Scientific Paper

Effect of fertilization on the yield of *Jatropha curcas* (Linn.) and associated crops

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Abstract

Objective: To determine the effect of chemical fertilization and the use of two bioproducts on the seed yield of *Jatropha curcas* (Linn.) and of the associated crops.

Materials and Methods: A complete randomized block design was used. Nine treatments were studied: T1 (control)-without application of fertilization, T2-300 kg/ha/year, T3-600 kg/ha/year, T4-IHPLUS®, T5-FitoMas-E, T6-300 kg/ha/year + IHPLUS®, T7-300 kg/ha/year + FitoMas-E, T8-600 kg/ha/year + IHPLUS® and T9-600 kg/ha/year + FitoMas-E. The productive variables of *J. curcas* and the yields of the associated crops *Cucurbita maxima Duchesne* and *Phaseolus vulgaris* L., were determined. The data were processed through a simple variance analysis. The statistical package Infostat®, version 1.1 was used.

Results: For the quantity of producing branches per plant, the highest values (14) were obtained for T6, T7, T8 and T9. In turn, T9-600 kg/ha/year + FitoMas-E recorded the highest quantity of fruits per raceme (12); while T7-300 kg/ha/year+ FitoMas-E showed the best performance for fruit and seed yield, with values of 2 405,5 and 1 796,3 kg/ha, respectively. The crops *C. maxima* and *P. vulgaris*, had productions of 7,5 and 0,7 t/ha, respectively.

Conclusions: The development of *J. curcas* is determined by the effect of nitrogen fertilization in this study. The increase of seed yield is possible, if 300 kg of N/ha/year of chemical fertilizers + FitoMas-E are combined, without affecting the production of associated crops.

Keywords: fertilizer application, biofuels, *Cucurbita maxima Duchesne*, nurse crops, *Phaseolus vulgaris*

Introduction

Jatropha curcas (Linn.) is a plant that has been studied since a few years ago in order to use it in agroenergy systems. It emerges as an alternative for this type of systems, not only because its composition of fatty acids makes it ideal for good-quality biodiesel, but because as it is considered a toxic plant for feeding, its use could decrease the demand for other oil plants, thus releasing them for consumption (Adriano-Anaya *et al*., 2014). In addition, this plant combines well when used in association with annual food crops.

The association of *J. curcas* with food crops is a practice that has been shown in several countries of Central America, South America and Africa (Ávila-Soler *et al*., 2018). According to studies conducted by Rucoba-García and Munguía-Gil (2013), when comparing two production systems of *J. curcas* in monoculture and in association with *Zea mays* L. and *Phaseolus vulgaris* L., the economic profitability of intercropping the tree with these crops could be determined. It was proven that with intercropping the profits were slightly higher than the ones obtained when these species are used as monoculture.

With intercropping, in Cuba higher results have been obtained in the yield of more than twenty crops. The productions of *J. curcas* fruits stand out, which can be used to obtain biodiesel and coproducts of high value for animal feeding (Suárez, 2015).

J. curcas is considered a crop resistant to drought, salinity, and attack by pests and diseases, and which is adaptable to different edaphoclimatic conditions, mainly to low-fertility soils (Montenegro-Ramos, 2017). Nevertheless, most of the evaluations of this oil plant have been conducted with plants that grew under wild conditions.

After using *J. curcas* under production conditions, the agronomic management that should be carried out to guarantee acceptable fruit yields per plant is still unknown.

Patíl and Parameshwarappa (2007), when applying respectively 80 kg/ha of N, P_2O_5, K_2O on the

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J. curcas crop, obtained seed yields of 1,3 t/ha per year. These authors also stated that in Brazil fertilizations have been applied between 120 and 400 kg N/ha/year, which vary from the first to the fourth year of the plant establishment.

However, in the constant search for more economic and sustainable alternatives, it is necessary to study about other fertilization sources, such as the utilization of bioproducts, which at the present times constitutes a need in the Cuban agricultural production to decrease the negative impacts of climate change.

FitoMas-E is an anti-stress product, elaborated from natural substances of the plant metabolism, which stimulates and invigorates practically any crop, from germination to fructification (Díaz-Medina *et al.*, 2016).

