Original Research Article

Phenology, Growth and Development of 'Magallanes' Pummelo (*Citrus maxima*) Tree as Influenced by Potassium Nutrition

Abstract

This study aimed to determine the influence of K fertilization on the vegetative growth, flowering and fruit development 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 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.

The critical stage of tree growth coincided with the months of May and August. Peak leaf flushing occurred in June and peak flowering with fruit set in April. The crucial stage of fruit development was two months after fruit set. Thus, optimum fertilization must be applied during these stages for maximum growth and production in pummelo.

The vegetative growth of pummelo was not affected by increasing K rates. The recommended rate (150g K basal per tree) significantly increased canopy diameter by 76% but higher K rates did not increase tree height due to the effect of fruit load and nutrient competition. On the other hand, increasing K rates to 50% of the recommended rate (225 g K per tree) increased the number of flushes by 36-100%.

Flowering, fruit set and yield of pummelo were also enhanced by higher K rates. Flowering was increased by 4 times, fruit set by 86-100%, fruit number by 7 times, weight per fruit by 22-26%, and yields up to 9 times on trees applied with 225 g K rates. The fruit size (diameter and length), however, did not increase by increasing the K level.

The results of the study indicated the vegetative growth, flowering and fruit development in 'Magallanes' pummelo under various K fertilization.

Keywords: Growth, Flowering, Fruit, Development, Pummelo, Potassium

1. Introduction

Pummelo [*Citrus maxima* (Burm. Ex Rumph.) Merr.; *C. grandis Osbeck*; *C. decumana L.*], locally known as suha or lukban has the largest fruit among all citrus species, growing as large as 30 cm in diameter and weighing as much as 10 kg. The peel is thick such that the fruit has a long shelf life that allows it to be transported to distant markets and resists pests and diseases. 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 [4,5,6].

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].

Hence, 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 growth and development of several plants such as orange, grapefruit, lemon, papaya, avocado, watermelon, plum, and peach. The potential effect of K on the growth and development of 'Magallanes' pummelo has not been investigated yet; thus, this particular study was conducted.

2. Materials and Methods

2.1 Field Experiment

The study 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 pummelo (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 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.

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 (^oC)	Maximum Temperature (^oC)	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 5.6-6.0	7.3-7.8 6.7-7.2	>9.0 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 (%)	Low		Medium		Adequate
OM (Wilde's Method)	<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

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.

2.2 Phenology, Growth and Development of ‘Magallanes’ Pummelo Tree

The overall growth and development of ‘Magallanes’ Pummelo tree was observed for 12-month duration. The effect of different rates of K on growth and development of ‘Magallanes’ pummelo was evaluated by counting the number of flushes, measuring canopy diameter and tree height, average number of single flower and inflorescence, total number of flowers and number of fruits that set, fruit diameter and fruit length. There were three sample trees per replication per treatment.

The number of flushes per tree was counted every month from the start of the study until harvest. The tree height was taken every month from the start of the study until harvest by measuring from the base of the tree up to the highest shoot tip using measuring steel tape. Increase in height was taken by subtracting the monthly height by the initial height. The canopy diameter was taken every month from the start of the study until harvest by measuring the longest and shortest length of the canopy using a measuring steel tape. Increase in diameter was taken by subtracting the monthly diameter by the initial diameter.

The number of single flower, inflorescence, and 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. The percent fruit set was taken by dividing the total number of fruits that set by the total number of flowers multiplied by 100.

Fruit diameter was measured one week after fruit set. This was done weekly until harvest using a hand caliper. Increase in fruit diameter was computed by subtracting the monthly diameter by the initial diameter. The length of fruits was measured one week after fruit set. This was done weekly until harvest using a hand caliper. Increase in fruit length was computed by subtracting the monthly length by the initial length.

3. Results and Discussion

3.1 Phenology of ‘Magallanes’ Pummelo

Flowering in pummelo simultaneously occurs with flushing. It is stimulated by water stress and promoted by heavy rainfall, irrigation and pruning. The amount and duration of flowering is dependent on the intensity of drought stress, maturity of terminals, flushing activity and tree health [12].

Observations in this study on the phenology of pummelo were made at Calinan, Davao City which has a Type 4 climate where there is no distinct dry or wet season and rainfall is evenly distributed throughout the year. The favorable weather condition throughout the year induces monthly flushing and flowering of pummelo trees in the area.

As shown in Figure 1, peak flushing as well as flowering and fruiting were observed during the month of June followed by April and August. Fruit harvesting is expected 5-6 months after fruit set starting in the month of September.

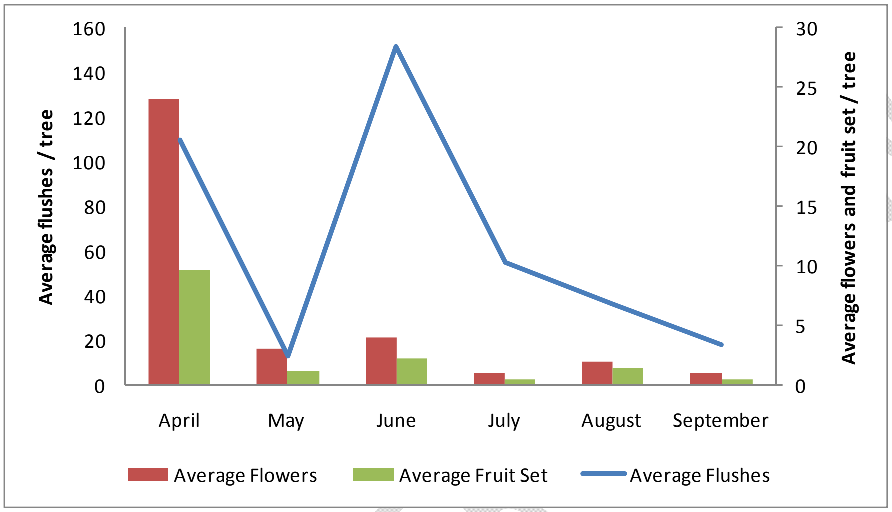

Figure 1. Monthly flushing, flowering and fruiting of 'Magallanes' pummelo in Calinan, Davao City.

