Article

Yield and profitability of papaya genotypes based on chemical, organic and biological fertilization

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Abstract

Papaya is one of the fruit trees with the greatest demand in world markets, so it is important to develop new agricultural technology (fertilization) that helps to produce papayas of excellent quality, in addition to reducing production costs. The objective of this study was to determine the effect of chemical, organic and biological inoculant fertilization on the yield and profitability of two papaya genotypes. The investigation was carried out in the Superior Agricultural College of the state of Guerrero. The study consisted of evaluating the two genotypes of papaya, Maradol and Mulata in combination with chemical fertilizers, organic and biological inoculants. The evaluated variables were days to flowering, height of plant, stem diameter, days to harvest, number of fruits per plant, diameter and length of the fruit, total soluble solids (°Brix), average weight of the fruit, yield and economic profitability. The genotypes of papaya Maradol and Mulata presented a better response in their growth with the application of chemical fertilizer, for having fewer days to harvest, as well as a larger stem diameter in comparison to biological and organic fertilization. The chemical fertilization in papaya plants Maradol generated the highest number of fruits (38) and content of soluble solids (11.49 °Brix) and in the genotype Mulata promoted a better fruit weight (1 906 g) and yield (99.19 t ha^{-1}). The biological inoculants favor the increase in the size of the fruit. Mulata with chemical fertilization was more profitable (GPI of $5.36) than Maradol with (GPI of $4.98).

Keywords: *Carica papaya* L., biofertilizer, nutrition, production.

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Introduction

Papaya (*Carica papaya* L.) is one of the fruit trees with the highest demand in world markets, due to its high profitability and demand for fresh consumption, as it has a high nutritional and digestive value (Mirafuentes and Azpeitia, 2008; Constantino *et al*., 2010; Martin-Mex *et al*., 2012). Currently, Mexico is ranked fourth in the world producing 1 034 532 t and the first fruit exporting country (12.13% of production) to the United States of America. The main producing states are Oaxaca, Colima, Chiapas, Veracruz, Michoacán and Guerrero that grows around 1 376 ha with a production of 44 725 t and yield of 39 217 t ha^{-1} (SIAP, 2018).

The production in Guerrero is located in the coastal zones, Northern regions and Tierra Caliente, where creole genotypes are grown that present low yields and quality (Alcántara *et al*., 2010). Therefore, it is important to develop new agricultural technology that helps increase production in papaya, as well as the generation of new varieties and the study of agronomic management (fertilization), which help reduce production costs, as well as not contaminating the ambient. The genotype most demanded by both the producer and the consumer is the Maradol due to its high productivity and quality, in the same way the Mulata genotype has desirable characteristics that make it competitive; however, each one presented characteristics that stand out depending on the region of production and agronomic management (Muñozcano, 2011).

The use of fertilizers is essential to achieve the highest yields in crops (Alvárez-Hernández *et al*., 2011). However, traditional forms of production; that is to say, with excess of chemical fertilizers, they have originated as a consequence the contamination of soils and waters, which causes degradation of these natural resources (Quiñones *et al*., 2012), for what has been chosen in search of alternatives to avoid the abuse of this practice, such as products of organic origin or biological inoculants.

Microorganisms such as arbuscular mycorrhizal fungi are microbiological components of the soil that can be used as inoculants to improve plant nutrition (Quiñones *et al*., 2012). In work done with bacteria or fungi have appreciated that you can increase the absorption of nutrients by plants and increase the yield in the field (Sangabriel *et al*., 2010; Quiñones *et al*., 2012; Quiñones *et al*., 2014). In this regard, Constantino *et al*. (2010) observed an improvement in the germination and growth of papaya seedlings with the use of mycorrhizal-arbuscular fungi and rhizobacteria in Villahermosa, Tabasco.

