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Effect of planting density on morpho-productive traits of *Jatropha curcas* intercropped with food crops

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Abstract

In order to determine the effect of planting density on the morpho-productive traits of *Jatropha curcas* intercropped with crops under rotation, the following treatments-systems (S) were studied in a completely randomized design: S1 (control): *J. curcas* at 2,5 x 2,0 m (2 000 plants/ha), S2: 50 % of the area with *J. curcas* at 2,5 x 2,0 m and 50 % of the area with crops under rotation (2 000 plants/ha), S3: *J. curcas* intercropped with crops at 5,0 x 2,0 m (1 000 plants/ha), S4 (control): crops under rotation. To interpret the results of plant height (H), number of primary branches (PB), stem diameter and primary branch diameter, quantity of racemes (NR) and fruit production (FP), a simple classification ANOVA was used and H, PB and NR were correlated; while descriptive statistics was used for the number of fruits per raceme (FR), weight and size of the seeds and crop yield. H and PB were higher for S1 and S2; nevertheless, higher NR was obtained with S3, and this last one did not differ regarding FP ($p < 0,05$) from the control (S1). There was high and positive correlation (r = 0,84) between H and PB, but they were not correlated with NR. In S3, the yield of the associated crops was 1,023; 4,281 and 0,320 t/ha for beans, sweet potato and sesame, respectively. It is concluded that when using 1 000 plants/ha in association systems, adequate yields and diversity of plant species can be obtained.

Keywords: spacing, yield, cultivation systems

Introduction

Among the most used crops for biodiesel production, *Jatropha curcas* represents an option, because its seeds are not edible. It is a fast-growth shrub, which can reach more than one meter and half of height under special conditions. The fruits are ovoid capsules, with three locules, and each of them contains one seed. They represent between 53 and 79 % of the fruit weight, and have an oil content between 33 and 38 % (Rucoba *et al*., 2013).

Seed production per plant varies depending on the crop management. Thus, in Brazil a production potential of 2,3 seeds/ha under arid conditions, without irrigation and in intensive cultivation, is reported; while with good water availability, around 5 t/ha can be reached (González *et al*., 2015; Rade *et al*., 2017).

In Cuba it has been proven that *J. curcas* can be cultivated throughout the country (Machado and Suárez, 2009); however, its fruit production potential has been little studied, for which there is lack of information about its technology to incorporate it in productive chains.

Some studies indicate that the adequate management of pruning, the supply of nutrients and water and the planting frame can cause variation in the fruit yield, which is the main objective to obtain high oil productions (Folegatti *et al*., 2013). With regards to the planting frame, it will depend on the purpose. For example, Moreno (2014) used distances of 2 x 2 m or 3 x 3 m in pure crops, to obtain high productions. Córdova *et al.* (2015) recommend distances of 4 or 6 meters and 2,5 m between plants if the purpose is to utilize the land more widely, so that the spaces between rows can be utilized to intercrop food crops.

It is important to take into consideration the adequate use of *J. curcas* cultivation systems, because the plant is capable of growing on marginal soils, restoring eroded areas and protecting other valuable food or commercial crops (García *et al*., 2017).

Several studies conducted in Eastern Cuba by Sotolongo *et al*. (2012) showed that *J. curcas* can be associated with more than twenty food crops without affecting the yields of the latter, which turned out to be similar to the ones obtained with monocrop systems. In addition, if it is considered that with the intercropping of the tree fruit productions are obtained which can be used to produce biodiesel, co-products of high value for animal feeding, fertilizers and raw materials for other local industries, higher benefit and better utilization of the space can be estimated.

Taking into consideration such elements, the objective of the study was to determine the effect of planting density on the morpho-productive traits of *J. curcas* intercropped with food crops.

Materials and Methods

Location of the experimental area. The study was conducted in the integrated food and energy production farm of the Pastures and Forages Research Station Indio Hatuey (EEPFIH), located between 22° 48' 7" North latitude and 81° 2' West longitude, at 19,01 m.a.s.l., in the Perico municipality –Matanzas province, Cuba.

Soil and sowing characteristics. For the experiment seeds of the Cape Verde provenance of *J. curcas* were used. The sowing was carried out directly in the field, in July, 2014, on a Ferralitic Red soil (Hernández-Jiménez *et al*., 2015).