3.2 Flower Development

Pummelo flowers in 14-17 days every month. Flowering coincides with flushing. As shown in Figure 2, flower development consists of flush buds and flower bud formation, anthesis and petal fall stage. At flushing stage, olive green flush buds borne singly or in cluster ranging from 0.1-0.5 cm in diameter developed within 7 days.

During flower bud stage at 11-12 days from flush bud, white petals with tiny green dots of 0.6-2.7 cm long flower buds developed in 4-5 days. Flower anthesis occurred after 13-15 days from flush bud with duration of 2-3 days. Fragrant, creamy, white flowers opened widely with petals ranging from 1.4-2.7 cm long. After 14-17 days from flush bud or petal fall stage, the white petals curled and turned to brown and eventually fell within 1-2 days exposing the fertilized embryo.

STAGE	DURATION	NO. OF DAYS	DESCRIPTION:	
Flush bud	7 days	0		Olive green flush buds borne singly or in cluster ranging from 0.1-0.5 cm in diameter occur simultaneously with flushing.
Flower bud	4-5 days	11-12 days from flush bud		White petals with tiny green dots of 0.6-2.7 cm long flower buds develop after flushing.
Anthesis	2-3 days	13-15 days from flush bud		Fragrant creamy white flowers open widely with petals ranging from 1.4-2.7 cm long.
Petal fall	1-2 days	14-17 days from flush bud		White petals curl and turn to brown and eventually fall exposing the fertilized embryo.

Figure 2. Flower development of pummelo.

3.3 Fruit Development

Fruit set began right after flower dehiscence, directly followed by fruit development which occurred for a period 156 days. Fruit growth was fastest during the first two months. Fruit growth increased slowly during the third and fourth months as fruit color changed from green to light green. Yellow green color of the fruit was observed at the 5th month until harvest.

Light green, marble-sized fruitlets with diameter ranging from 0.5-1.0 cm developed and underwent natural thinning during fruit set (Figure 3). Two weeks after fruit set, olive green fruitlets increased in size with fruitlet diameter ranging from 1.0-4.5 cm. Fruits increased in diameter ranging from 5.0-7.7 cm during the first month after fruit set. At the second month after fruit set, the fruits increased in diameter ranging from 6.7-10.7 cm and increased to 8.0-13.7 cm in diameter on the third month after fruit set.

Fruits approached maturity and expand to 9.0-14.4 cm in diameter at the fourth month after fruit set. At the 5th month after fruit set, mature green fruits changed to light green in color with diameter ranging from 9.0-15 cm. At harvest, mature fruits were yellow green in color, measuring 9.0-15.7 cm in diameter and 630 g to 1.4 kg in weight.

3.4 Monthly Number of Flushes

Flowering in citrus plants commences with flushing, which is induced by water stress followed by adequate rainfall or irrigation [12]. In this study, fertilizer treatments applied in June significantly affected the number of flushes produced in pummelo but not on the rest of the months. Highest number of flushes was observed in June; high number of flushes also took place in April. On the other hand, lowest monthly flushes occurred in May (Figure 4).

Production of flushes in pummelo was affected by the rainfall distribution in the experimental area during the duration of the study. Rainfall increased from 52.9 mm in March to 124 mm in April. Irrigation was done on the 4th week of March to 1st week of April 2010 due to scarce rainfall. From April to September 2010, the lowest rainfall of 57.2 mm was obtained in May, which increased to 87.8 mm in June. Highest rainfall was observed in August followed by July but flushes at these times were significantly lower than those in June and April. Thus, dry period followed by increase in rainfall, as observed in March to April as well as May to June was seen to induce higher flushing than continuous high rainfall as observed during the months of July to September. Nonetheless, scarcity in rainfall inhibited flushing; May, which had the lowest rainfall, exhibited the least number of flushes.

The observation obtained in this study corroborated previous findings that adequate rainfall and irrigation enhanced flushing in pummelo. The main shoot growth flushes of pummelo in conjunction with flowering follows the onset of the monsoon rains, unless it is brought forward by irrigation [13]. Peak flushing occurred on June followed by April due to adequate rainfall and irrigation applied, respectively in these months on the experimental area. Thus, adequate fertilization should be applied on months where peak flushing occurs to maximize growth.

Meanwhile, significant difference among treatments in terms of number of flushes was only observed during the month of June. The 225 g K basal + foliar treatment produced the highest number of flushes, followed by no K, 225 g K basal and 150 g K basal treatments. The 225 g K basal + foliar treatment increased up to 146% compared with the rest of the treatments. The number of flushes in no K treatment was, however, not different from 225 g K basal treatments and were higher by 36-92% than the 150 g K and control. The 225 g K basal had the same effect with 150 g K, which was 41-64% higher than the control. This shows that fertilizer application enhanced the number of flushes in 'Magallanes' pummelo, which was highest in 225 g K basal + foliar treatment. This also corresponds to the previous study conducted by that K fertilization increased the number of leaves and leaf area of papaya [14].

STAGE/DURATION:	DESCRIPTION:	
Fruit set		After petal dehiscence, light green fruitlets with diameter ranging from 0.5-1.0 cm develop and undergo natural thinning.
2 weeks		After fruit set, olive green fruitlets increase to 1.0-4.5 cm in diameter.
1 month		Fruits increase with diameter ranging from 5.0-7.7 cm.
2 months		Fruits increase with diameter ranging from 6.7-10.7 cm.

Figure 3. Fruit development of pummelo.