Similarly, it has been observed that nutrition from organic matter such as compost, fertilizers, etc., make important contributions in the plant and soil; green manures and manure from confined animals can be used as primary compounds, although there are currently commercially available products on the market, which have the purpose of expanding and improving the fertilization of soil and crops, producing fruits that provide benefits to the consumer and not pollute the environment (Rodríguez *et al*., 2011).

In relation to the above, Acevedo and Pire (2004) found that when using vermicompost the growth of papaya plants was stimulated. On the other hand, Maruchi *et al*. (2008) reported that with chemical fertilization in mixture with citricomposte in papaya plants Maradol achieved a height of the plant of 191.2 cm, stem diameter of 10.2 cm, with a number of fruits per plant of 40.6 and a yield of 140.8 t ha^{-1}, in the City of Habana, Cuba.

This study aims to verify the benefits, by using three nutrition alternatives, in the papaya crop. The objective of this study was to evaluate the effect of chemical fertilization, organic and biological inoculants on the yield and profitability of two papaya genotypes.

Materials and methods

The research was conducted in the agricultural field of the Professional Studies Center of the Agricultural College of the state of Guerrero, located at km 14.5 of the Iguala-Cocula highway, between the coordinates 18º 19’ North latitude and 99º 39’ West longitude, 640 m of altitude. In the region, a dry tropical climate predominates [Awo (w) (i) g], with rains in summer. The average annual precipitation and temperature are 797 mm and 26.4 ºC, respectively (García, 2005). Before the establishment of the experiment, a soil sampling was carried out, which was taken to the edaphology laboratory of the Agricultural College of the state of Guerrero, to know the initial characteristics of the soil.

The genetic material used was the commercial genotypes Maradol and Mulata, which were planted on December 28, 2013, in trays with 200 cavities previously washed with soap and water, then submerged in a container containing 6% commercial chlorine, at a ratio of 10 mL L^{-1} of water, for 5 min. For the seedbed sterile substrate was used, placing one seed per hole at a depth of 1 cm, it was watered daily in the morning. After 50 days of sowing, the most vigorous plants without deformations were selected for subsequent transplantation in black polyethylene pots of 15 x 20 cm, which was filled with the same substrate used in the seedbed.

The plantation method used was rectangular 2.10 x 3 m, giving a population density of 1 587 plants ha^{-1}. A chemical, organic and biological fertilization was applied to the genotypes under study, carried out in three periods of application, the first on February 12, the second on May 7 and the third on June 16, 2014. The treatments used are described in Table 1. To compensate for micronutrient deficiencies, foliar fertilizer applications (Bayfolan®) were applied to all the plants.

Table 1. Treatments used in the study.

Treat.	Genotype	Fertilization	Dose
1	Maradol	Urea (46%N) + 18-46-00 + KCl (66%K)	60 + 230 +100 g $plant^{-1}$
2	Maradol	Natur-abono® (organic fertilizer)	1.5 kg $plant^{-1}$
3	Maradol	Bio Bravo® (*Glomus intraradises* + *Glomus fasiculatum* + *Trichoderma* spp. + *Azospirillum brasilense*)	250 + 250 mL ha^{-1} (40 000 spores) + 250 mL ha^{-1} (1x10^{11} spores) + 250 mL ha^{-1} (5x10^{11} spores)
4	Mulata	Urea (46%N) + 18-46-00 + KCl (66%K)	60 + 230 +100 g $plant^{-1}$
5	Mulata	Natur-abono® (organic fertilizer)	1.5 kg $plant^{-1}$
6	Mulata	Bio Bravo® (*Glomus intraradises* + *Glomus fasiculatum* + *Trichoderma* spp. + *Azospirillum brasilense*)	250 + 250 mL ha^{-1} (40 000 spores) + 250 ml ha^{-1} (1x10^{11} spores) + 250 mL ha^{-1} (5x10^{11} spores)

The six treatments were distributed in a randomized complete block design in an arrangement of divided plots and four repetitions. Each experimental unit was formed by four plants which occupied a surface of 6.3 m long and 1.5 m wide, this was used as a useful plot.