Also IHPLUS®, elaborated at the Pastures and Forages Research Station Indio Hatuey, is a bioproduct whose production is based on the inoculation of crops with microorganisms that are beneficial for the soil. It has been used for stimulating the germination, growth and development of plants, because it produces many bioactive compounds (Díaz-Solares, *et al.,* 2019). Although no references have been found related to the effect of this product on the plant flowering and fructification process, it is assumed that it could have influence on these phases due to the action exerted by the metabolites that compose it.

The objective of this work was to determine the effect of chemical fertilization and the use of bioproducts on the yield of *J. curcas* seeds and the associated crops.

Materials and Methods

Location. The study was conducted at the integrated food and energy production farm of the Pastures and Forages Research Station Indio Hatuey (EEPFIH), located in the central zone of Matanzas province, in the Perico municipality, at 22°48' 7'' North latitude and 81°2' West longitude, at an altitude of 19,01 m above the sea level.

Soil and climate characteristics. The experiments were conducted on a lixiviated ferralitic red soil (Hernández-Jiménez, 2015).

In order to know the chemical characteristics of the study area, soil samples were taken at two depths, 0 -15 and 15 - 30 cm (Anderson and Ingram, 1993), at five different spots. The content of nitrites (diazotization method), nitrate (Cadmium reduction method), sulfur (chloride method), iron (bipyridyl method), ammoniac nitrogen (nesslerization method), potassium (tetraphenylboron method) and phosphorus (ascorbic acid reduction method), was determined. All the analyses were carried out with the portable soil lab (SMART3 Soil 1.11) of the EEPFIH.

According to the characteristics that are shown in table 1, the studied area was identified as of low fertility, taking into consideration the criteria expressed by Lamotte (2012).

Table 2 shows the values of the climate variables during the two years of evaluation. For this period, the rainfall was higher than 1 000 mm. The mean temperature oscillated between 25,6 and 27,2 ºC, evaporation was higher in the first year and relative humidity fluctuated between 81,2 and 83,6 %. In general, the variables were discreetly higher than the mean of the last five years.

Sowing and seed provenance. The soil was prepared before sowing. For such purpose, alternately, plowing and harrowing were performed twice. *J. curcas* seed, provenance Cape Verde, was used. Two seeds per hole were deposited, and the planting distance was 6 x 2 m, for a density of 833 plants/ha.

Table 1. Results of the soil analyses of the study area (kg/ha).

Indicator	Depth, cm		Content classification
	0 – 15	15 – 30	
Nitrites	8,21	10,25	Moderate - high
Nitrate	25,74	14,32	Moderate
Ammoniac nitrogen	85,12	114,22	High
Sulfur	10,15	26,44	Low
Potassium	94,61	120,21	Moderate
Phosphorus	11,34	12,95	Low
Iron	0,21	0,80	Very low

Table 2. Performance of the climate variables during the evaluation period.

Year	Rainfall, mm	Mean temperature, °C	Evaporation, mm	Mean relative humidity, %
1	1 258,9	25, 6	1 592,3	81,2
2	1 334,2	27,2	1 307,3	83,6
Mean[¥]	1 310,6	25,1	1 094,3	81,4

[¥]Mean of the climate variables in the five years previous to the study.

Experimental design and treatments. A complete randomized block design was used. Nine treatments were studied, which were replicated four times for a total of 36 plots. The treatments were: T1 (control) – without applying fertilization, T2-300 kg/ha/year, T3-600 kg/ha/year, T4-IHPLUS®, T5-FitoMas-E, T6-300 kg/ha/year + IHPLUS®, T7-300 kg/ha/year + FitoMas-E, T8-600 kg/ha/year + IHPLUS® and T9-600 kg/ha/year + FitoMas-E.

Characteristics of the plots. The size of the rough plots was 30 m wide x 8 m long. Each plot was composed by 20 plants and four replicas; that is, 80 plants per treatment. The net plot had a size of 18 m wide x 4 m long. Six plants were evaluated for a total of 24 plants per treatment. Before the study, one year in advance, a homogenization pruning was performed on all the plants (12 months of age), at a height of 10 cm over the soil basis.

