Planting Densities and Nutrient Rates on the Growth and Fruit Set of 'Solo' Papaya (*Carica papaya L.*)

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ABSTRACT

Optimizing plant density per area and fertilization application are basic ways to practice scientific agriculture. These are essential for cost-effective and profitable crop production. This study was conducted at Central Mindanao University to determine the effects of varying planting densities and nutrient rates on the growth and fruit set of 'Solo' papaya. Planting densities (plants per ha or pph) served as Factor A. Nutrient rates in reference to a recommended rate (RR) as Factor B. The experiment was arranged in a 3 x 3 factorial in RCBD with three replications. Plants in 3,333 pph with 50% nutrient RR were the tallest among treatment combinations at 8 MAT and 10 MAT. Those in 2,500 pph with 100% nutrient RR had widest stems at flowering stage. Plants in 3,333 pph formed longest flowers and fruits with 150% nutrient RR. Highest fruit count per plant was recorded in 2,000 pph at 8 MAT. As per hectare basis, highest planting density produced the most number of developed fruits (117,217) at 6 MAT. However, fruit count per hectare was comparable for all planting densities and nutrient rates at 8 MAT.

Keywords: *'Solo' papaya, planting density, nutrient rate, fruit set, papaya, Bukidnon*

INTRODUCTION

Papaya (Carica papaya L.) is one of the export fruit crops of the Philippines. Usually, the fruits are exported fresh to foreign markets for consumption. The country ranked as the eight producer of papaya in the world with a total of 172,628 tons (FAOSTAT, 016). Dole, Del Monte, and Unifrutti are among the large private companies in the country that export this commodity. These multinational companies grow the 'Solo' papaya variety in Bukidnon.

One of these companies grows the cultivar (cv.) 'Solo' papaya using a 2,067 plants per ha (pph) planting density. This was adopted from the recommendation of commercial papaya growers in Florida, USA because of the dearth of information on 'Solo' production in the country (Castro, 2012). According to Goswami et al. (2014), there were papaya varieties that can be grown in high density planting (HDP) like 'Pusa Nanha.' It is a dwarf variety and may be spaced at 1.25 m x 1.2 5m (or at 6,400 pph). Orchards that adapt this HDP may have 3 to 4 times higher yields (60 to 65 tons/ha) vs. traditional orchards with only 15 to 20 tons/ha.

'Solo' papaya is a perennial variety and is grown for fresh consumption. Thus, it requires huge amounts of nutrients through regular fertilization to produce more quality and marketable fruits. However, due to diversity of soil types, climatic conditions and agricultural practices, it is necessary to develop recommendations for specific production areas (Paull and Duarte, 2011).

Optimizing plant density per area and fertilization application are basic ways to practice scientific agriculture. These are essential for cost-effective and profitable crop production.

Hence, this study was conducted to determine the effects of varying planting densities and nutrient rates on the growth and fruit set of 'Solo' papaya.

METHODOLOGY

This study was conducted at the Germplasm Area of the Department of Horticulture, College of Agriculture, Central Mindanao University (CMU), from October 2015 to October 2016.

A zigzag pattern of soil sampling was done prior to land preparation. A composite sample taken from 30 cm depth was brought to the university's Soil and Plant Analysis Laboratory for determination of primary plant nutrients available in the soil.

The soil of the experiment area was classified as Adtuyon clay. Soil texture was clay-loam based on feel method assessment. Soil pH (5.29) was slightly acidic for papaya cultivation. Soil organic matter (4.25%) was highly favorable for most agricultural crops production. Extractable phosphorus (1.20 ppm) was extremely low, whereas exchangeable potassium (129 ppm) was at optimum level.

Figure 1 shows that the seeds used in the study which were taken from selected fruits (total soluble sugar at table ripe stage of ≥14O) of red flesh 'Solo' papaya. These were sown in vermicast (25%) and soil (75%) media as recommended by Baugbog (2015). Figure 2 shows that seedlings were then placed on an elevated nursery bed to prevent damage by pests and diseases, as well as, to protect against stray animals. Figure 3 presents all other recommended nursery operations were employed until the seedlings reached the optimum height (30 cm) for field transplanting.