STAGE/DURATION:	DESCRIPTION:	
3 months		Fruits increase in diameter ranging from 8.0-13.7 cm.
4 months		Fruits approach maturity and expand to 9.0-14.4 cm diameter.
5 months		Mature fruits change from green to light green in color with diameter ranging from 9.0-15 cm.
Harvest (156 days from fruit set)		Mature fruits turn to yellow green in color with 9.0-15.7 cm in diameter and 630 grams to 1.4 kg in weight.

Figure 3. continued ……

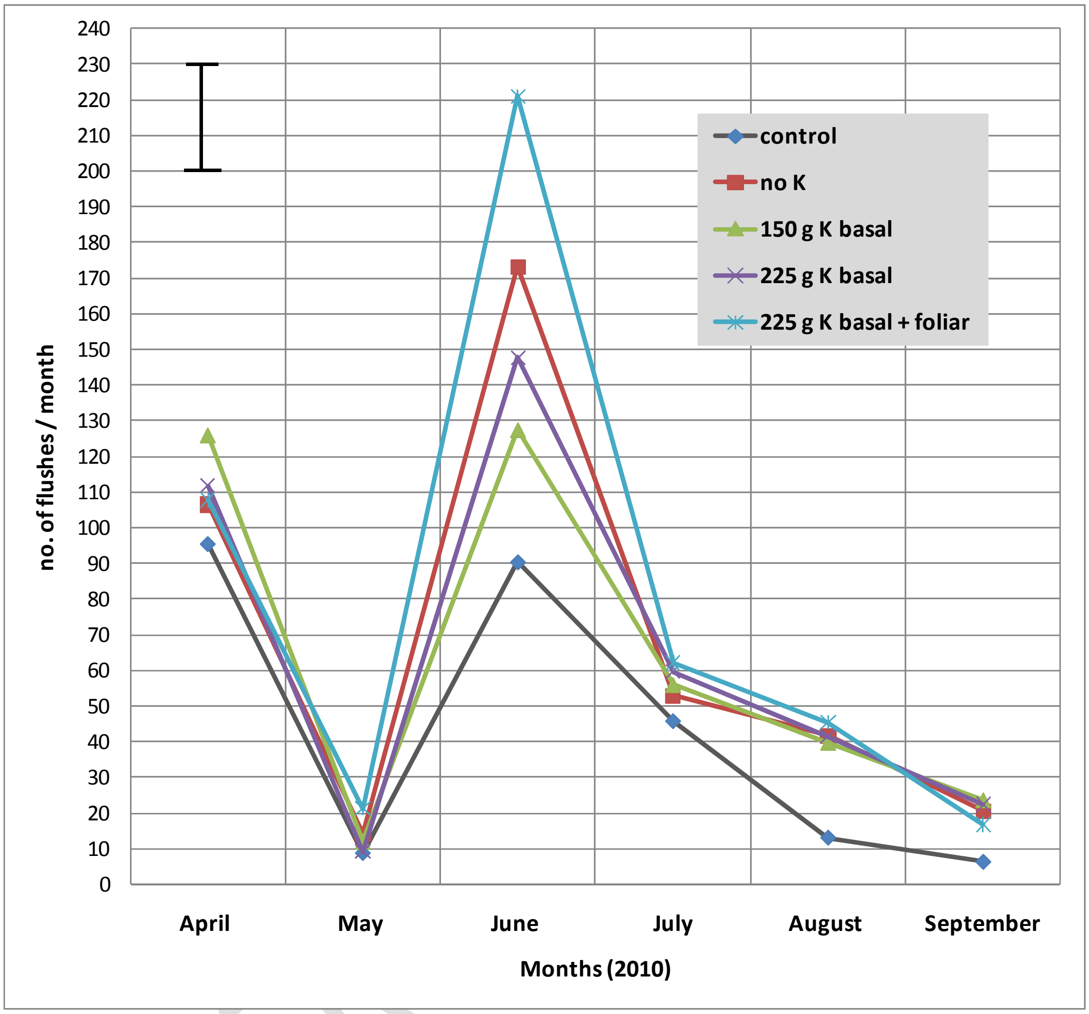

Figure 4. Monthly number of flushes in 'Magallanes' pummelo as influenced by K fertilization. Bar indicates HSD value at 0.05 level. All treatments were applied with recommended rate of NP except for the control (no fertilization).

3.5 Tree Height Increment

The height increment in pummelo was not affected by the different treatments applied but significant difference was observed among various months.

Result suggests that increasing levels of K fertilizer have no significant influence on tree height increment. K content do not usually affect tree growth over a wide range of variation, unless it falls below 0.4% [15]. This was also demonstrated in the vegetative growths of peach, plum [16] and pistachio [17].

However, it was observed that there was an increase in tree height every month (Figure 5). There was no difference in tree height increase between the 1st and 2nd months as well as between the 4th and 5th months after first fertilizer application.

The height increment increased from 0.18 m to 0.32 m on the third month and 0.67 m after five months. Highest increase was observed on the fifth month after first fertilizer application. The month of August had the highest height growth rate (0.25 m) followed by

May (0.18 m) and lowest in June (0.02 m). This shows that the fourth month (August) after flowering was a critical stage for tree growth of pummelo.