Design and treatments. The design was completely randomized, with four treatments. Each plant constituted a replica and 20 plants were evaluated per treatment, which are described below:

- System 1 (control): *J. curcas* in pure stand, planted at 2,5 m between rows and 2,0 m between plants (2 000 plants/ha).
- System 2: 50 % of the area with pure stand of *J. curcas*, planted at 2,5 m between rows and 2,0 m between plants, and 50 % of the area planted only with annual crops under rotation (2 000 plants/ha).
- System 3: *J. curcas* intercropped with annual crops under rotation, planted at 5,0 m between rows and 2,0 m between plants (1 000 plants/ha).
- System 4: area planted only with annual crops under rotation (control).

The studied factor was planting density (1 000 and 2 000 plants/ha). Systems 1 and 4 were the controls, because pure stands of *J. curcas* and annual crops under rotation were planted, respectively, and served to compare the variables under study in each case.

The crops under rotation were: beans (*Phaseolus vulgaris*), sweet potato (*Ipomea batata*) and peanut (*Sesamun indicum*), which were planted in different seasons taking into consideration the climate demands of each one.

In addition, soil studies were conducted, at two depths: 0-15 and 15-30 cm (Anderson and Ingram, 1993), in five different spots of the studied area, to determine the content of nitrite (diazotization method), nitrate (cadmium reduction method), sulfur (chloride method), iron (bipyridyl method), ammoniacal nitrogen (Nesslerization method), potassium (tetraphenylboron method) and phosphorus (ascorbic acid reduction method). All the analyses were carried out in the soil portable laboratory (SMART3 Soil 1.11) of the EEPFIH. Table 1 shows the results for each depth. According to LaMotte (2012), the soil is classified as of low fertility.

The morphological variables were studied during the establishment. When the plants were considered established, after reaching more than 2,5 m of height (12 months after planting), one homogenous pruning was performed on the entire plantation, 40 cm over the soil basis, so that several productive branches were developed; and, at the beginning of their fructification, the productive variables were measured (January-March and August-October); in both variables the recommendations made by Campuzano (2009) were used.

Morphological variables

- Plant height. It was measured from the basis of the plant to the apex of the main stem, with a graduated ruler, monthly, until 12 months after planting.
- Number of primary branches per plant. The ones inserted in the main stem were considered primary branches. The measurements started since

Table 1. Results of the soil analyses in the area.

Depth (cm)	Nitrite	Nitrate	Ammoniacal nitrogen	Sulfur	Potassium	Phosphorus	Iron
	(kg/ha)						
0-15	6,17	30,27	42,04	0,60	95,29	1,76	0
Level in the soil	Moderate- high	Moderate	Moderate	Low	Moderate	Low	Very low
15-30	9,53	13,45	124,43	627,03	50,45	2,15	0,70
Level in the soil	Moderate-high	Moderate	High	Very high	Low	Low	Very low

the fifth month after planting, when the plants started their development, and were finished when this stage was considered ended, at 12 months.

- Stem diameter in the basis. It was measured with a metric tape, at a height of 10 cm from the soil surface, when the plantation was considered established.
- Diameter of the primary branches. It was measured with a metric tape, just 10 cm away from the main stem.

Productive variables

- Number of racemes per plant (NR). The number of racemes per plant was counted when fructification was considered ended.
- Number of fruits per raceme (FR). The number of fruits per raceme was counted, in two racemes per plant.
- Harvested fruits (HF). The fruits that were gathered per plant in each harvest were added.
- Seed weight, g (SW). The weight of 100 seeds was quantified, with a scale.
- Seed length and width.

The rules for the planting and establishment of the legumes were similar. For the beans and peanut a planting distance of 70 cm between rows and 30 cm between plants was used, so that between two rows of *J. curcas* were five rows of the crop under rotation separated from the tree by 120 cm on each side, for a total of 540 plants per plot, 2 160 m per treatment; this represented a density of 168 750 plants/ha. Ten plants per plot were sampled, that is, 40 plants per treatment; and it was taken into consideration that they were within the defined net area for the *J. curcas* crop.

For planting *I. batata*, cuttings from 25 to 30 cm long, were used, which were placed at 30 cm of distance each, for a density of 500 000 cuttings/ha. Such planting was carried out on humid soil, guaranteeing that two thirds of the cuttings were buried at a depth of 7-10 cm and putting them as horizontally as possible with regards to the plot (INIVIT, 2007).

For each crop the agricultural yield was determined (t/ha), according to the methodology proposed by IPGRI (2001) and Huamán (1991) for the legumes and the tuber, respectively.