Figure 1. Selection of 'Solo' Papaya Fruits (source of seeds)

Figure 2. Small-scale Elevated Nursery for Papaya Seedling Establishment

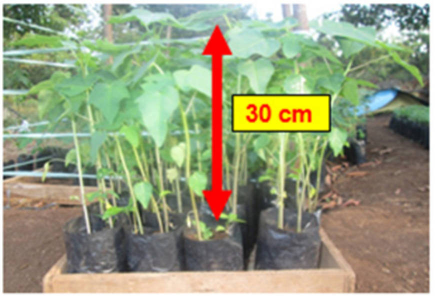

Figure 3. 'Solo' Papaya Seedlings Ready for Field Transplanting

The experiment was arranged in a 3x3 factorial in Randomized Complete Block Design (RCBD) with three replications. The experiment area measured 2,700 m2. Each experimental unit measured 10 m x 10 m or had an area of 100 m2. Table 1 presents that Factor A included the three varying planting densities. A1 (3,333 pph), A2 (2,500 pph), and A3 (2,000 pph) with corresponding planting distances.

Table 2 reveals the three nutrient rates (B1: 50 % of 'Solo' papaya local grower's recommended rate [RR]; B2: 100 % RR and B3: 150 % of RR) which served as Factor B. These nutrient rates were supplied through bi-monthly application (sole or mixed) of fertilizer materials that commenced one month after transplanting (1 MAT) until 3 MAT, and at monthly intervals from 3 MAT to 10 MAT. Fertilizer materials applied included dolomite (22% Ca and 11% Mg), ammonium sulphate (21% N and 24% S), complete (14% N, 14% P2O5, 14% K2O and 12% S), ordinary superphosphate (18% P2O5), potassium chloride (60% K2O) and solubor (20% B). A total of 12 split applications for all fertilizer materials was done.

Table 1
Varying Planting Densities used in the Study

Planting Density (Factor A)	Planting Distances
3,333 pph (A1)	1.5 m x 2.0 m
2,500 pph (A2)	2.0 m x 2.0 m
2,000 pph (A3)	2.0 m x 2.5 m

*pph (plants per hectare)

Table 2
Nutrient Rates used in the Study

Nutrient Rate (Factor B)	Total Nutrients (kg) Applied per Hectare						
	N	N	N	N	N	N	N
B1 (50% of RR)	257	111	282	110	55	262	11
B2 (100% or RR)	514	222	564	220	110	524	22
B3 (150% of RR)	771	333	846	330	165	786	33

*RR or recommended rate of a "Solo" papaya local grower

The field was plowed twice at one week interval using a disc harrow. Holes (30 cm diameter and 60 cm depth) were dug using a digging bar. Pre-plant fertilizers (vermicast, dolomite and 14-14-14) were applied per hole based on the assigned treatment. Transplanting was done late in the afternoon at three seedlings per hole. Adequate water was immediately provided per hole to prevent seedlings from suffering transplanting shock.

Manual weeding was done to control weeds growing in the experiment area during dry periods when weed population density was low. During the rainy season, integrated weed management (IWM) was implemented. IWM strategies included uprooting of weeds that grew within the canopy of papaya plants (round weeding), as well as, application of Round-up herbicide (a.i. glyphosate) to all weeds growing outside the plant canopies based on the supplier's recommended rate. Water was provided per plant using a sprinkler especially during periods of near nil rainfall. Regular removal of non-functional leaves (deleafing) was done to prevent insects from hiding in these plant parts. Thinning was done when plants started to produce flowers. Only hermaphrodite plants were retained per plot.

