Original Research Article

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

Abstract

This study aimed to determine the influence of potassium (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-months duration. Five treatments were observed with increasing K levels were applied per tree: control (no fertilization), without K, 150 g K basal (recommended rate based on soil analysis), 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 noted two months after fruit set. Thus, optimum fertilization must be applied during these stages for maximum growth and production in 'Magallanes' 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% higher than the recommended rate (225 g K per tree) increased the number of flushes by 36-100%.

Flowering, fruit set and yield of 'Magallanes' 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 composted with 225 g K rates. The fruit size (diameter and length), however, did not increase by increasing the K level.

Keywords: **Citrus, Development, Flowering, Fruit, Growth, 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, allowing it to be transported to distant markets and to resists to 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 for 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].

Potassium (K) is a macronutrient 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 found in fruits and the main nutrient removed from the soil. Thus, K is considered a key element in fruit production and fruit quality worldwide [11].

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 citrus, it is important to provide an efficient fertilizer program.

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 with this objective.

2. Materials and Methods

2.1 Field Experiment

The study was conducted at South Davao Corporation (SODACO), Calinan, Davao City, Philippines, for 12-months duration to evaluate the effect of different rates of potassium (K) application on the flowering, fruit set, yield, and quality of 'Magallanes' pummelo cultivar. The area is located 7°0′ 0.00″N and 125°0′ 0.00″E with an elevation of 700 m Mean Sea Level (msl) (Figure 1). 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), at the weather station of Sasa, Davao City. Temperature, amount of sunshine, relative humidity, rainfall and wind speed were favorable for the growth and development of 'Magallanes' pummelo (Table 1).

The cultivar used in this study was a 13-year old 'Magallanes' pummelo, being 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 m x 8 m, in a rectangular planting system. Fruits were sampled from the middle of the 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 conducting the study, to determine the nutrients 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 of 4-6 months old 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 fertilization), without K, 150 g K basal, 225 g K basal, and 225 g K basal + foliar application.

Figure 1. Location map of the area at SODACO farm, Calinan, Davao City, Philippines.

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

	Temperature (°C)					
Year of 2010	Mean	Maximum	Rainfall (mm)	Relative humidity (%)	Sunshine (%)	Average wind speed (Km/hr)
January	27.2	30.6	157.5	83	41.5	72
February	27.7	32.5	16.0	78	70.9	72
March	29.0	33.5	52.9	77	71.5	86
April	29.2	32.5	124.0	81	59.0	67
May	29.2	32.8	57.2	82	57.3	59
June	28.8	32.6	87.8	83	57.9	47
July	28.5	31.8	251.6	84	51.5	66

August	28.2	31.9	281.8	84	53.8	72
September	28.5	32.3	117.6	82	57.5	63

Table 2. Initial soil analysis and after the conduct of the study for organic matter (OM), organic carbon (OC), nitrogen (N), phosphorus (P) and potassium (K).

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 under 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 (%) 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

The orchard was composted with basal and foliar fertilizers following the recommendations according to soil and leaf tissue analysis as practiced by the farm. The different rates of fertilizers were applied in 3 installments: at flushing or flowering initiation, 30 and 60 days after flowering (DAF). All treatments were applied under recommended rate of NP, except for the control (no fertilization). The sources of NPK fertilizers were as follow: Urea (46-0-0), Complete (14-14-14) fertilizer, Solophos (0-18-0) and Muriate of Potash (0-0-60). Fertilizers were applied basally at 1.5-meter radius around the canopy. The 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 'Magallanes' pummelo trees were maintained by irrigating, weeding, pruning and applying pesticide and fungicide whenever necessary. The 'Magallanes' 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 'Magallanes' 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. It was evaluated with 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.

The start of measuring fruit diameter was 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 start of measuring length of fruits was 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

The flowering of ‘Magallanes’ 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 ‘Magallanes’ 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 ‘Magallanes’ pummelo trees in the area. As shown in Figure 2, peak flushing as well as flowering and fruiting, were observed during the month of June, followed by April and August. Fruit harvesting was made 5-6 months after fruit set, starting in September.

