries on the peel of pummelo.

2.1 Data Gathered

2.1.1 Effect of K fertilization on the flowering and fruit Set of pummelo

To determine the effect of different rates of K on the flowering and fruit set of 'Magallanes' pummelo, the total number of flowers and number of fruits that set were recorded. There were three sample trees per replication per treatment.

The total number of flowers were counted per tree every month from the start of the study until harvest. The number of fruits that set per tree was counted every month after petal fall from the start of the study until harvest. This was taken by dividing the total number of fruits that set by the total number of flowers multiplied by 100.

2.1.2 Effect of K fertilization on the fruit yield of pummelo

The number of fruits harvested per tree were counted and classified accordingly. The fruit weight per tree and fruit yield was taken. There were three sample trees per replication per treatment. The total number of large, medium, small and seňorita fruits harvested per tree was counted. The weight of fruits after harvest was determined and classified according to large (901-1,150 g or more), medium (651-900 g), small (401-650 g) and seňorita (250-400 g) sizes. The yield (kg/tree) of large, medium, small and seňorita fruits per harvest were taken and the yields of the different fruit sizes in terms of kg ha^{-1} were computed using the formula:

Yield (kg ha^{-1}) = (Yield per tree (kg) / Area per tree (m^2)) x 10,000 m^2

The return of investment (ROI) was determined by recording the total expenses, gross sales of yield and computing the net income per treatment.

3. RESULTS AND DISCUSSION

3.1 Effect of K Fertilization on the Flowering and Fruit Set of Pummelo

The 225 g K basal + foliar treatment had the highest total flowers, total fruits that set and percentage of fruit set in 'Magallanes' pummelo (Table 3). The total flowers in 225 g K basal + foliar treatment increased by 43 flowers compared with the control. The values for the 225 g K basal, 150 g K basal, and no K treatments were statistically the same with that of the control. In terms of total fruits that set, the 225 g K basal + foliar treatment had 26-31 more number of fruits that set than no K treatment and control. Application of 225 g K basal and 150 g K basal treatments had the same effect with the control. The percent fruit set in 225 g K basal + foliar treatment increased from 36-42% and 78% compared with the no K treatment and control, respectively. On the other hand, the 225 g K basal and 150 g K basal treatments were no different from the control.

Though 225 g K basal + foliar increased the total number of flowers and fruit set in 'Magallanes' pummelo, there is still no scientific evidence to prove that K alone has a direct role in citrus flowering and fruit set. K possibly enhanced flowering and fruit set in 'Magallanes' pummelo through activation of enzymes involved in the regulation of flowering and fruit set. K also improves water and nutrient uptake [12], most importantly in the translocation of starch reserve necessary in flower induction of pummelo. Fruit set is apparently supported by the availability of

Table 3. Flowering and fruit set of 'Magallanes' pummelo as influenced by K fertilization

Treatments	Total flowers	Total fruits that set	% Fruit set
Control	10 b	4 c	36 c
no K	21 ab	9 bc	42 bc
150 g K basal	32 ab	15 abc	53 abc
225 g K basal	41 ab	26 ab	75 ab
225 g K basal + foliar	53 a	35 a	78 a

Values with a common letter in a column are not significantly different at 0.05 level using HSD. All treatments were applied with recommended rate of NP except for the control (no fertilization)

Table 4. Number of fruits per tree of ‘Magallanes' pummelo within a size category as influenced by K fertilization

Treatments	Fruit size category				Total
	Seňorita ^{ns} 250-400g	Small ^{ns} 401-650g	Medium 651-900g	Large 901-1,150g	
Control	0.4	0.8	1.2 c	0.2 c	2.7 c
no K	0.4	2.2	2.9 c	0.8 bc	6.3 bc
150 g K basal	0.4	2.3	4.9 bc	2.1 b	9.8 b
225 g K basal	0.6	2.7	10.9 ab	5.4 a	19.6 a
225 g K basal + foliar	0.2	1.6	13.8 a	5.2 a	20.8 a

Values with a common letter in a column are not significantly different at 0.05 level using HSD. All treatments were applied with recommended rate of NP except for the control (no fertilization). ns - no significant difference

nutrients mostly mineral elements, carbohydrates and water [13]. K contributes to phloem loading and transport of sucrose and amino compounds [14] act as an osmoticum to regulate water and solute uptake [15] which are important in fruit set of pummelo. Hence, adequate supply of K ensures higher fruit set. Under severe K deficiency, fruit drop could occur [16].