Plant height data were collected at two months interval starting at 2 MAT until 10 MAT. Plants were measured from ground level to the tip of apical leaves using a pre-calibrated measuring stick. Stem diameter was measured at flowering stage 30 cm above the ground using a pre-calibrated Vernier caliper.

Plants started to flower at 4 MAT. Male and female plants were rouged out to prevent interplant competition. Six reproductive growth data (number of flowers, number of fruits, floral length, floral width, fruit length and fruit width) were taken at 6 MAT and 8 MAT.

Number of flowers and fruits per hectare were also gathered. These were determined using the formula:

Potential number of flowers per hectare = average number of flowers per plant **X** planting density
Potential number of fruits per hectare = average number of fruits per plant **X** planting density

Data were analysed using the MStat-C software (Freed, 1988). Treatment means were compared using the Duncan's Multiple Range Test (DMRT).

RESULTS AND DISCUSSION

Plant Height

Significant plant height differences were only apparent starting at 8 MAT. In commercial papaya production, shorter plants would be advantageous to growers as it would be easier to harvest the fruits. Figure 4 shows that the highest planting density (3,333 pph) resulted to taller plants at 8 MAT (152 cm) and 10 MAT (212 cm). Usually, in closer planting densities, light competition is more pronounced. Thus, plants tend to grow taller and more erect in order to capture more light especially when canopy closure begins. A similar observation was reported by Zimmerman (2010), that 'Maradol', 'Tainung 5' and 'Yuen Nong 1' papaya cultivars were taller when cultivated in high planting density (HPD) than in low planting density (LPD).

However, Figure 5 reveals that taller plants (200 cm) were recorded in 50% of nutrient RR at 10 MAT than in 100% and 150% nutrient applications with 189 cm and 190 cm mean heights, respectively. These results are contrary to those of Adjei et al. (2007) in which the three fertilizer regimes did not affect the plant height of 'Solo' papaya in Ghana, Africa.

Papaya growth rate peaks at flowering then declines as the tree starts bearing. Rate of growth is influenced by nitrogen and phosphorus supply, irrigation and temperature (Paull and Duarte, 2011). Figure 6 presents that 'Solo' papaya plants were still on growth peak (241 cm) in 3,333 pph with 50% nutrient RR even at fruit bearing stages (8 MAT and 10 MAT). This could mean that growth of papaya was predominantly vegetative in high density planting and with reduced nutrient application.

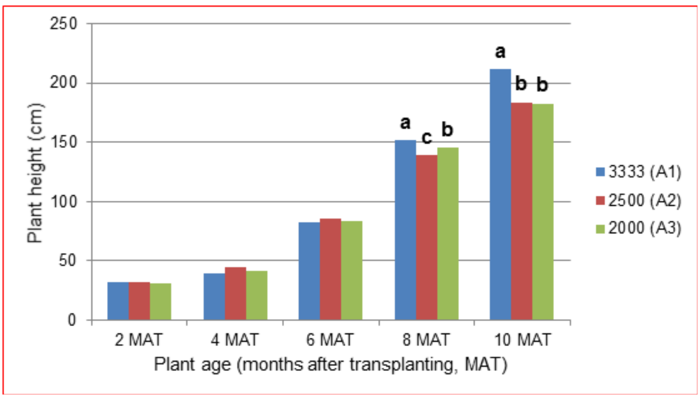

Figure 4. Effect of Varying Planting Densities on the Plant Height of 'Solo' Papaya