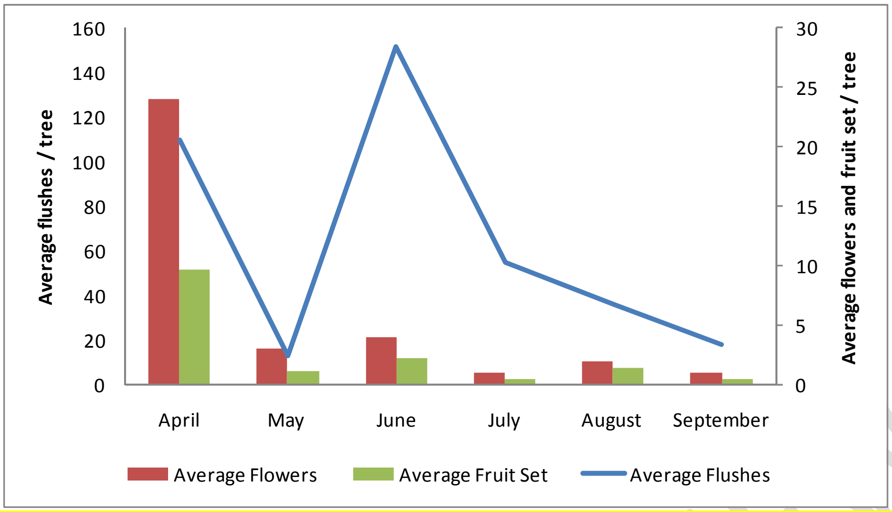


Figure 2. Monthly Flushing, Flowering and Fruiting of 'Magallanes' Pummelo in Calinan, Davao City.

3.2 Flower Development

'Magallanes' pummelo flowered in laps of 14-17 days every month. The flowering coincided with flushing. As shown in Figure 3, flower development consisted 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 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 3. Flower Development of Pummelo.

3.3 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 'Magallanes' 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 species. 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 differences 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 without K. The 225 g K basal and 150 g K basal treatments were not significantly different (Figure 4). The 225 g K basal + foliar treatment increased the number of flushing up to 100% compared with the other treatments. The number of flushes in without K treatment was, however, not significantly 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 than 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 with 225 g K basal + foliar treatment. This also corresponds to the previous study conducted [14], showing that K fertilization increased the number of leaves and leaf area of papaya.

3.4 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 5). 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.