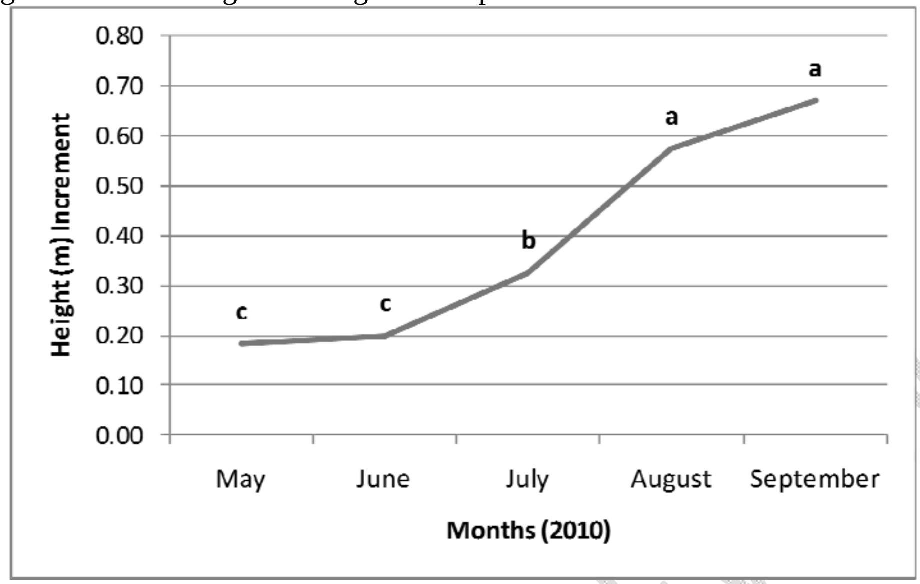

Figure 5. Monthly height (m) increment of ‘Magallanes’ pummelo. Means with a common letter are not significantly different at 0.05 level using HSD.

3.6 Canopy Diameter Increment

The effect of the interaction between the different treatments and the monthly determination on canopy diameter increment was not significant. ANOVA revealed only the significant main effects of treatments and monthly determination.

Figure 6A shows the canopy diameter increment as affected by the different treatments. The canopy diameter increment in 150 g K basal treatment significantly increased by 0.66 m compared with the control. The control had the same effect on canopy diameter increment with that of no K and the other K rate treatments.

Results showed that 150 g K basal application increased the canopy diameter of ‘Magallanes’ pummelo. Further increase in K rates did not anymore affect this parameter. This agrees with that effect of K fertilization in enhancing the canopy volume of grapefruit [18]. The result obtained in canopy diameter every month was the same with tree height increment. No significant increase in canopy diameter occurred between the 1st and 2nd months as well as on the 4th and 5th months after first fertilizer application (Figure 6B). The canopy diameter increment increased by 0.66 m on the 3rd month and 1.22 m on the 5th month compared with the first month.

The month of May had the highest canopy growth rate (0.61 m) followed by August (0.49 m) while the month of September (0.07 m) had the lowest. Thus, optimum fertilization must be supplied when growth rates are highest to attain maximum growth and development.

K was found to serve a vital role in photosynthesis by directly increasing growth and leaf area index, and hence CO_2 assimilation and increasing the outward translocation of photosynthate [19].

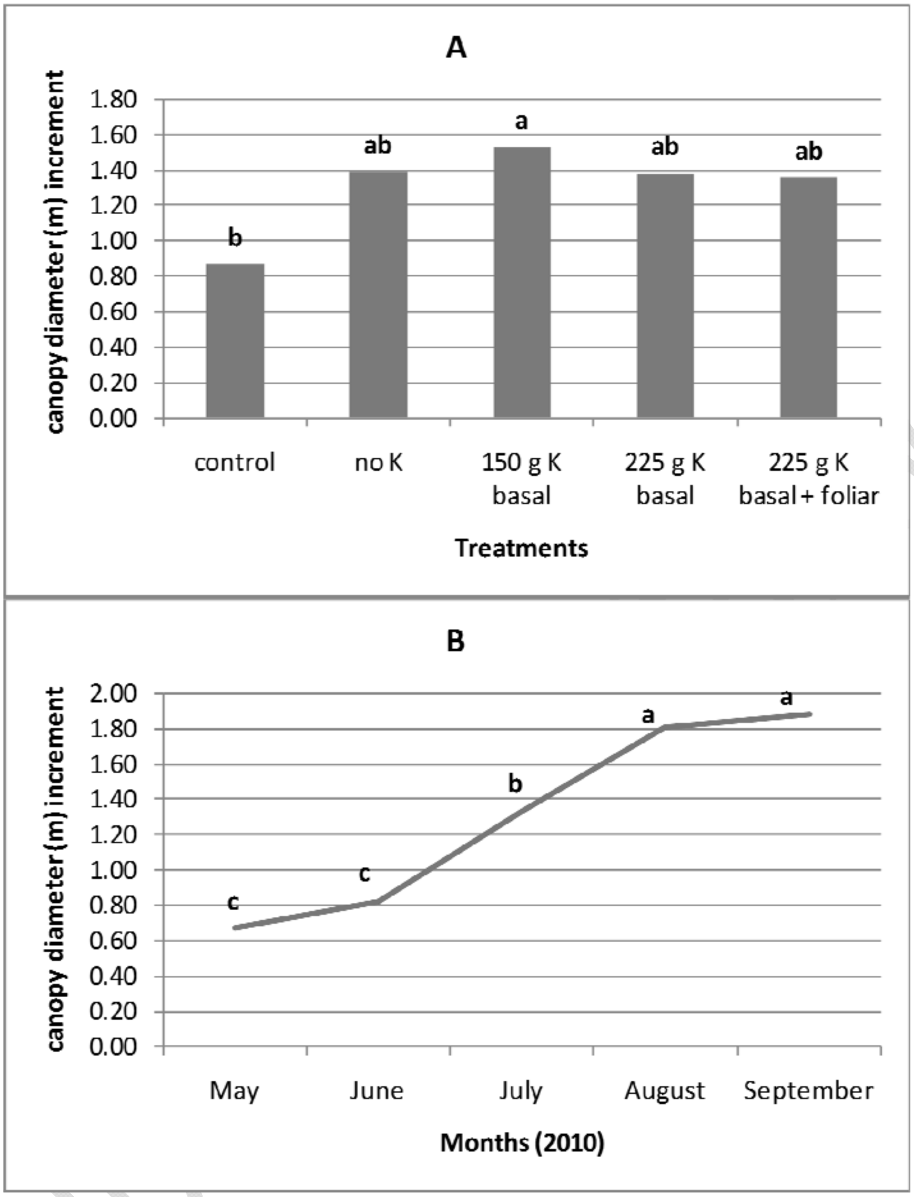

Figure 6. Canopy diameter (m) increment of 'Magallanes' pummelo as influenced by K fertilization (A) and month within the experimental period (B). Means with a common letter are not significantly different at 0.05 level using HSD. All treatments were applied with recommended rate of NP except for the control (no fertilization).