Statistical analysis. A simple classification ANOVA was used, after verifying that the assumptions of variance homogeneity and normal distribution were fulfilled. The means were compared by Duncan's test, for a significance level of $p \leq 0{,}05$. For the variables number of fruits per raceme, weight and size of the seeds, the minimum and maximum indicators were described, based on descriptive statistics. In addition, the correlation analysis was used to know the interrelation among the variables plant height, number of primary branches and quantity of racemes per plant. The yield of the associated crops was descriptively compared according to the evaluated treatments. For all the processing the statistical package Infostat, version 1.1, was used.

Results and Discussion

Figure 1 shows the mean height of the plants, according to the planting density used. As plant density per hectare increased, the stem height throughout the evaluation period increased, with significant differences ($p < 0{,}05$) from the treatment with lower density.

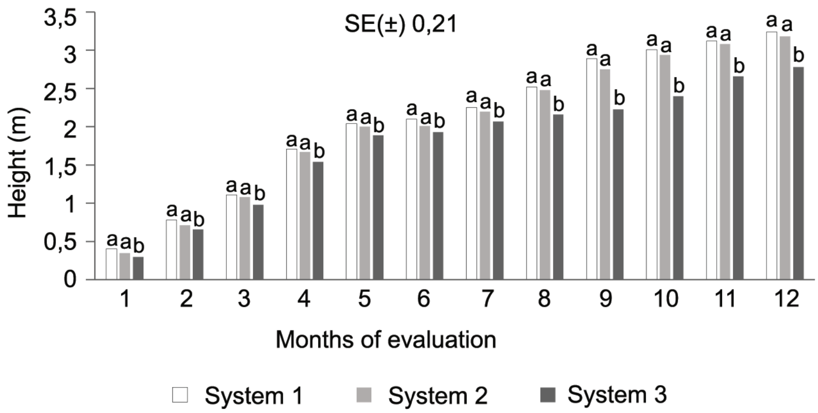
These results can be related to the effect of shade among the plants sown at higher planting density, which increases the concentration of auxins, by reducing the luminosity that has incidence on these tissues, and causes cell enlargement; this is due to the fact that, under shade conditions, the indoleacetic acid increases and acts in a synergic way with gibberellins (Raposo *et al*., 2014).

Bharti *et al*. (2016) stated that the increase in the population density of diverse crops causes plant height to increase since 30 to 75 days after planting. In addition, according to these authors, the plants established at lower density grow approximately 31 % less than the ones established at higher density.

The *J. curcas* plants, after 12 months, reached a mean height higher than 3 m. In this regard, Iguarán *et al*. (2017) described the species as a tree capable of reaching between 3 and 5 m or more in full development (five years), moment in which other morphological and productive traits can also reach their highest degree of quantitative expression.

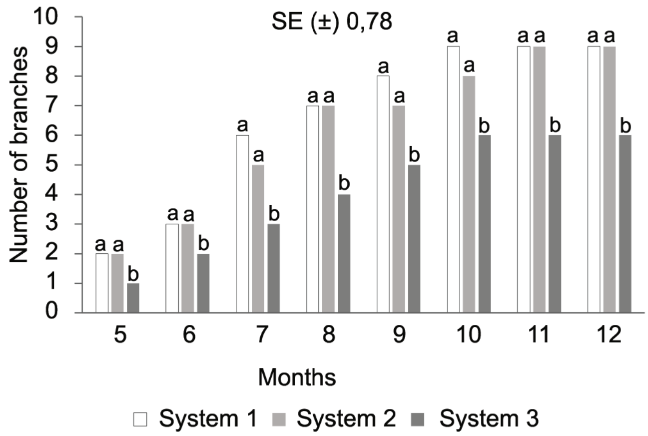
The number of primary branches that were developed in each treatment due to planting density is shown in figure 2. There were significant differences among the densities ($p < 0{,}05$), and the highest value was found with 2 000 plants/ha. System 2 did not differ from the control (System 1) in any of the observations, and both reached nine primary branches at the end of the establishment period.

In *J. curcas*, the quantity of primary branches the plant develops is a very important variable for the crop production, because the inflorescences are formed on the terminal ends of branches (Kumar *et*



a,b: different letters indicate significant differences at p < 0,05.

Figure 1. Effect of planting density on the height (m) of *J. curcas*.



a, b: different letters indicate significant differences at p < 0,05.