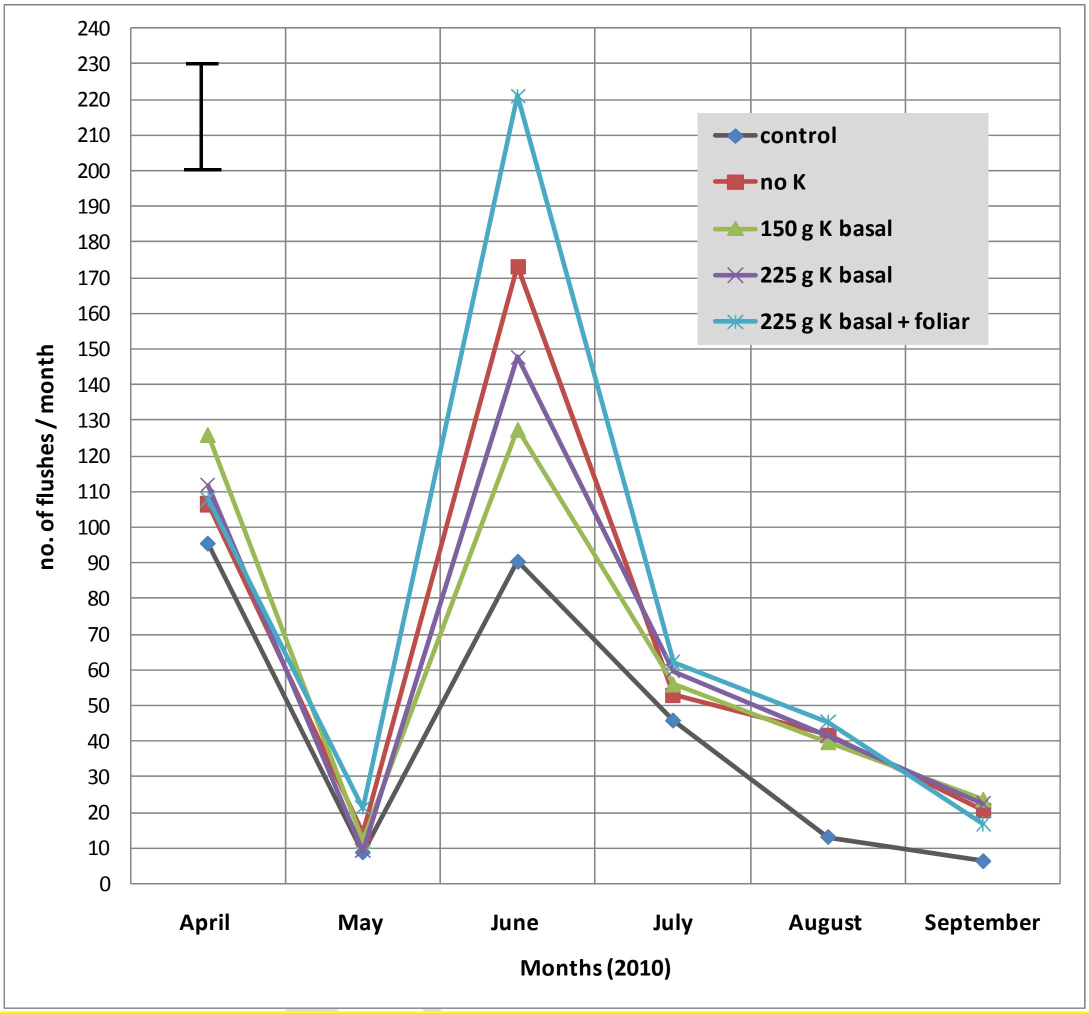


Figure 4. Monthly Number of Flushes in ‘Magallanes’ Pummelo as Influenced by K Fertilization Treatment. Bar Indicates HSD Value at 0.05 level. All Treatments were Applied with Recommended Rate of NP, Except for the Control (without fertilization).

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.

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 5. Fruit Development of Pummelo.

3.5 Tree Height Increment

The height increment in the 'Magallanes' pummelo was not affected by the different treatments applied but significant difference was observed among various months (Figure 6).

Result suggests that increasing levels of K fertilizer have no significant influence on tree height increment. K content does 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 6). 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 of various treatments. 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 'Magallanes' pummelo.

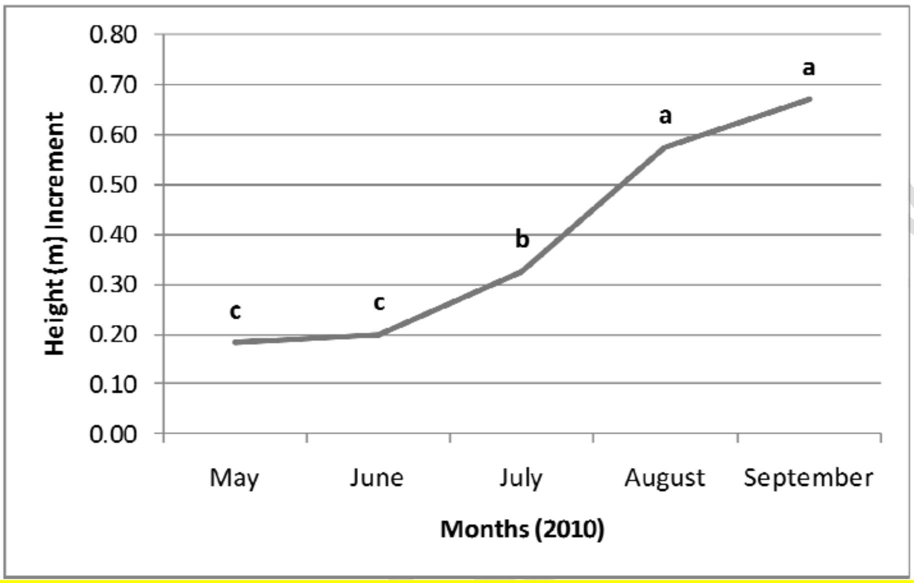


Figure 6. Monthly Height (m) Increment of 'Magallanes' Pummelo. Means with a Common Letter are not Significantly Different at 0.05 Level Using HSD.