$$Yijk= \mu + \beta i + A_j + \varepsilon_{ij} + B_k + (AB)_{jk} + e_{ijk}$$

Where: Y_{ijk}= is the response variable; β_i= is the effect of the ith block; A_j (genotype)= effect of the jth treatment; ε_{ij}= random error in the large plot; B_k (fertilizers) effect of the kth sub-treatment; $(AB)_{jk}$= effect of the interaction between the jth treatment and the kth sub-treatment; and e_{ijk}= random error in the small plot.

The variables evaluated in the flowering stage were days to flowering where they were counted, from the moment of the transplant until the budding of the flower bud began. The stem diameter of the plant was recorded using a digital vernier (Caliper®) taking the reading exactly on the neck of the plant. The height of the plant was measured with a tape measure, from the neck to the apex of the plant. The harvest was made weekly, once the formation of betas in the fruit began. Five manual cuts were made, which were on November 14, 21 and 28, 2014, as well as on December 04 and 11, 2014.

In the harvest, the days to the harvest were evaluated, from the moment of the transplant until the day when the first cut of the fruit per plant was made. The number of fruits per plant was also evaluated, counting all the fruits including the fruit set (mooring) and those that were in the process of maturation. The length and diameter of the fruit was measured with a vernier (Caliper®) in the middle part of the fruit and from the insertion of the peduncle to the other distal end of the fruit. As for the total soluble solids (°Brix) this was evaluated when the fruits reached the edible maturity, approximately between 6 and 8 days after the cut, using a refractometer (Precision Instruments®, REF040).

The harvested fruits were weighed on an electronic scale (IBN®, B-30) with 30 kg capacity to obtain the average weight of the fruit. The yield of fruits was estimated per hectare, taking into account the average values of the weight of the fruit, the number of fruits per plant and the density of population per hectare.

A variance analysis was performed on the evaluated variables, with the statistical program of the SAS (Statistical Analysis System, Version 9.0) and the comparison test of Tukey means with a probability of 5%.

For the economic analysis, the costs incurred by each treatment were estimated using the following equations (Bueno *et al*., 2005):

Total cost (CT). It is the sum of the fixed (CF) and variable (CV) costs.

CT= (CF + CV)
Total income (IT). This was calculated with the following formula:

IT= Py Y

Where: Py= price of the product ($6.58 for that year); Y= production ha^{-1}.

Net income (IN). It is the difference between the total cost (CT) and the total income (IT).

IN= (IT-CT)

Gain by invested weight (GPI). It was obtained by dividing the net income (IN) by total cost (CT).

GPI= (IN/CT)

Results and discussion

The soil physicochemical analysis showed that the study was established in a soil with clay texture (63%), pH 7.1 neutral, bulk density of 1 g cm^{-3}, electrical conductivity of 0.206 dS m^{-1}, organic matter of 3.6%.

Days to flowering

Table 2 shows the effects of the types of nutrition used in the two papaya genotypes. According to the analysis of variance between genotypes, no significant differences were observed ($p\leq 0.05$); however, Maradol started to bloom 2 days before the Mulata genotype. This indicates, a greater precocity on the part of Maradol. Regarding the type of fertilization used, it was found that flower buds, on average, needed 127 days to flower when using organic products, while plants fertilized with chemicals and biologicals bloomed on average at 126 days, respectively.

Statistically the differences were not significant, the effect of the fertilizers did not influence the days to flowering, due to the availability of the nutrients that favored floral biology. The above, agrees with what was observed by Vázquez (2008), in the south of Tamaulipas, where they found that Maradol required an average of 123 days to begin to flower, using a chemical fertilization.