Figure 2. Effect of planting density on the number of primary branches developed in *J. curcas*.

al., 2016); if it is taken into consideration that from each primary branch other secondary and tertiary ones must be originated; this would lead proportionally to the formation of more fruit racemes per plant in those that develop more primary branches.

Machado (2011), when morphologically and productively characterizing a collection of *J. curcas*, reported that the primary branches were developed in a range between 2 and 10. In addition, he stated that some provenances did not emit secondary and/or tertiary branches during the evaluation period; nevertheless, their growth was delayed. In this study the second and third order branches were not evaluated, because performing one pruning a year after planting to induce the production of more branches was established, as agronomic management of the plantation (Córdova-Mendoza, 2017).

The stem diameter means varied between 5,06 and 5,54 cm for 2 000 and 1 000 plants/ha, respectively. Regarding the diameter of the primary branches, the values did not exceed 2 cm. There were no significant differences among the treatments for any of the variables (table 2).

Machado (2011) reported means for the stem diameter between 3,4 and 8,4 cm, and for the primary branches between 1,6 and 4,1 cm. The author states that this is a varietal characteristic, which can also vary if other factors influence development, such as planting density.

However, in this study the absence of significant differences between densities can be ascribed to the little time of plant establishment at the moment of evaluation; thus, they did not have sufficient time to express differences in the stem diameter, because

Table 2. Effect of planting density on the diameter of the stem and primary branches in *J. curcas*.

Planting density (plants/ha)	System	Stem diameter in the base (cm)	Diameter of the primary branches (cm)
2 000	1	5,26	1,16
2 000	2	5,06	1,93
1 000	3	5,54	2,00
SE ±		0,84	0,06

during the first year after planting they prioritized their growth and for that purpose they used all the reserve, which was remarkably shown through the height they reached. It is likely that this aspect behaves differently as the exploitation time passes (Campuzano *et al*., 2016).

Table 3 shows the productive characteristics of *J. curcas* due to the planting density. System 3 (1 000 plants/ha) showed more racemes, and differed from the higher density in systems 1 and 2 ($p < 0,05$).

Such effect could have been given by the accumulation of reserves in the plant, because by developing less height and less primary branches the distribution of the necessary compounds for the flowering and fructification processes are benefitted (Avilán *et al*., 2003). Such arguments could be verified through the correlation analyses.

In system 3 more fruits were obtained per raceme, between 1 and 12, numerically different values from the other treatments, even higher than those of the control (table 3). Such aspect is important, if it is taken into consideration that in this treatment the planting distance was 5 x 2 m and that annual crops were associated with *J. curcas*; in that sense, it will be possible to increase the fruit production of the tree and utilize the area better, by obtaining additional foodstuffs (Moreno, 2014).

There were significant differences in the quantity of harvested fruits, according to planting density; in each evaluation a different performance was observed for this variable (table 3). Initially, the control significantly differed from the other treatments ($p < 0,05$), with a total of 546 fruits; but when carrying out the later harvests, it was possible to collect a higher quantity in system 3.

Nevertheless, when adding the total harvested fruits no significant differences were found between systems 1 and 3. These results constitute the first ones obtained in this topic, about which no bibliography was found, so it is difficult to compare this with other studies. In addition, although *J. curcas* is acknowledged as a plant of high variability among different environments, this research will serve as basis for future projections, from the plant densities to be used per hectare and the utilization of association systems, because the results suggest that planting *J. curcas* at 5 x 2 m propitiates similar yields as when it is planted at 2,5 x 2,0 m and other foodstuffs are also produced.

Table 3. Effect of planting distance on the production of *J. curcas*.

Evaluation	Average quantity of racemes per plant				Number of fruits per raceme Minimum-maximum			Total productivity[1]			
	System										
	1	2	3	SE ±	1	2	3	1	2	3	SE ±
1	6[b]	2[c]	8[a]	0.7*	1-8	1-6	1-12	546[a]	20[c]	314[b]	10,2*
2	-	-	-	-	-	-	-	66[b]	36[c]	195[a]	6,1*
3	-	-	-	-	-	-	-	140[b]	55[c]	180[a]	8,3*
4	-	-	-	-	-	-	-	30[b]	10[c]	68[a]	4,2*

[1] Harvested fruits per system.

a, b, c Values with different superscripts differ at P<0,05, * P<0,05

As shown in table 4, there was a high ($p < 0,05$) and positive ($r = 0,84$) correlation between height and the development of primary branches. However, these variables were not correlated with the quantity of racemes per plant, because low coefficients (r = 0,24 and 0,46, respectively) were found.