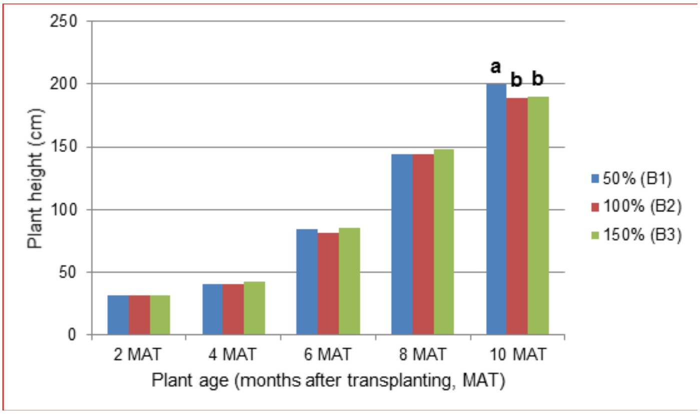

Figure 5. Effect of Nutrient Rates on the Plant Height of 'Solo' Papaya

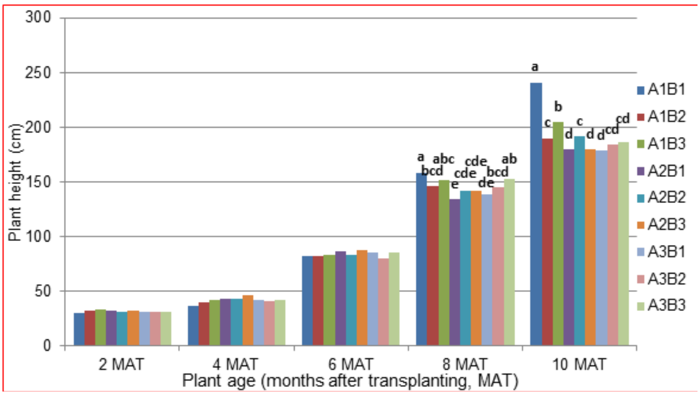

Figure 6. Effects of Different Treatment Combinations on the Plant Height of 'Solo' Papaya

Stem Diameter

The stem is very critical especially during the papaya fruiting stage. It supports the developing flowers and fruits. Stem diameters of adult plants vary from 10 cm to 30 cm at the base to 5 cm to 10 cm at the crown (Morton, 1987). This study measured plant stem diameter at flowering 30 cm from ground level.

Solo papaya stems at flowering stage were wider when grown in 3,333 pph (6.18 cm) and 2,500 pph (5.97 cm). These results were contrary to those of

Zimmerman (2010) of which three papaya cultivars ('Maradol', Tainung 5' and 'Yuen Nong 1') had wider stems in LPDs. In the case of banana, thicker pseudostem girth at shooting stage was recorded in the lowest planting density, whereas highest planting density produced plants with thinner girths (Chaudhuri and Baruah, 2010).

Papaya takes up relatively large quantities of nutrients and the demand continues until plants are about 12 months old (Oliveira et al., 2007). In this research, plants applied with 514 kg N, 222 kg P2O5, 564 kg K2O, 220 kg Ca, 110 kg Mg, 524 kg S and 22 kg B (100% nutrient RR) have the widest stems regardless of planting density. Based on growers' experience, this nutrient level was found to be the ideal in growing 'Solo' papaya (at 2,067 pph) in Bukidnon soil condition (Castro, 2012).

In papaya plants, the single stem provides structural support, body mass, storage capacity, height, competitive ability, and carries a bidirectional flow of water, nutrients, various organic compounds, and chemical and physical signals that regulate root and shoot relations (Jimenez et al., 2014). There is really a need to supply the optimum amount of nutrients and grow the crop in proper planting density that will allow vigorous plant growth. Table 4 indicates that 'Solo' papaya grown in 2,500 pph with 100% nutrient RR applied had the widest stems (6.75 cm) at flowering stage among all treatment combinations.

Number of Flowers

Papaya flowers are formed profusely near the stem apex. Under Bukidnon condition and following the 100% nutrient RR, plants are expected to start flowering as early as 2 MAT. In this research however, flowering was late (at the end of 4 MAT).