Height of plant and stem diameter

Statistical analysis for plant height and stem diameter showed no significant differences ($p> 0.05$) between papaya genotypes with different types of fertilization. However, it can be observed that the Mulata variety expressed a greater height, with the use of biological inoculants. However, with chemical fertilization larger diameter stems were generated. The Maradol variety also reached its highest height with biological fertilizer as well as organic fertilizer; as for the thickness of the stem, it became wider with chemical fertilization.

This indicates that the application of chemical fertilizers generates plants with greater thickness of the stem, but also of lower height, which could be related to the precocity of the plant. The stimulation of essential nutrients in the soil possibly promoted an early floral induction, because the plant stopped its vegetative growth activity to start the stage of flower and fruit formation (Azcon-Bieto and Talon, 2008; Maruchi *et al*., 2008; Rodríguez *et al*., 2011).

In this regard, Quiñones *et al*. (2012; 2014) when evaluating the papaya crop, they found a greater growth in plant height and stem diameter with biological fertilization (*Glomus* sp.) and organic matter composting in contrast to chemical fertilization. Acevedo and Pire (2004) in Tarabana, state of Lara, Venezuela, reported higher stem height and diameter in the Thai variety papaya with the application of vermicompost compared to chemical fertilization (Table 2).

Days to harvest

In the days to the harvest, the fertilization showed significant differences ($p \leq 0.05$) for each genotype, where there was a reduction in the days elapsed to carry out the harvest with the chemical fertilizer, contrasting with the organic and biological fertilization in which Maradol required 12 and 24 more days to carry out the first harvest and Mulata 5 and 10 days, respectively. This indicates that chemical fertilization manages to reduce the days to harvest in the Maradol genotype compared to organic and biological fertilization. The availability of essential nutrients in the soil promoted a rapid accumulation of sugars in the fruit, thus initiating the harvest sooner (Alcántara *et al*., 2010; Alvárez and Munro, 2011) (Table 2).

Table 2. Effect of the type of fertilization on the growth of two papaya genotypes.

Genotype	Fertilizer	Days to flowering	Height of the plant (cm)	Diameter of the stem (cm)	Days to harvest
Maradol	Chemical	125 a	1.67 a	13.1 a	323 c
	Organic	127 a	1.8 a	11.6 a	335 bc
	Biological	124 a	1.8 a	11.8 a	347 a
Mulata	Chemical	127 a	1.69 a	13.2 a	327 bc
	Organic	127 a	1.71 a	12.5 a	333 bc
	Biological	128 a	1.81 a	12.5 a	337 ab
Tukey α= 0.05 (DMS)		3.7	14.1	1.6	8.6
CV (%)		1.3	7.4	7.2	1.2

Columns with the same letters indicate that variables with statistically equal (Tukey, $p = 0.05$).

Number of fruits per plant

The amount of fruit presented by the Mulata genotype stood out to Maradol with the application of organic and biological fertilizers, but not in chemical fertilization where the highest number of fruits was observed in the Maradol genotype; however, these values were not significant ($p > 0.05$) with respect to Mulata in chemical fertilization (Table 3). This indicates that chemical fertilization increases the number of fruits in the papaya plant. In this regard Rodríguez *et al*. (2011), compared effects of biological and chemical fertilization in the Maradol variety, obtaining 19.8 and 20.2 fruits per plant, respectively.

It should be noted that organic fertilization generates a greater number of fruits than biological fertilization in both genotypes. Since the organic matter improves the physical and chemical properties of the soil and increased the water and nutrient retention capacity, in addition to some sources of organic matter have a high availability of nutrients that promote the reproduction of plants (Quiñones *et al*., 2014). Likewise, Maruchi *et al*. (2008) conducted an investigation in Maradol Roja papaya, where they found averages of 40.6 fruits plant^{-1}, in treatments with chemical and organic fertilization (citricomposte).