3.2 Effect of K Fertilization on the Number of Fruits per Tree

Marketable fruits were classified either as Seňorita (250-400 g), Small (401-650 g), Medium (651-900 g) and Large (901-1,150 g or more) sizes [17]. There were more medium fruits in all treatments, comprising 34-56% of the total fruits produced (Table 4). Highest number of medium and large size fruits and total number of fruits per tree were obtained with application of 225 g K rates. There was no observed difference in the medium and large size fruits between the basal and basal + foliar application of 225 g K.

The number of medium fruits per tree in 225 g K rates was higher by 11-13 fruits compared with the no K and control. The control and no K application were not significantly different from the 150 g K basal in terms of number of medium fruits produced. There were 3-5 more number of large fruits and 11-18 more total number of fruits per tree in 225 g K rates compared with the 150 g K, no K and control. The no K treatment was not significantly different from the control and 150 g K treatment in terms of large and total number of fruits produced. However, the number of large fruits and total number of fruits per tree in 150 g K basal were higher by 2 and 7 fruits, respectively than the control.

Results showed that 225 kg K rates significantly increased the number of fruits of ‘Magallanes' pummelo from 3 to 21 fruits, an indication of the function of K in the fruit production of pummelo trees. The same result was also obtained on papaya where K increased the number of papaya fruits per plant [18]. K is involved in the activation of enzymes, improves water and nutrient uptake [12], most importantly in the translocation of starch reserve which are necessary for fruit increase of pummelo.

3.3 Effect of K Fertilization on the Weight per Fruit

The application of 225 g K basal + foliar produced the highest medium and large fruits and average weight per fruit (Table 5). Basal applications of 225 g K and 150 g K were no different from the control and no K. The weight of the medium and large size fruits, and the average weight per fruit in 225 g K basal + foliar increased by 110 g, 171 g 181 g, respectively compared with the control.

Previous studies on citrus also indicated that higher levels of K increased fruit weight of ‘Hamlin,' ‘Pineapple,' and ‘Valencia,' orange cultivars [19,20] and ‘Marsh' grapefruit [21]. Higher K rates with foliar application also increased fruit weight of various crops such as papaya [18], Black Star plum and Royal Glory peach [22]. Fruit weight is enhanced by the availability of nutrients mostly mineral elements, carbohydrates and water [13]. K act as an osmoticum to regulate water and solute uptake [15] and mainly responsible to phloem loading and transport of sucrose and amino compounds [14], which all contributed to heaviness of the fruit.

Thus, application of 225 g K basal + foliar significantly increased the fruit weight (g) of ‘Magallanes' pummelo by 22-26% per fruit compared with the control. This finding indicates the importance of K in increasing the fruit weight of ‘Magallanes' pummelo since fruit price is based on it.

Table 5. Weight (g) per fruit of 'Magallanes' pummelo within a size category as influenced by K fertilization

Treatments	Fruit size category				Average
	Seňorita ^{ns} 250-400g	Small ^{ns} 401-650g	Medium 651-900g	Large 901-1,150g	
Control	304	514	756 b	964 b	683 b
no K	310	571	777 b	973 b	711 b
150 g K basal	325	590	835 ab	1,002 ab	764 ab
225 g K basal	363	599	836 ab	1,030 ab	782 ab
225 g K basal + foliar	350	598	866 a	1,135 a	864 a

Values with a common letter in a column are not significantly different at 0.05 level using HSD. All treatments were applied with recommended rate of NP except for the control (no fertilization). ns - no significant difference

Table 6. Yield (kg/tree/harvest) of 'Magallanes' pummelo within a size category as influenced by K fertilization

	Fruit size category				
Treatments	Seňorita ^{ns} 250-400g	Small ^{ns} 401-650g	Medium 651-900g	Large 901-1,150g	Total (kg/tree)
Control	0.1	0.4	1.0 c	0.2 b	1.7 b
no K	0.1	1.0	1.9 c	1.0 b	3.8 b
150 g K basal	0.1	1.4	3.9 bc	2.2 b	7.5 b
225 g K basal	0.2	1.6	8.3 ab	5.6 a	15.7 a
225 g K basal + foliar	0.1	0.9	11.0 a	5.7 a	17.6 a