Table 4 presents the flower count per plant at 6 MAT and 8 MAT was not affected by planting density and nutrient rate. However, numerically, Figure 7 shows that the highest flower count was in HDP (3,333 pph) with 48,833 at 6 MAT and 54,995 at 8 MAT. Further, Figure 8 shows the nutrient rate and Figure 9 presents the combination effects did not influence the number of flowers produced by 'Solo' papaya at 6 MAT. However, at 8 MAT the lowest nutrient rate (50%) produced the most number of flowers per hectare (51,665). This observation is supported by the report of Oliveira et al. (2007) that larger amounts of N and K in the same ratio decreased the yield of 'Solo' papaya.

Likewise, the combination effects of planting density and nutrient rate revealed that 2,500 pph with 50% nutrient RR and 3,333 pph with 150% nutrient RR produced the most number of flowers per hectare at 8 MAT with 85,000 and 83,328, respectively. Goswami et al. (2007) suggested the use of HPD for dwarf papaya. Based on results of this study, perhaps the fertilizer rates applied can be augmented to allow more flowers or fruits to develop per 'Solo' plant/area.

Size of Flowers

Papaya has male, female and hermaphrodite or andromonoecious flowers. This study only retained hermaphrodite plants. Hermaphrodite flowers were measured using a pre-calibrated Vernier caliper.

Papaya plants flower continuously and consequently, and demand constant nutrients. Although floral width was comparable to all plants, floral length was found to be influenced by planting density and nutrient rate. Papaya plants grown in 3,333 pph with increased nutrient rate (150 %) produced the longest flowers. This result implies the need to increase nutrient application in high density planting to produce vigorous flowers.

Number of Fruits

Plants grown in 3,333 pph produced the most number of fruits (16) at 6 MAT. This result implies that closer planting distance is advantageous during the first fruit setting in 'Solo' papaya since canopy closure is incomplete during this period. This result is supported by several studies wherein highest numbers of fruits can be attained using high density planting. Valleser and Valleser (2015) reported that highest number of boxes per hectare in pineapple was recorded in high density planting.

However, when canopy closure was complete at 8 MAT, the lowest planting density (2,000 pph) used in this study was the most productive as per fruit number per plant (72.33). This implies that competition for soil moisture, nutrient and sunlight is less in lower planting densities thereby, allowing more fruit development.

Papaya plants were also responsive to varying nutrients. The 150% rate resulted to the most number of fruits developed per plant at 6 MAT. Although not statistically significantly, an increase in fruit number was observed as nutrient rate increased at 8 MAT. These results are contrary to those of Oleveira et al. (2007) where larger amounts of N and K in the same ratio decreased yields in 'Solo' papaya grown in Brazil.

Likewise, the combination of highest planting density (3,333 pph) and highest nutrient rate (150 %) produced the highest fruit count per plant (25). This suggests that 'Solo' papaya plant will be productive if grown in HDP as long as nutrient application will also be adjusted. However, Figure 10 shows that as plants mature, those in HDP were no longer responsive to the increasing nutrient rate and consequently, fruit formation started to drop.

Highest fruit count per hectare was produced in 3,333 pph (117,217) at 6 MAT. However, fruit formation stabilized as plants mature (Figure 11). Fruit count per hectare of 'Solo' papaya was not improved by nutrient rates (Figure 12) and treatment combinations (Figure 13) in this study.

Fruit Size

Fruits from hermaphroditic papaya plants tend to be elongated and vary from cylindrical to pear-shaped. Width and length of 'Solo' papaya fruits were measured using a pre-calibrated Vernier caliper.

Plants in 3,333 pph produced the widest (8.80 cm), as well as, the longest (10.93 cm) fruits. Closer planting density regulates the soil surface temperature which is advantageous during papaya fruit development. Goswami et al. (2014) suggested closer planting distances for dwarf papaya cultivars like Pusa Nanha to produce higher yields.