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 7A shows the canopy diameter increment as affected by the different treatments. The canopy diameter increment under 150 g K basal treatment, significantly increased by 0.66 m, as compared with the control. The control had the same effect on canopy diameter increment with that of no K and with higher K rate treatments.

Results showed that 150 g K basal application increased the canopy diameter of 'Magallanes' pummelo but 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 7B). 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 regardless of treatment.

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.

The fertilizer 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].

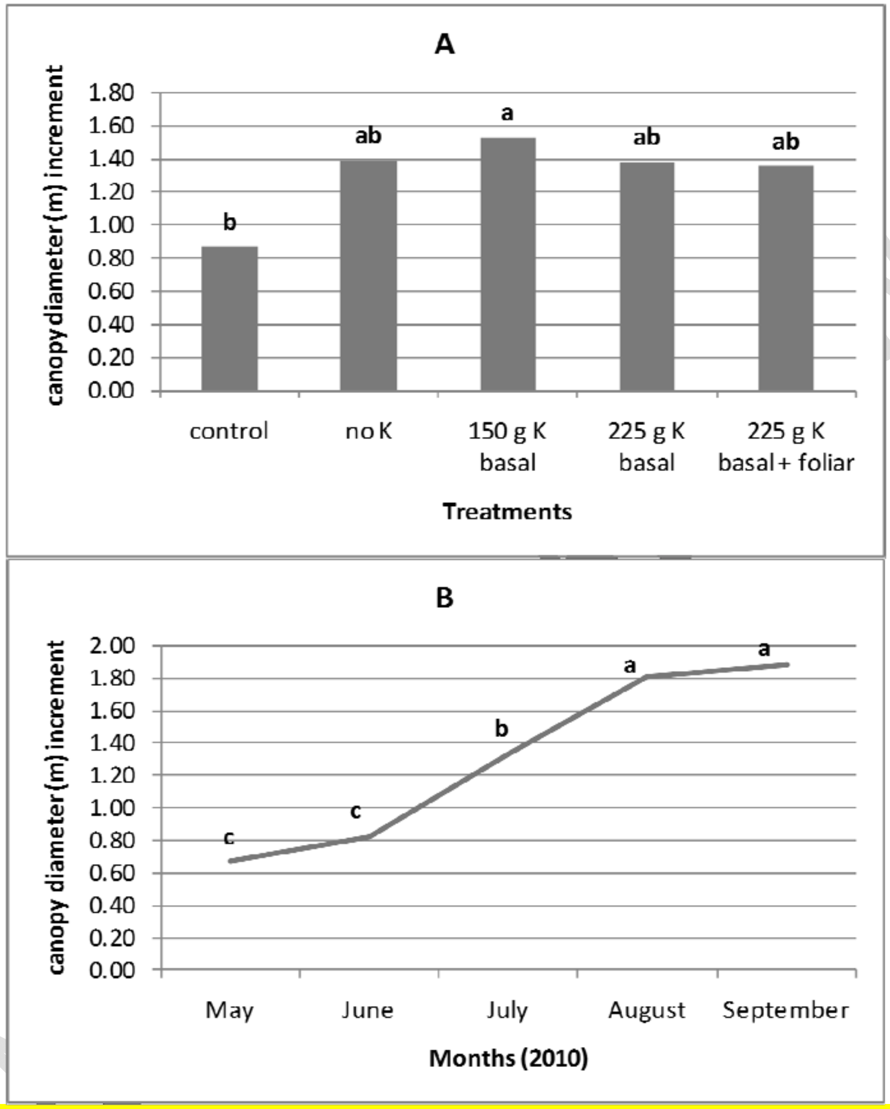


Figure 7. Canopy Diameter (m) Increment of 'Magallanes' Pummelo as Influenced by K Fertilization (A) and Month within the Experimental Period (B). Means with a Common Letter are not Significantly Different at 0.05 Level using HSD. All Treatments were Applied with Recommended Rate of NP Except for the Control (without fertilization).