Values with a common letter in a column are not significantly different at 0.05 level using HSD. All treatments were applied with recommended rate of NP except for the control (no fertilization). ns - no significant difference

Table 7. Yield (kg ha^{-1}/harvest) of 'Magallanes' pummelo within a size category as influenced by K fertilization

	Fruit size category				
Treatments	Seňorita ^{ns} 250-400g	Small ^{ns} 401-650g	Medium 651-900g	Large 901-1,150g	Total (kg ha^{-1})
Control	24	75	171 c	41 b	312 b
no K	26	184	339 c	176 b	682 b
150 g K basal	24	242	690 bc	384 b	1,340 b
225 g K basal	34	286	1,489 ab	996 a	2,806 a
225 g K basal + foliar	15	157	1,958 a	1,011 a	3,141 a

Values with a common letter in a column are not significantly different at 0.05 level using HSD. All treatments were applied with recommended rate of NP except for the control (no fertilization). ns - no significant difference

Table 8. Cost and return of pummelo per hectare per harvest

Production and maintenance cost of 13-year old Pummelo bearing trees- 178 trees/ha (7x8 m^2)	Control (no fertilizer)	No K	150 g K basal	225 g K basal	225 g K basal + foliar
Gross Sales [Yield (kg/ha x P30.00/kg farm gate price]	312 x 30	682 x 30	1,340 x 30	2,806 x 30	3,141 x 30
Gross Sales	P 9,360	P 20,460	P 40,200	P 84,180	P 94,230
Total Cost of Production	27,250	34,802	35,199	35,760	35,438
Net income	-17,890	-14,342	5001	48,420	58,792
Return on Investment			14%	100%	100%

3.4 Effect of K Fertilization on the Yield per Harvest

The 225 g K rates produced the highest medium and large size fruits and total yield in terms of kg/tree and kg/ha^{-1} per harvest (Table 6-7). The applied 150 g K rate had the same effect with the control and no K in terms of yield.

Application of 225 g K rates increased the yield (kg/tree) per harvest of 'Magallanes' pummelo by 10 kg in medium size fruits, 6 kg in large fruits, and in total yield by 16 kg than the control. The yield of 'Magallanes' pummelo in terms of kg/ha^{-1} per harvest also increased from 171 kg to 1,958 kg in medium size fruits, from 41 kg to 1,011 kg in large size fruits, and from 312 kg to 3,141 kg in total yield with an application of 225 g K rates compared with the control.

The yield obtained in this study was equivalent to 38 t/ha/yr, which was higher compared with the yield of 20 t/ha/yr in mature pummelo trees as reported [1]. Similarly, K fertilization also increased the yield of various crops like orange cultivars [19,20], grapefruit [21], and papaya [18]. This showed that 225 g K rates increased the yield of the 'Magallanes' pummelo which entails a role of K in the fruit production of pummelo.

The functions of K on the growth and development of plants are well-documented. Owing to its high mobility, K increased the fruit number, weight and yield by activating enzymes for the synthesis of proteins and carbohydrates and helping in the transport of sugars, water and nutrients from the source to the sink since fruits have stronger sink [12,14,23,24]. Hence, available K in the fruits and leaves must be adequate to facilitate fruit growth for optimum fruit production.

3.5 Cost and Return Analysis of Pummelo per Hectare per Harvest

Table 8 showed that trees applied with 225 g K basal + foliar had the highest Gross sales of Php 94,230, net income of Php 58,792 and return of investment (ROI) of about 100% followed by trees with 225 g K basal application. Moreover, application of 225 g K basal had the highest cost of production.

This indicates that foliar application is more economical compared with basal application of K fertilizer.

4. CONCLUSIONS

Higher K rates improved flowering, fruit set and yield of pummelo. Application of 225 g K increased the number of flowers and number of fruits that set by 4-6 times. Percent fruit set increased by 86-100% in those applied with 225 g K. Increasing K rates to 225 g significantly increased the number of pummelo fruits by 7 times, weight per fruit by 22-26%, and yield up to 9 times.

Results of the study elucidate the important role of K in improving the flowering, fruit set and yield in 'Magallanes' pummelo. The role of K may involve the activation of at least 60 different enzymes needed for metabolic processes and catalytic functions which include the synthesis of carbohydrates and proteins and its act on as an osmoticum for the uptake and transport of assimilates.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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