3.7 Total Number of Flowers

All pummelo trees simultaneously flowered every month during the duration of the study, bearing single flowers or inflorescence that contained 2-8 individual flowers. Total number of flowers, which included all single flowers and the individual flowers of inflorescence, were noted.

There was a significant difference in total number of flowers among treatment means as well as among various months. However, the effect of the interaction between different treatments and the monthly sampling on the total number of flowers was not significant.

The highest total number of flowers was obtained in 225 g K basal + foliar which had four times more total number of flowers than the control (Figure 7A). On the other hand, the 225 g K basal, 150 g K basal and no K treatment had the same effect with the control. Though 225 g K basal + foliar increased the total number of flowers in 'Magallanes' pummelo, there is still no scientific evidence to prove that K alone has a direct role in citrus flowering unlike N which had been shown to improve flower yield for over three years [20].

In terms of monthly duration, it was observed that the month of April significantly had the highest total number of flowers having 22 flowers compared with the rest of the months with 0.5-4 flowers (Figure 7B). The total number of flowers decreased towards the end of the experimental period.

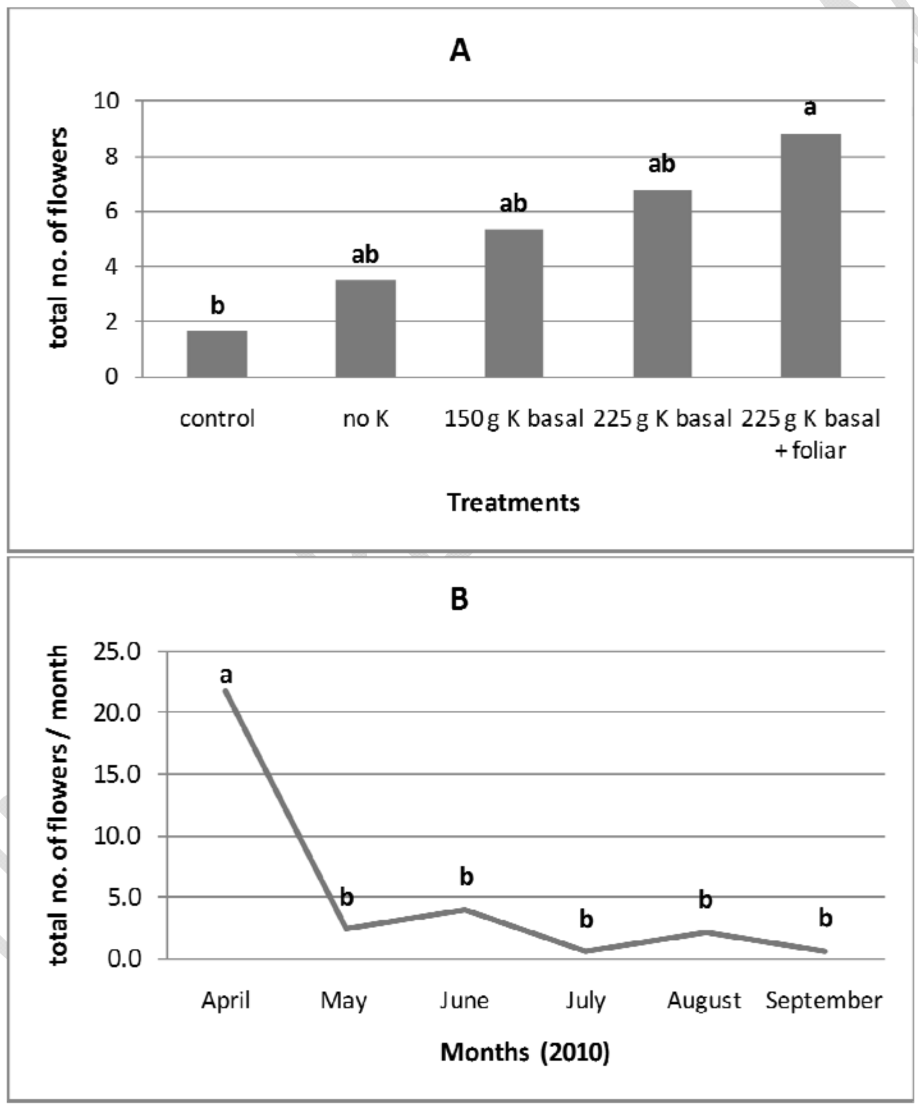

Figure 7. Total number of flowers of 'Magallanes' pummelo as influenced by K fertilization (A) and month within the experimental period (B). Means with a common letter are not significantly different at 0.05 level using HSD. All treatments were applied with recommended rate of NP except for the control (no fertilization).

3.8 Number of Single Flowers

The different treatments had no significant influence on the number of single flowers but there was a significant difference in the number of single flowers among various months. Moreover, the number of single flowers produced every month in all treatments was the same.

A similar trend in monthly production of single flowers was observed with the previous result in the monthly total number of flowers (Figure 8). The month of April still had the highest number of single flowers, twice higher than the rest of the months. Number of single flowers also decreased towards the end of the experimental period.