Average fruit weight

In the average weight of the fruit, the genotypes evaluated showed no significant differences ($p>$ 0.05) between the fertilizers used; however, despite the null significance, the Mulata genotype showed a higher weight than Maradol, with chemical fertilization in both genotypes being of greater weight than organic and biological fertilizations (Table 3). The results indicate that chemical fertilization improves the weight of the fruit, which is related to a higher yield. In this regard Rodríguez *et al*. (2011) obtained an average weight of 1.62 kg in the chemical treatment and 1.71 kg in the organic, which were not significant among themselves. While Vázquez (2011) in a study conducted in papaya Maradol with chemical treatments and mycorrhizal *Glomus musseae*, found averages of 1 432 and 2 078 kg, respectively.

Diameter and length of the fruit

The statistical analysis for the diameter and length of the fruit presented significant differences ($p\leq$ 0.05) between genotypes, being Mulata the one that produced fruits of greater diameter and length (Table 3).

Table 3. Physical and chemical characteristics of two papaya genotypes according to the type of fertilization.

Genotype	Fertilizer	Fruits per plant	Weight of the fruit (g)	Diameter of the fruit	Length of the fruit	°Brix
Maradol	Chemical	38 a	1 706 a	12.58 b	18.49 c	11.49 a
	Organic	22 b	1 683 a	12.4 b	20.03 bc	11.45 a
	Biological	14 c	1 510 a	13.71 b	21.37 bc	11.45 a
Mulata	Chemical	30 a	1 906 a	14.46 b	23.31 ab	10.93 b
	Organic	31 a	1 806 a	12.52 b	22.31 ab	10.8 b
	Biological	18 bc	1 773 a	15.14 ab	24.54 ab	10.77 b
Tukey α = 0.05 (DMS)		10.7	493.2	2.3	2.9	0.1
CV (%)		25.9	11	6.8	7.1	0.5

Columns with the same letters indicate that variables with statistically equal (Tukey, p= 0.05).

What is related to the greater weight of fruit? In this regard, Muñozcano (2011) mentions that the Mulata genotype develops larger fruits than Maradol. This may be related to the low amount of fruit that the plant presented, causing a minimum competition for the nutrients between the fruits, generating larger fruits.

Total soluble solids (°Brix)

The concentration of soluble solids showed significant differences ($p \leq 0.05$) among the genotypes and not in the type of applied fertilization. The highest content of soluble solids was found in the Maradol genotype compared to Mulata. The statistical analysis showed no statistical differences in the type of fertilization (Table 3). This indicates that papaya Maradol is sweeter Mulata. Because the concentration of soluble solids is a genetic characteristic that is related to the genotype used. In this regard, Santamaría *et al*. (2009) report that the content of total soluble solids achieved by the Maradol papaya fruit is 11.5 °Brix.

Fruit yield

The yield for the two genotypes evaluated showed significant differences ($p \leq 0.05$) between the fertilizers used, but not between genotypes. However, the Mulata genotype surpassed Maradol, which showed higher production. Therefore, the best yield was found in the Mulata genotype with the application of the chemical fertilizer, which is related to the highest fruit weight. The chemical treatment obtained the highest average value that was 95.16 t ha^{-1} and managed to surpass the organic and biological ones, which registered an average of 56.58 and 48.56 t ha^{-1}, respectively. This indicates that chemical fertilization directly influences crop yield (Figure 1).