3.7 Total Number of Flowers

All 'Magallanes' pummelo trees simultaneously flowered every month during the duration of the study regardless of treatments, 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 significant difference only between 225 g K basal + foliar and the control (Figure 8A), as well as among the various months, but no significant differences were observed between plants treated and not treated with K fertilization. And also, the presence of K fertilizer did not significantly influence on total number of flowers.

The highest total number of flowers was obtained with 225 g K basal + foliar which had four times more total number of flowers than the control (Figure 8A). On the other hand, the 225 g K basal, 150 g K basal and no K treatments 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 8B). The total number of flowers decreased towards the end of the experimental period.

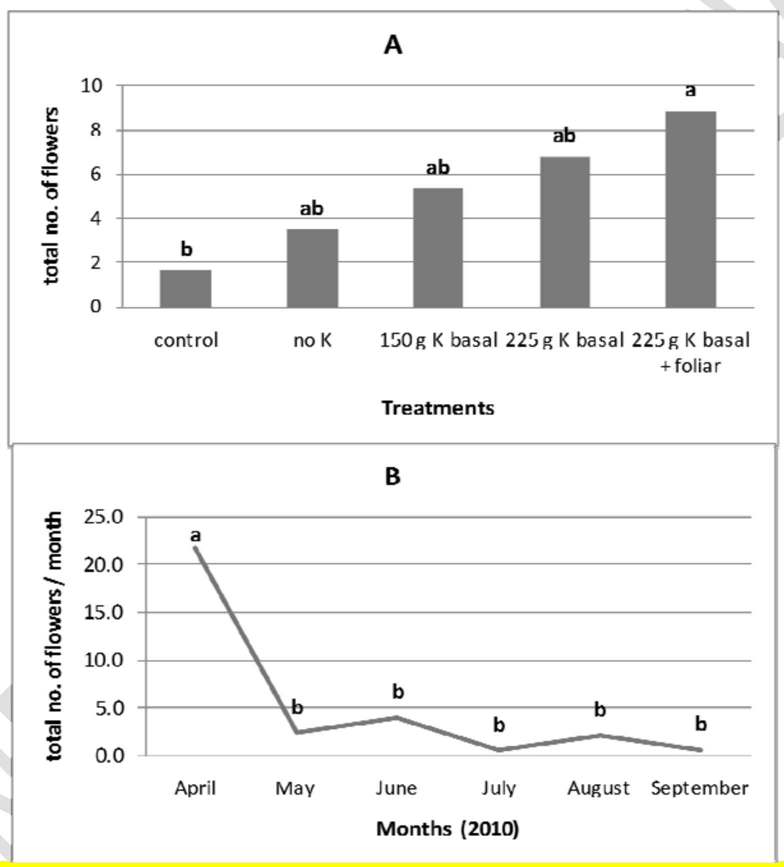


Figure 8. Total Number of Flowers of 'Magallanes' Pummelo as Influenced by K Fertilization rates (A) and time (month) within the Experimental Period (B). Means with a Common Letter are not Significantly Different at 0.05 Level using HSD. All Treatments were Applied with Recommended Rate of NP Except for the Control (without fertilization).

3.8 Number of Single Flowers

The different treatments had no significant influence on the number of single flowers, but there was significant difference only between the single flowers of April and all the other months (Figure 9), but not between the number of single flowers observed from May to September.

A similar trend in monthly production of single flowers was observed with the previous result in the monthly total number of flowers (Figure 9). The month of April still had the highest number of single flowers, twice higher than the other months. Number of single flowers also decreased but with no significant differences between the last five months.