Experimental procedure. The trial was conducted during two years. Each year the two fructification periods of *J curcas* for the edaphoclimatic conditions of Cuba (July-September and December-February) were taken into consideration. Urea was used as chemical fertilizer. The doses were 0, 300 and 600 kg N/ha/year. The applications were made twice per year, in May and October, always around the stem basis.

The bioproducts were FitoMas-E and IHPLUS®, elaborated by the Cuban Research Institute of Sugarcane Products (ICIDCA, for its initials inSpanish) and the EEPFIH, respectively. The application was done considering the procedure that was followed with the chemical fertilization, regarding the moment and way of application, with a concentration of 0,5 and 1 L/ha of IHPLUS® and FitoMas-E, respectively (Alvarez-Rodríguez *et al.,* 2015; Tellez-Soria and Orberá-Ratón, 2018).

Measurements. The variables to be studied were the ones proposed by Campuzano (2009), which were:

Number of producing branches per plant (BP). The quantity of branches that produced fruits was counted per plant. It was done 18 months after sowing.

Number of racemes per branch (RB). The number of racemes per primary branch was counted, in two branches per plant, weekly, in each fructification time of the plant.

Number of fruits per raceme (FR). The number of fruits per raceme was counted, in two racemes per plant on different branches, weekly, in each fructification time of the plant.

Weight of the fruits (FW). With the aid of a scale the weight of 10 mature fruits (yellow shell color) with the aid of a scale. It was done only once, after the harvest was finished.

Seed weight (SW). The weight of 100 seeds was quantified with the aid of a scale.it was done only once, after the harvest was finished.

Yield of fruits and seeds (kg/ha). The variables BP, RB, FR, FW and SW served to estimate the fruit yield (FY) and seed yield (SY); with the following formulas:

$$FY = \frac{(FW \times \text{Number of fruits per plant} \times \text{plant density})}{} \div 1\,000$$

$$SY = \frac{(SW \times \text{Number of seeds per plant} \times \text{plant density})}{} \div 1\,000$$

During the experimental stage squash (*Cucurbita maxima Duchesne*), variety RG, and beans (*P. vulgaris*), variety Cuba Cueto 25-9, were sown. These crops were planted in association with the tree.

For *C. maxima*, the planting distance was 1,0 m between plants and 6,00 m between rows, for which only one row was planted between two of *J. curcas*, for a density of 1 666 plants/ha.

For *P. vulgaris*, a planting distance of 0,7 m between rows and 0,3 m between plants was used, for which between two rows of *J. curcas* there were five rows of the legumes. The rows of the associated crop edges were separated by 1,2 m from *J. curcas*, which represented a density of 47 619 of *P. vulgaris* plants/ha.

For maintaining the plantations the technical norms of each crop were considered (MINAG, 1984; INIVIT/MINAG, 2012).

The agricultural yield per hectare of each associated crop was calculated. In both cases, this variable was estimated from the yield per plot and per treatment (IPGRI/IITA, 2001).

Statistical analysis. The variables quantity of producing branches per plant and of constituted racemes per branch, weight and yield of *J. curcas* fruits and seeds, as well as the yields of *C. maxima* and *P. vulgaris*, were processed taking into consideration a simple classification variance analysis, after verifying that the assumptions fulfilled the variance homogeneity and normal distribution adjustment. For such purpose, the statistical package Infostat®, version 1.1 was used. The means were compared by Duncan's test, for a significance level of $p \leq 0,05$. For the variable quantity of fruits developed per racemes of *Jatropha*, descriptive statistics was used and the minimum and maximum values obtained were taken into consideration.