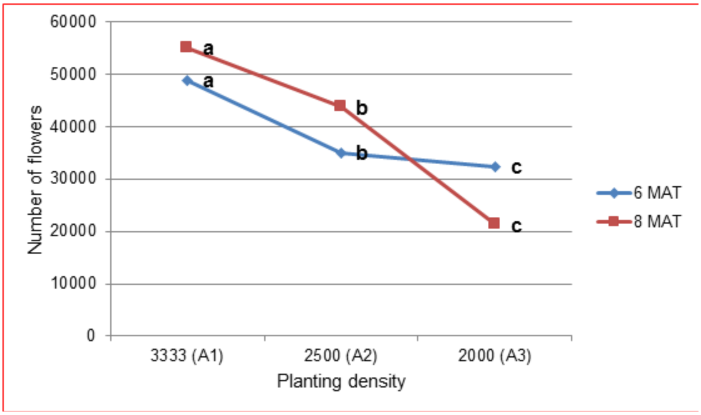

Figure 7. Effect of Planting Density on the Number of Flowers per Hectare

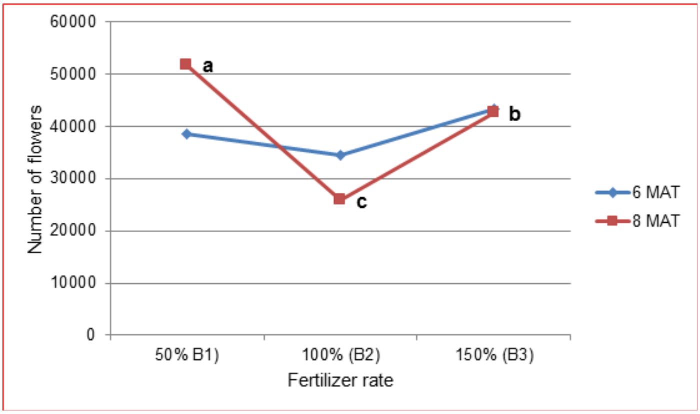

Figure 8. Effect of Nutrient Rate on the Number of Flowers per Hectare

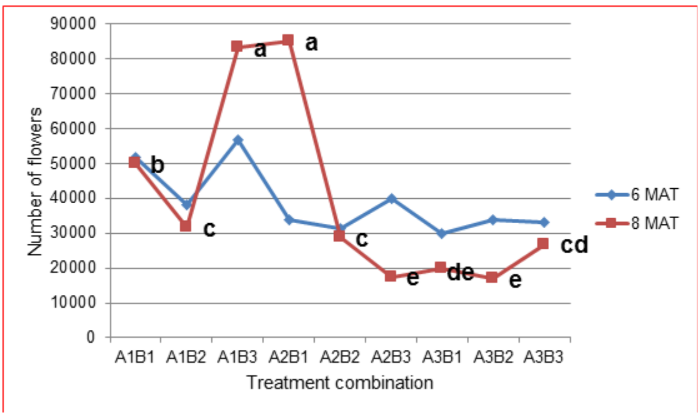

Figure 9. Effects of the Treatment Combinations on the Number of Flowers per Hectare

For nutrient rates, 100% RR produced the widest (9.20 cm) 'Solo' papaya fruits. However, fruit length was comparable to all nutrient rates in the study. Although not statistically significant, the ideal fruit size (8.18 cm width and 10.21 cm length) for commercialization was recorded at 150% nutrient RR.

Papaya growers are cautious in using HDP because fruit size might be affected. However in this study, treatment combination 3,333 pph with 150% nutrient RR produced the best fruit size (10.80 cm width and 13.88 cm length). This suggests that fruit sizes of papaya in HDP can be augmented with application of higher rates of nutrients. Papaya takes up moderately huge quantities of nutrients and the demand continues until the plants are about 12 months old. Because harvests are alternating from the start of production, plants need frequent applications of water and nutrients to ensure the nonstop production of fruits and flowers (Oliveira et al., 2007).