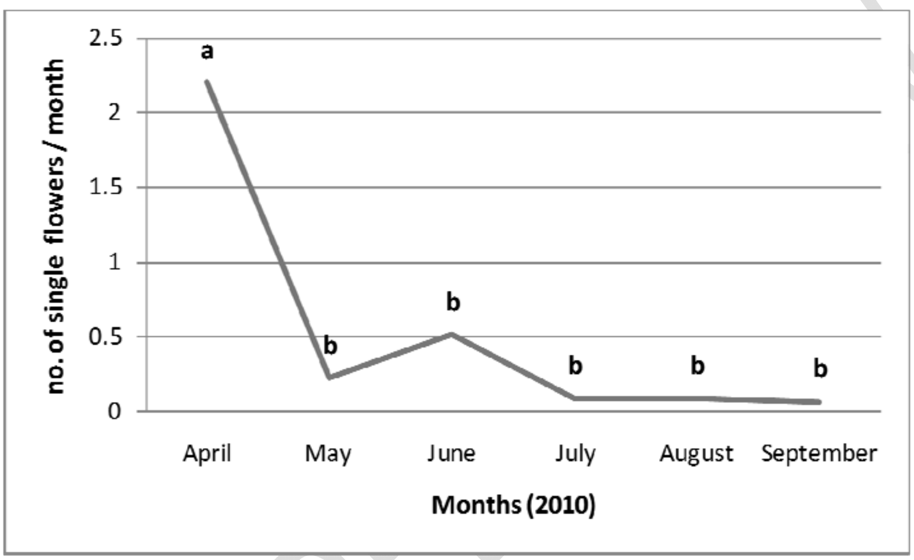

Figure 8. Monthly number of single flowers of 'Magallanes' pummelo. Means with a common letter are not significantly different at 0.05 level using HSD.

3.9 Number of Inflorescence

The number of inflorescence was significantly affected by the different treatments and the monthly duration.

Number of inflorescence was highest in pummelo applied with 225 g K basal + foliar treatment, which was four times more than the control (Figure 9A). Application of 225 g K basal, 150 g K basal and no K treatment had no difference in the number of inflorescence over that of the control. This trend was also similar with the parameter on total number of flowers as discussed earlier. Increased flowering of 'Magallanes' pummelo with the 225 g K basal + foliar suggested a possible role of K in the flower development of fruit trees.

Moreover, the month of April had the highest number of inflorescence which was four times higher than May to September (Figure 9B). Thus, peak flowering occurred in the month of April having the highest number of inflorescence, single flowers and total number of flowers, compared with the rest of the months.

It was also observed that peak flowering occurred when rainfall increased and irrigation was supplied in April following dry period of March. This condition enhanced flowering in 'Magallanes' pummelo which coincided with previous reports [12,13].

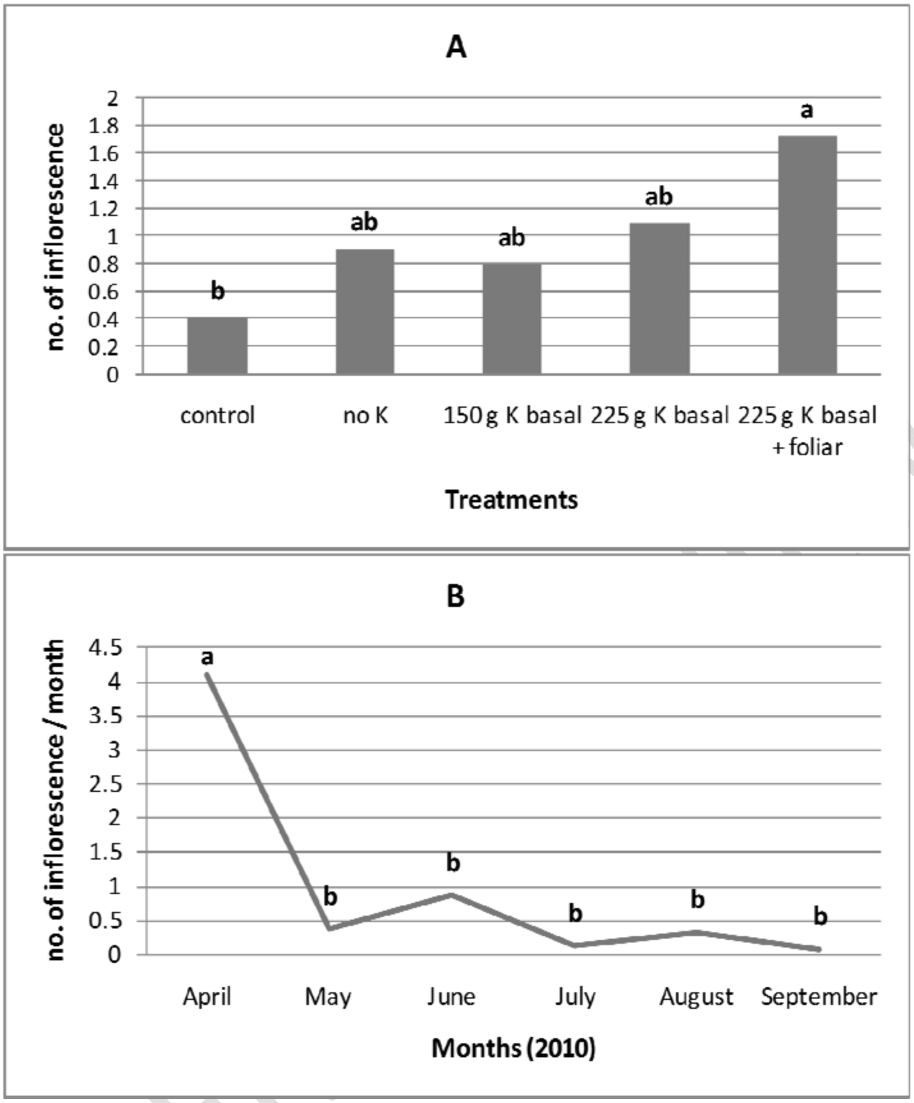

Figure 9. Number of inflorescence of ‘Magallanes’ pummelo as influenced by K fertilization (A) and month within the experimental period (B). Means with a common letter are not significantly different at 0.05 level using HSD. All treatments were applied with recommended rate of NP except for the control (no fertilization).