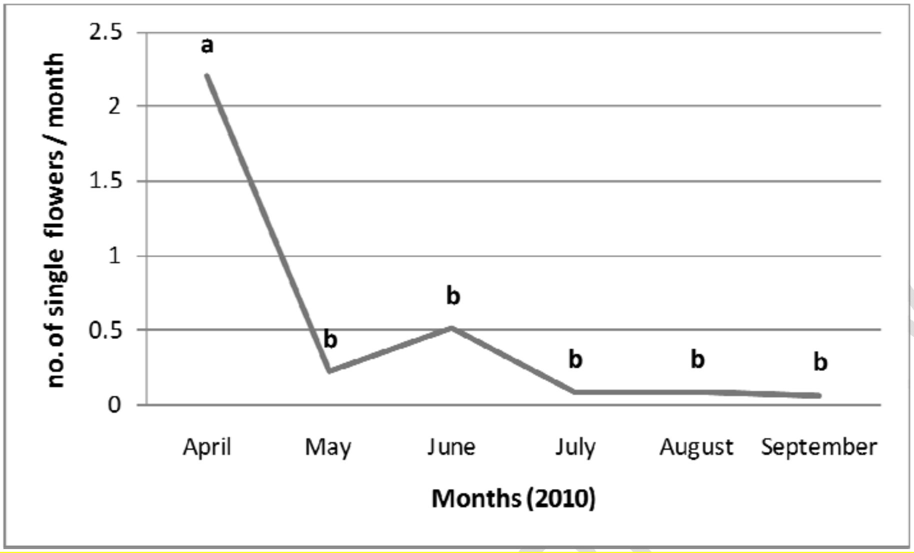


Figure 9. Monthly Number of Single Flowers of 'Magallanes' Pummelo. Means with a Common Letter are not Significantly Different at 0.05 level Using HSD.

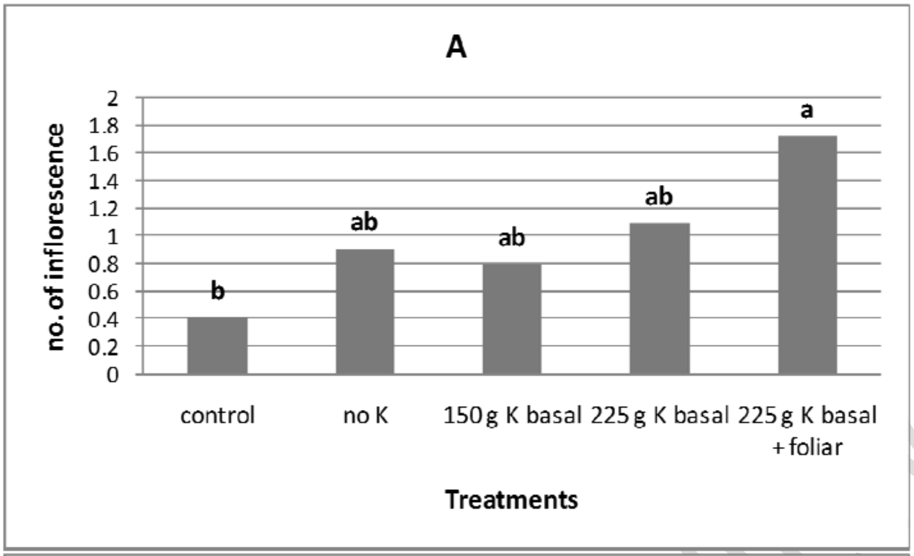
3.9 Number of Inflorescence

The only significant difference in number of inflorescence is between the 225 g K basal + foliar and the control and the monthly duration (Figure 10A). The treatment 225 g K basal + foliar was not significantly different than the other treatments, even with the treatment with no K. This means that the K fertilization did not influence on the number of inflorescences.

Number of inflorescence was highest on 'Magallanes' pummelo under the treatment with 225 g K basal + foliar, which was four times more than the control (Figure 10A). Application of 225 g K basal, 150 g K basal and no K treatments 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 suggests 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 10B). Thus, peak flowering occurred in April with the highest of both, number of inflorescence, single flowers and total number of flowers, compared with the other months.