Fig. 10a. 3,333 pph; 50 % nutrient RR (A1B1)

Fig. 10b. 3,333 pph; 100 % nutrient RR (A1B2)

Fig. 10c. 3,333 pph; 150 % nutrient RR (A1B3)

Fig. 10d. 2,500 pph; 50 % nutrient RR (A2B1)

Fig. 10e. 2,500 pph; 100 % nutrient RR (A2B2)

Fig. 10f. 2,500 pph; 150 % nutrient RR (A2B3)

Fig. 10g. 2,000 pph; 50 % nutrient RR (A3B1)

Fig. 10h. 2,000 pph; 100 % nutrient RR (A3B2)

Fig. 10i. 2,000 pph; 150 % nutrient RR (A3B3)t

Figures 10a-10i. Fruit set of 'solo' papaya plants in varying planting densities and nutrient rates at 8MAT

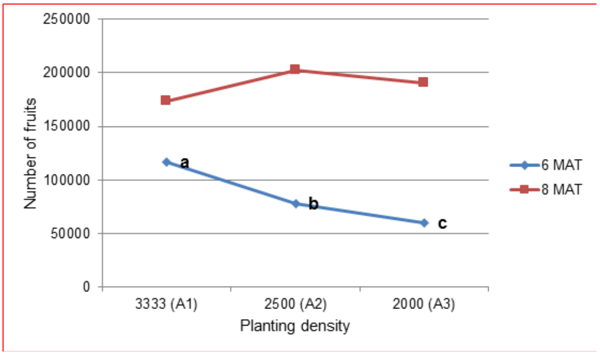

Figure 11. Effect of planting density on the number of fruits per hectare

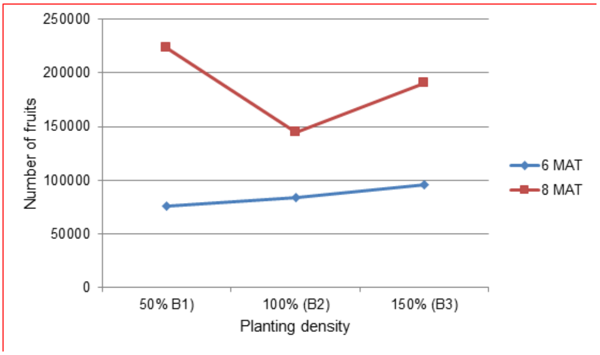

Figure 12. Effect of nutrient rate on the number of fruits per hectare

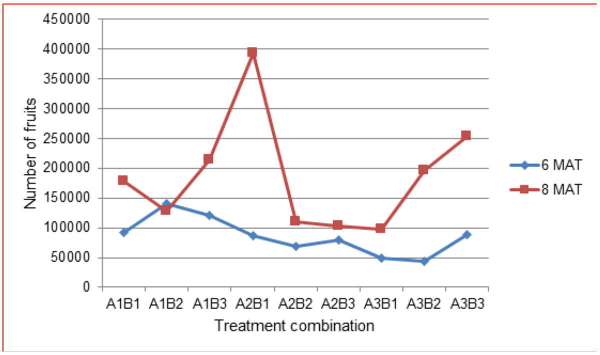

Figure 13. Effects of treatment combinations on the number of fruits per hectare

CONCLUSIONS

Based on the results of the study, three conclusions are drawn for cv. 'Solo' papaya. First, the combination of 3,333 pph with 50% nutrient RR produced the tallest plants at 8 MAT and 10 MAT. On the other hand, 2,500 pph with 100% nutrient RR produced plants with the widest stems at flowering stage. Second, longest flowers and fruits were formed by plants in 3,333 pph with 150% nutrient RR. On the other hand, most number of fruits per plant was produced in the lowest planting density (2,000 pph) at 8 MAT. Third, in terms of per hectare basis, highest planting density resulted to the most number of developed fruits (117,217) at 6 MAT. However, number of fruits produced per hectare was comparable for all densities and nutrient rates at 8 MAT.

RECOMMENDATION

As papaya is a perennial crop, additional data should be gathered on the second year of this study and thereafter, for definite recommendations to be made for the cv. Solo on planting density and nutrient rate.

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