3.10 Number of Fruits that Set

The effect of the K treatments on the number of fruits that set in ‘Magallanes’ pummelo differed significantly at various months of determination. As shown in Table 3, significant difference among treatment means was only observed on the months of April and June.

Highest fruit set in April was obtained in 225 g K basal and 225 g K basal + foliar treatments which had 10-18 more fruits that set compared with the 150 g K, no K and control. The 225 g K basal + foliar also obtained the highest fruit set in June, which had 4-5 more fruits that set than the 225 g K basal, no K and control. The control had the same effect with 225 g K basal, 150 g K basal and no K treatments.

Result indicates that 225 g K basal + foliar significantly increased the number of fruits that set in ‘Magallanes’ pummelo up to 16 times than that of the control. This implies a role of K in enhancing fruit set of pummelo.

It was also observed that the month of April significantly had the highest fruits that set while fruit set after April was very low. The peak flowering and fruit set occurred in the month of April. Thus, this month is the crucial stage of optimum fertilization for maximum fruit setting.

Table 3. Number of fruits that set per month in ‘Magallanes’ pummelo as influenced by K fertilization.

TREATMENTS	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER
Control	3.0 b A	0.6 B	0.2 b B	0.2 B	0.0 B	0.0 B
no K	6.4 b A	1.2 B	1.1 b B	0.0 B	0.3 B	0.0 B
150 g K basal	9.8 b A	1.0 B	2.8 abB	0.3 B	1.0 B	0.0 B
225 g K basal	20.2 a A	1.0 B	1.2 b B	0.4 B	3.0 B	0.1 B
225 g K basal + foliar	21.4 a A	2.2 B	5.4 a B	1.1 B	2.9 B	1.7 B

Values with a common letter are not significantly different at 0.05 level using HSD. Capital and small letters are for row and column comparison, respectively. All treatments were applied with recommended rate of NP except for the control (no fertilization).

3.11 Percent Fruit Set

The total flowers, total fruits that set and percentage of fruit set in ‘Magallanes’ pummelo was significantly affected by the different treatments. As shown in Table 4, the 225 g K basal + foliar treatment significantly had the highest values for these parameters.

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.

The percent fruit set in ‘Magallanes’ pummelo obtained in this study was much higher than in the literature reported for citrus which ranged from 0.1-3% [21]. K is required to activate at least 60 different enzymes involved in plant growth [22]. Hence, 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 [23], most importantly in the translocation of starch reserve necessary in flower induction of pummelo in response to heavy rainfall and irrigation after a dry period.

Fruit set is apparently supported by the availability of nutrients mostly mineral elements, carbohydrates and water [24]. K contributes to phloem loading and transport of sucrose and amino compounds [25] and act as an osmoticum to regulate water and solute uptake [26] 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 [27].

Table 4. Percent 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).

3.12 Fruit Diameter Increment

Analysis of variance revealed that there was a significant difference in fruit diameter of 'Magallanes' pummelo among various months but not among treatments. The significant increase in fruit diameter occurred every month; it was highest in June, which was two months after fruit set (Figure 10). The fruit diameter increased by 3.4 cm in the 2nd month from 1.3 cm in the 1st month. The fruit diameter increment decreased by 1.6 cm to 0.5 cm on the 3rd month to the 5th month.

The rate of growth in terms of diameter was highest on the 2nd month and decreased in the following months where the lowest was on the 5th month. Fruit diameter growth of pummelo was remarkable two months from fruit set.

During the rapid growth period, the fruit experiences a huge increase in size by cell enlargement while water accumulation occurs during the fourth to sixth months [24].

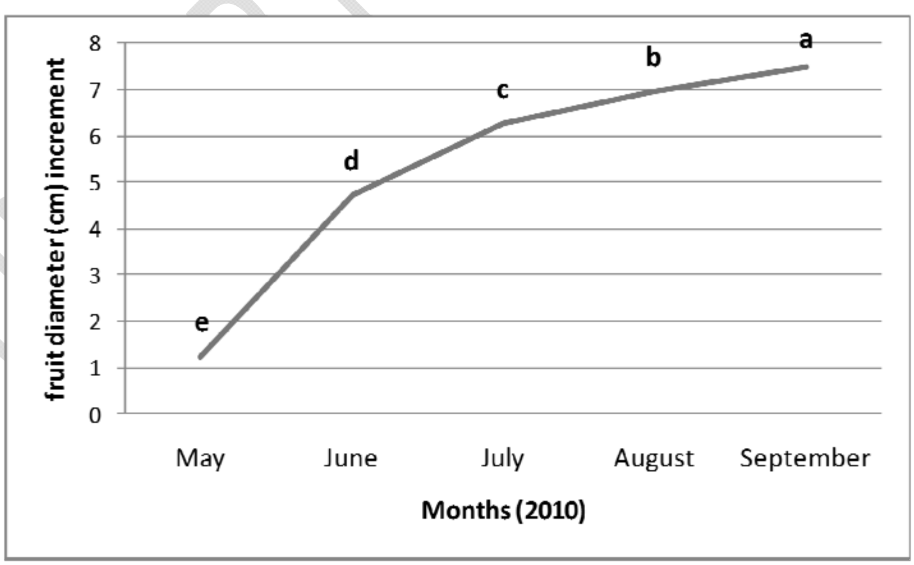

Figure 10. Monthly fruit diameter (cm) increment of 'Magallanes' pummelo. Means with a common letter not significantly different at 0.05 level using HSD.

3.13 Fruit Length Increment

Fruit length and diameter determine the final size and weight of the pummelo fruit. Effects of the different treatments on the fruit length increment were significantly different on various months.