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



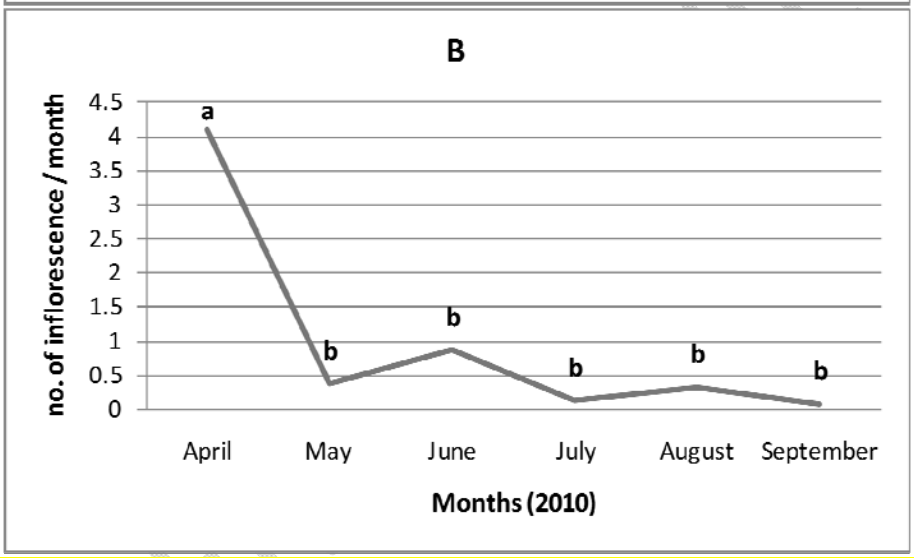


Figure 10. Number of Inflorescence of 'Magallanes' Pummelo as Influenced by K Fertilization (A) and Month within the Experimental Period (B). Means with a Common Letter are not Significantly Different at 0.05 Level Using HSD. All Treatments were Applied with Recommended Rate of NP Except for the Control (without fertilization).

3.10 Number of Fruits that Set

The effects of the K treatments on the number of fruits that set on 'Magallanes' pummelo differed significantly along the various months of this study. As shown in Table 3, significant difference among treatment means was only observed on the months of April and June.

Highest fruit sets in April was obtained with 225 g K basal and 225 g K basal + foliar treatments, which had 10-18 more fruits that set, compared the results obtained in the 150 g K, no K and control. The 225 g K basal + foliar also induced the highest fruit set in June, which had 4-5 more fruits that set than the 225 g K basal, no K and control. For the fruit set of this month, the treatment with 225 g K basal, 150 g K basal and no K treatments had no significant effect, as compared to the control (Table 3).

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

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

Table 3. Number of fruits that set per month in 'Magallanes' pummelo as influenced by K fertilization at SODACO farm, Davao City, Philippines for 12 months' duration.

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 refer to row (months) and column (treatments) comparison, respectively. All treatments were applied with recommended rate of NP except for the control (no fertilization).

3.11 Percentage of Fruit Set

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

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 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 of 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 with the 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 reported in the literature 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. Percentages of fruit set of 'Magallanes' pummelo as influenced by K fertilization at SODACO farm, Davao City, Philippines for 12 months' duration.

Treatments	Total Flowers	Fruit Set	
		Number of fruits	Percentage
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 (Figure 11). The significant increase in fruit diameter occurred every month interval; it was highest in June, which was two months after fruit set. 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 from 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 'Magallanes' 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].

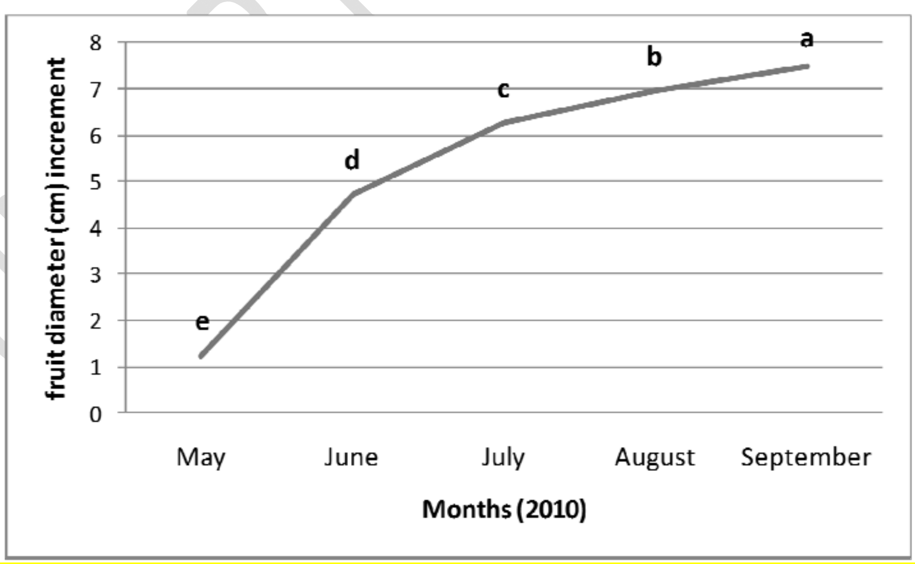


Figure 11. Monthly Fruit Diameter (cm) Increment of 'Magallanes' Pummelo. Means with a Common Letter not Significantly Different at 0.05 Level Using HSD.