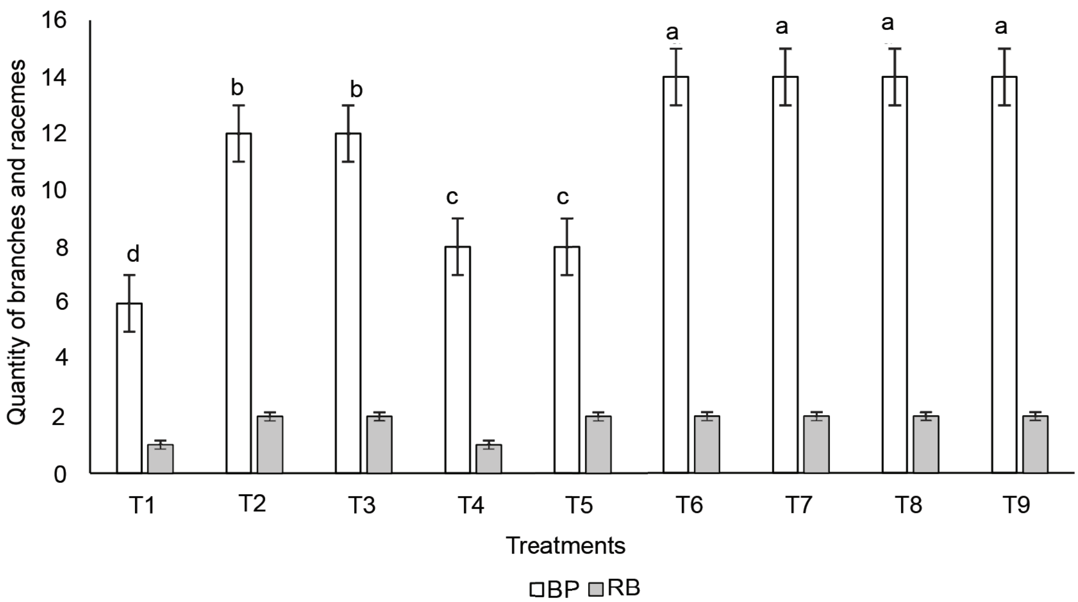
Results and Discussion

Figure 1 shows the quantity of producing branches per plant (BP) and the number of racemes per branch (RB). The variable BP varied among treatments with significant differences. The highest values were obtained for T6, T7, T8 and T9, with means of 14 branches, which indicates that the combination of the application of chemical fertilization and the use of bioproducts stimulated this variable.

López *et al.* (2018) stated that the quantity of branches that form the *J. curcas* plants at the end of the establishment stage is between three and four. However, in this study, when using as management practices the formation pruning, and the later application of chemical fertilizers, as well as biological products, allowed the increase of the number of branches, approximately four times.

With T2 and T3 mean values of 12 BP were obtained, without differences between both treatments. For T4 and T5, eight BP were found, and for T1 (control) the lowest values were observed, with only six producing branches. This indicates that this variable responds favorably to the application of fertilizers and bioproducts, but more effectively to the combination of both.

Teniente-Oviedo *et al.* (2011) stated that *J. curcas* assimilates efficiently the application of the nutrient sources, organic as well as inorganic. These authors, when evaluating in this species the chemical fertilization based on nitrogen and phosphorus, and the biological fertilization with mycorrhizae from the genus *Glomus* and *A. brasilense*, did not find significant differences between the treatments for the morphological variables (number of branches and inflorescences), which determine plant growth and development, and have significant repercussion on *J. curcas* yield.



a, b, c, d: Different letters indicate significant differences at $p \leq 0,05$
BP: quantity of producing branches per plant, RB: quantity of racemes formed per branch
T1-without application (control), T2-300 kg/ha/year, T3-600 kg/ha/year, T4 IHPlUS®,
T5-FitoMas-E, T6-300 kg/ha/year +IHPLUS T6-300 kg/ha/year +IHPLUS®,
T7-300 kg/ha/year +FitoMas-E, T8-600 kg/ha/year +IHPLUS®, T9-600 kg/ha/year +FitoMas-E.

Figure 1. Quantity of producing branches per plant and racemes per branch in *J. curcas* due to fertilization.

Martiñón-Martínez *et al.* (2017) promoted up to five branches, when applying other bioproducts, such as the rooter Rooting® and Trichoderma. Likewise, Kannan and Kannan (2013), in an experiment conducted with bio-inoculants, farm manure and chemical fertilization (N P K), found that the mixtures which contained Azospirillum + Trichoderma + Arbuscular mycorrhiza, generated a higher number of branches per plant (27 to 36 branches).