Figure 11 shows that highest fruit length increment and growth rate occurred on the 2nd month and lowest on the fifth month after fruit set. The fruit length increment on the second month was 3 cm higher than the 1st month and decreased by 1.9 cm to 0.6 cm towards the end of the month. It was observed that the increase in fruit length and diameter as well as fruit growth rates was significant after two months from fruit set.

Significant difference among treatments was observed every month except on the first month. Highest fruit length was exhibited by the control followed by 225 g K basal + foliar. The fruit length from 225 g K basal + foliar application was not statistically different from the rest of the treatments. The control was 2 cm higher in fruit length of 225 g K basal, 150 g K basal and no K treatments.

This showed that different rates of K fertilizer did not increase the fruit diameter and length increment of 'Magallanes' pummelo. This finding deviates from results of previous studies on citrus such as orange cultivars [28,29,30], grapefruit [31] and other crops such as watermelon [26].

The variable effects on fruit size can be caused by several factors like soil condition and method of fruit sampling. Based on the result of the soil analysis, the K content was adequate in all treatments after the conduct of the study. Though there was no fertilizer application in the control, there was still an increase of NPK level in the control which showed that the nutrient content in the soil was still adequate for fruit growth.

Moreover, random sampling of fruits was done right after fruit set both on single flowers and inflorescence regardless of the number of fruits per tree. It was observed during the conduct of the study that fruits from single flowers have higher fruit size than fruits from inflorescence containing three to four fruits. Fruit sizes of both single flowers and inflorescence of trees fertilized with increasing levels of K rates were comparable with the control and no K treatments.

The insignificant effect of K fertilization on fruit size is considered to be the result of competition among the developing fruits for a limited supply of metabolites [21]. As discussed earlier, higher K rates resulted to higher number of flowers and fruit set. Hence, fruit size from unfertilized trees had the same or even higher size compared with trees fertilized with higher K rates. There was a lower competition of metabolites on unfertilized trees with less number of fruits than trees fertilized with higher K rates having more number of fruits and higher competition of metabolites.

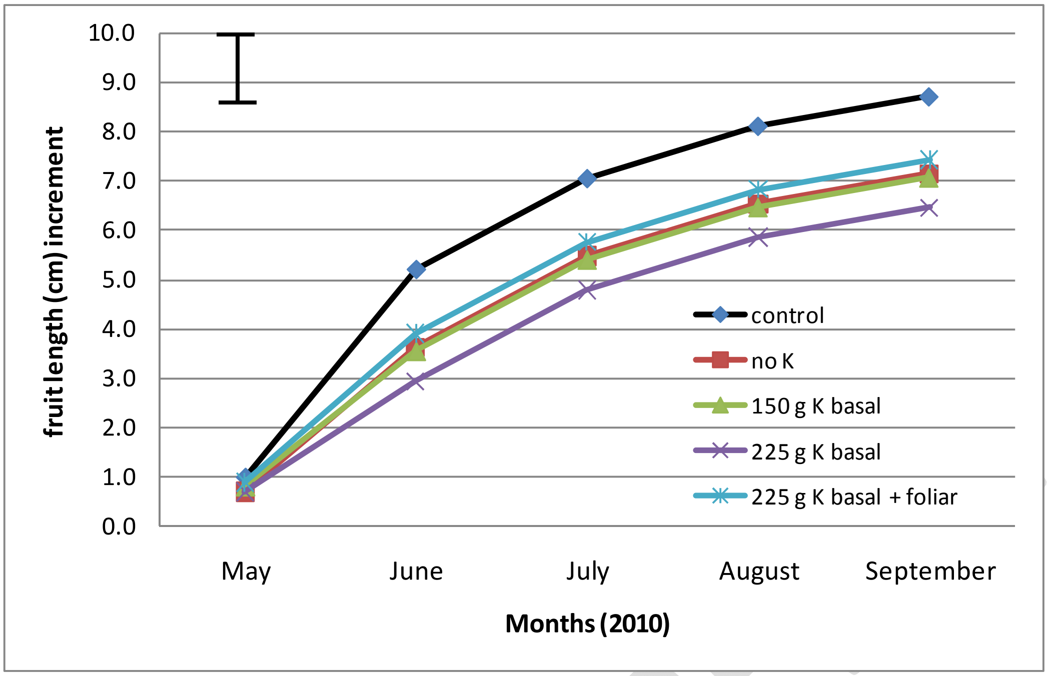

Figure 11. Monthly fruit length (cm) increment of 'Magallanes' pummelo as influenced by K fertilization. Bar indicates HSD value at 0.05 level. All treatments were applied with recommended rate of NP except for the control (no fertilization).

4. Conclusion

The critical stage of tree growth coincided with the months of May and August. Peak leaf flushing occurred in June and peak flowering with fruit set in April. The crucial stage of fruit development was two months after fruit set. Thus, optimum fertilization must be applied during these stages for maximum growth and production in pummelo.

The vegetative growth of pummelo, specifically tree height was not affected by the increase in K rates. The canopy diameter of trees applied with 150 g K basal treatment increased by 76% but no further increase was observed when K rate was increased to 225 g. Nevertheless, the number of flushes increased by 36-100% with the application of 225 g K rates.

Higher K rates improved flowering and fruit set 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. In terms of fruit development, fruit diameter was not significantly affected by increasing the K level. Higher K rates did not also increase the fruit length. However, the control, devoid of NPK, exhibited the highest fruit length.

Results of the study elucidate the important role of K in improving the flushing, flowering and fruit set 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.

Though significant difference between basal alone and basal + foliar application of K was observed in terms of number of flushes and number of fruits that set, the highest number of flowers, and % fruit set, however, were obtained from the basal + foliar application. This indicated that there was higher mobilization of K in the leaves than K uptake by the roots.

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