3.13 Fruit Length Increment

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

Figure 12 shows that the 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 differences among treatments for fruit length was observed every month except for the first month (Figure 12). Highest fruit length was exhibited by the control. 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 made after the conduct of the study, the K content was adequate for the fruit growth of 'Magallanes' pummelo in all treatments. Though it was not applied with fertilizers in the control, there was still an increase of NPK level in this treatment, which showed that the nutrient content in the soil was still adequate for fruit growth of 'Magallanes' pummelo.

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 lengths of both single flowers and inflorescences 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 observed in this study may be 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 on 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 for metabolites on unfertilized trees, where there was with less number of fruits than trees fertilized with higher K rates, who's had more number of fruits and higher competition of metabolites.

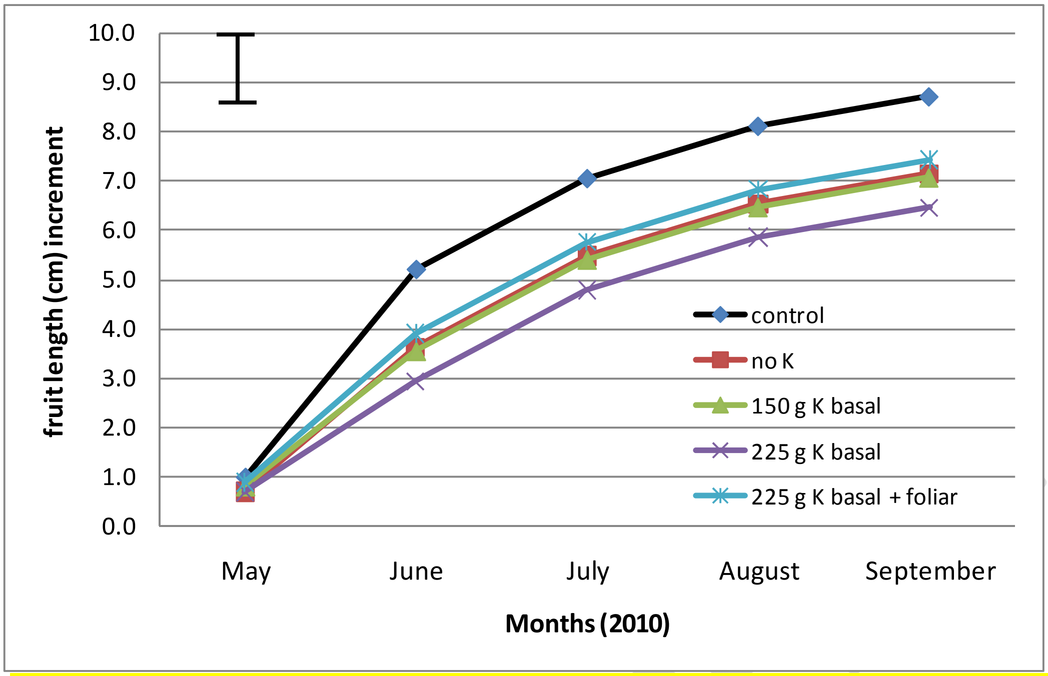


Figure 12. Monthly Fruit Length (cm) Increment of 'Magallanes' Pummelo as Influenced by K Fertilization. Bar Indicates HSD Value at 0.05 Level. All Treatments were Applied with Recommended Rate of NP Except for the Control (without fertilization).

4. Conclusion

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

The vegetative growth of 'Magallanes' pummelo, specifically tree height, is not affected by the increased K rates applied. Higher K rates improve flowering and fruit set of 'Magallanes' pummelo. The highest number of flushes, number of fruits that set, number of flowers, and % fruit set were obtained from the basal + foliar application.

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

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