Regarding the quantity of formed racemes per branch (RB), there were no significant differences among treatments. The mean values oscillated between one and two racemes on each branch, for which it was not determined that the application of fertilizers and bioproducts used had incidence on this aspect. Also Martiñón-Martínez *et al.* (2017) found, approximately, eight floral racemes per plant. If it is taken into consideration that the quantity of developed branches was between four and five, it is possible to infer that between one or two racemes per each branch were obtained.

Table 3 shows the productive characteristics of *J. curcas* due to fertilization. The quantity of fruits found per raceme was a variable that was analyzed descriptively. It was found that there was variation in the maximum developed fruits, according to the treatment. For T1 the lowest quantity was obtained (6), and for T9, twice as much (12).

For the fruit weigh (FW) and seed weight (SW) no significant differences were found among the treatments. For the other variables, there were differences among the treatments ($p \leq 0{,}05$) for each case. T7 was the one with the best performance in terms of FY and SY, and differed significantly from the others.

Seed yield is the most important variable from the productive point of view, if it is taken into consideration that its composition is, approximately, 40 % oil (Adriano-Anaya *et al.*, 2014). Thus, the results in this research indicate that to achieve the highest oil yields, the best combination consists in the application of 300 kg/ha/year of the chemical fertilizer and FitoMas-E, with which 1,8 t of seeds/ha were obtained.

Díaz-López (2015), in Guatemala, when applying 400 kg N/ha, obtained yields of 1 564 kg seeds/ha, for which the controversy that can exist in the agricultural production of this crop is deduced. It is assumed that other biotic or abiotic factors can also determine the *J. curcas* yield.

It is considered that *J. curcas*, under cultivation conditions, needs fertilization like most plant species. In this regard, Montenegro-Ramos (2017) states that if the plant is not fertilized, the productive yields can be considerably affected, mainly in the fruit-formation stage.

Campuzano-Duque *et al.* (2016) proved that the seeds are relatively rich in nitrogen, which implies that the crop requires the supply of this element, through the soil or fertilizers. Vásquez-Mayorga (2017) states that if N is not applied on the *J. curcas* plantations, the flowers could abort, which would decrease seed production.

Patolia *et al.* (2009), when evaluating the effect of fertilization on the semiarid desert of Gujarat,

Table 3. Productive characteristics of *J. curcas* during two years of evaluation.

Treatment	Fruits per raceme	Fruit weight, kg$^{¥}$	Seed weight, kg$^{¥¥}$	Fruit yield, kg/ha	Seed yield, kg/ha
T1	1-6	0,724	1,220	1 081,4^{g}	757,0^{i}
T2	1-8	0,720	1,216	1 326,7^{d}	942,0^{e}
T3	1-8	0,721	1,224	1 291,5^{de}	916,3^{f}
T4	1-7	0,723	1,223	1 185,2^{f}	840,6^{h}
T5	1-8	0,719	1,226	1 230,0^{f}	873,3^{g}
T6	1-10	0,726	1,218	1 357,3^{d}	966,3^{d}
T7	1-10	0,722	1,219	2 405,5^{a}	1 796,3^{a}
T8	1-10	0,720	1,220	2 316,4^{b}	1 638,0^{b}
T9	1-12	0,719	1,224	2 178,3^{c}	1 5419^{c}
SE ±		0,01263	0,01642	40,442*	12,801*

a, b, c, d, e, f, g, h, i: Different letters in each row indicate significant differences at $p < 0{,}05$
T1-without application (control), T2-300 kg/ha/year, T3-600 kg/ha/year, T4 IHPLUS®, T5-FitoMas-E, T6-300 kg/ha/year + IHPLUS®, T7-300 kg/ha/year + FitoMas-E, T8-600 kg/ha/year + IHPLUS®, T9-600 kg/ha/year+ FitoMas-E.
¥The weight of 10 fruits was taken into consideration.
¥¥The weight of 100 seeds was taken into consideration.

in India, indicated that fertilization is highly efficacious on *J. curcas* growth and yield, effect that was determined with the application of 45 and 20 kg N/ha during the first year of cultivation. These authors also suggest that adjustments should be made to the fertilization plans, because as it is a perennial species the demand for these nutrients is dynamic and changes with the age of the plantation. Thus, it is necessary to make a good supply of nutrients in the soils that are aimed at the cultivation of *J. curcas* to reach high yields, because this species accumulates a quantity of N in the fruits, which surpasses in up to 3,6 times other oil plants, such as sunflower and castor bean (Montenegro-Ramos, 2017).