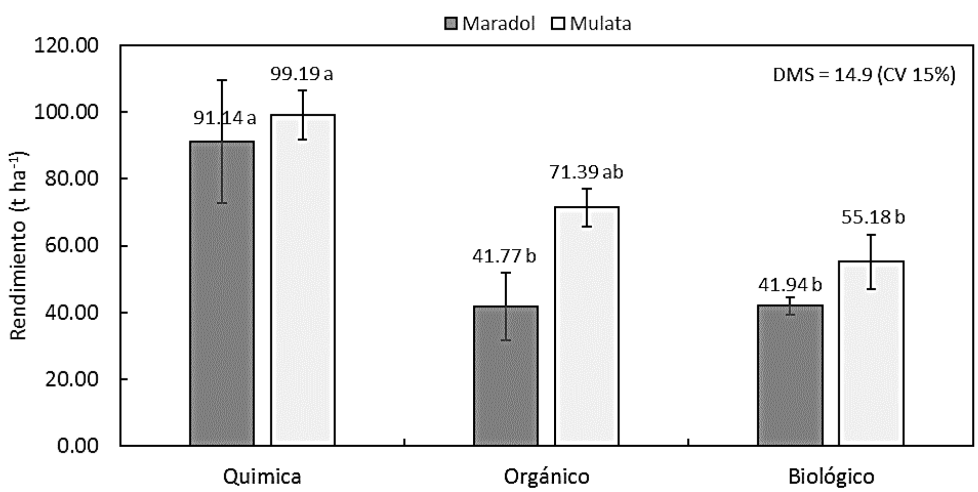

Figure 1. Yield of two papaya genotypes according to the type of fertilization.

In this regard, Rodríguez *et al*. (2011) presented a yield of 53.8 t ha^{-1} in the Maradol cultivar with the chemical treatment; while with the organic registered 56.4 t ha^{-1}. Maruchi *et al*. (2008) report 140.8 t ha^{-1} in treatments with chemical and organic nutrition (citricomposte), respectively. Vazquez (2011) in papaya Maradol with chemical treatments and mycorrhizae *Glomus musseae*, obtained averages of 70.6 and 144.9 t ha^{-1}, respectively.

Economic analysis

Table 4 shows the economic estimate of the production and commercialization of papaya genotypes evaluated according to the type of fertilization.

Table 4. Yield (R), total income (IT), fixed costs (CF), variable costs (CV), total costs (TC), net income (IN) and profit per invested weight (GPI) in genotypes (G) of papaya depending on the type of fertilization.

G	Fertilizer	R	IT	CF	CV	CT	IN	GPI
		($t\ ha^{-1}$)	($)					
Maradol	Chemical	91.14	549 574.20	73 329.28	18 633.10	91 962.38	457 611.82	4.98
	Organic	41.77	251 873.10	73 329.28	26 423.60	99 752.88	152 120.22	1.52
	Biológico	41.94	252 898.20	73 329.28	6 573.60	79 902.88	172 995.32	2.17
Mulata	Chemical	99.19	598 115.70	73 329.28	20 702.70	94 031.98	504 083.72	5.36
	Organic	71.39	430 481.70	73 329.28	28 493.20	101 822.48	328 659.22	3.23
	Biológico	55.18	332 735.40	73 329.38	8 643.20	81 972.48	250 762.92	3.06

R= performance; IT= R x price per kg of papaya ($6.03); CF= includes cost of land preparation, planting, irrigation, weed management and pests; CV= includes the cost of the seed and fertilization.

Chemical fertilization generated the highest total income, net income, and the highest GPI, in the Mulata genotype, as in Maradol. Thus, for every peso invested in the production of Mulata, $5.39 was recovered. The lowest GPI were those obtained with the Maradol variety in both organic and biological nutrition. In this regard, Bueno *et al*. (2005) in Veracruz with papaya sowing Maradol observed the best net income with a high chemical fertilization. Therefore, the use of the Mulata genotype is recommended, since with chemical fertilization a higher net income is generated; however, organic fertilization can be an alternative for farmers who grow and market organic products.

Conclusions

The genotypes of papaya Maradol and Mulata presented a better response in their growth with the application of chemical fertilizer, for having fewer days to harvest, as well as a larger stem diameter in comparison to biological and organic fertilization. The chemical fertilization in papaya Maradol plants, generated the highest number of fruits and content of soluble solids (°Brix) and in the genotype Mulata promoted a better weight of fruit and yield. The biological inoculants favor the increase in the size of the fruit. Mulata with chemical fertilization is more profitable, because it achieved a gain by invested weight of $5.36.

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