In this study no significant differences were found among the treatments, for the yields of *C. maxima* and *P. vulgaris* (table 4). In addition, it was estimated that the total production was 7,5 and 0,7 t/ha, respectively.

The yields for *C. maxima* and *P. vulgaris* are within the parameters reported by literature, when they are used in association. These systems are highly advantageous, if it is considered that diverse species can be obtained and the soil minerals and available surface for the plants are utilized, pollinator insects are attracted or other insects that can become pests are fought, and also the disease outbreaks are minimized (Ávila-Soler *et al*., 2018).

In studies conducted by Rucoba-García and Munguía-Gil (2013), in which the profitability perspectives for two *J. curcas* production systems were analyzed, for the third and fourth year of establishment, in monoculture and in association with *Z. mays* and *P. vulgaris*, these authors obtained for the third year a better performance of the economic indicators in the association system. For the fourth year, the best results were in favor of the monoculture, due to the *J. curcas* yield. Nevertheless, they report that from the agroecological perspective crop association is more desirable, having higher capacity of resource utilization and of regeneration of the agroecosystem.

Diverse crops have been planted in association with *J. curcas*. In Mexico, Euler and Gorriz (2004), during the first two years of the tree, intercropped watermelon, chili, squash, vanilla and tomato, because they are short-duration plants and can be profitable when they are planted in these systems.

It is considered that this species can harmonize with the existing agricultural production, where the combination of the tree and food crops can result in higher production per hectare, compared with poorly managed monoculture systems.

The correct use of *J. curcas* at small scale could constitute a sustainable option. If it is taken into consideration that production is diversified, environmental problems can be mitigated, and incomes and activity can be generated for developing countries. In addition, as it is a tree plant, it can be easily integrated in the farms, in intercropped agricultural systems, in order to produce not only biofuels but other byproducts derived from the industrialization process, such as fertilizers, meals and glycerol for medicinal and cosmetology uses (Betancur-Prisco *et al*., 2014).

Table 4. Yield of *C. maxima* and *P. vulgaris* in *J. curcas* due to fertilization.

Treatment	Estimated productive yield, t/ha	
	C. maxima	*P. vulgaris*
T1	0,8	0,08
T2	0,8	0,07
T3	0,8	0,08
T4	0,8	0,07
T5	0,8	0,09
T6	0,7	0,07
T7	0,8	0,08
T8	0,8	0,08
T9	0,8	0,08
Total	7,5	0,72
SE ±	0,144	0,028

T1- without application (control); T2-300 kg/ha/year; T3-600 kg/ha/year; T4 IHPLUS®; T5-FitoMas-E; T6-300 kg/ha/year +IHPLUS®; T7-300 kg/ha/year + FitoMas-E; T8-600 kg/ha/year + IHPLUS®; T9-600 kg/ha/year + FitoMas-E

Conclusions

Under the conditions of this study, the development of *J curcas* is determined by the effect of nitrogen fertilization. The increase of seed yields is possible, if 300 kg N/ha/year of chemical fertilizers + FitoMas-E are combined, without affecting the production of associated crops.

To conduct studies in the different development stages of the crop is recommended to generate knowledge about the nutrient demand, according to the different phenological phases of the species.

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Authors' contribution

- Yolai Noda-Leyva. Conducted the trials, data collecting and processing, manuscript writing and revising.
- Giraldo Jesús Martín-Martín. Contributed in the trial design and setting-up, as well as in the research advisory.

Conflict of interests

The authors declare that there are no conflicts of interests among them.

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