Table 4. Matrix of correlations of the morpho-productive variables.

Indicator	Height	PB	QRP
Height	-		
PB	0,84*	-	
QRP	0,24	0,46	-

PB: primary branches, QRP: quantity of racemes per plant.
*The correlation is significant at the level of 0,05.

In spite of the absence of bibliography about these topics for *J. curcas*, different performances have been observed in other trees. In that sense, Wencomo (2008) described a high and positive correlation among yield, height and number of branches in *Leucaena* spp.

These results corroborate the ones reported by Machado (2011), who evaluated 18 provenances and obtained a fruit yield between 0 and 559, range that is considered normal, because according to Díaz-Hernández *et al*. (2013), in the first years low productions are expected.

The weight and size of 100 seeds, according to the effect of planting density, are shown in table 5. The numerical values were similar in each treatment, which could have occurred because in all cases the Cape Verde provenance was used, because in a study conducted by Brunet (2012) marked differences were found in these indicators due to the evaluated provenance. Another important aspect in such study was that Cape Verde was ranked among the most outstanding ones, which favored that afterwards significant yields were obtained that differed from those of the other accessions.

The productive response (table 6), in all the cases, was numerically higher for system 4 (annual crop, control), with yield of 1,9 t/ha; however, this value was similar to that of system 3 (1,0 t/ha). They are similar to the mean values reported for Cuban conditions. In this regard, Fé-Montenegro *et al*. (2016) reported annual yields of 0,6 t/ha for the state sector and 1,1 t/ha for the non-state sector.

When *I. batata* was intercropped between the *J. curcas* rows (system 3), 4,2 t/ha of the tuber were obtained, although when compared with the control (system 4) there were 2,7 t/ha of difference. Nevertheless, Sotolongo *et al*. (2012) stated that when associating food crops with *J. curcas*, their yields decrease by 30 % with regards to monocrop, as corroborated in this study. However, the losses are not significant, if the additional production of the shrub is taken into consideration, because its fruits can be used in the production of biodiesel and other byproducts.

The *S. indicum* yields were considered low for system 2 (0,2 t/ha) and moderate for system 3 (0,3 t/ha); both, when compared with system 4, turned out to be numerically lower. These yields were below the range reported by MAG (1991).

Table 5. Effect of planting distance on the seed weight and size.

Planting density (plants/ha)	System	Weight of 100 seeds (g)	Seed length (cm)	Seed width (cm)
2 000	1	104,24	1,09	1,09
2 000	2	100,85	1,15	1,15
1 000	3	103,64	1,14	1,14

Table 6. Yield of the associated crops during the evaluated period.

Crop	Yield (t/ha)		
	System		
	2	3	4
P. vulgaris	0,9	1,0	1,9
I. batata	3,7	4,2	6,9
S. indicum	0,2	0,3	0,8

It is important to state that these are preliminary reports of the first production year of *J. curcas*, in which different planting frames were evaluated and the association with annual crops was consideredas; it is a technological option in tropical regions, shows certain advantages for its diversification in time and space, and also allows higher agrobiodiversity and distribution of economic resources and higher tolerance to pests and diseases (Edrisi *et al*., 2015).

In addition, according to Solís *et al*. (2015), the yield of a species is lower when it is associated than when it is in monocrop. Nevertheless, polycrops show higher production stability and lower risk through the years than monocrop; and for the particular case of *J. curcas*, in Cuba there is an «emptiness of knowledge» about the agronomic performance of production systems of this species in association with other crops.

It is concluded that when using 1 000 plants/ha of *J. curcas* intercropped with annual crops under rotation, such as *P. vulgaris*, *I. batata* and *S. indicum*, the morphological traits, or the yields of the tree or the associated plants, were not affected. Thus, better utilization is made of the soil, space and time; and diversity of plant species is obtained.

Likewise, it is recommended to continue these studies at long term, as well as to evaluate the incidence of other agronomic factors on *J. curcas*, taking into consideration the systems of associations with annual food crops.

Bibliographic references

Anderson, J. M. & Ingram, J., Eds. *Tropical soil biology and fertility. A handbook of methods*. 2nd ed. Wallingford, UK: CAB International, 1993.

Avilán, L.; Azkue, M.; Soto, E.; Rodriguez, M.; Ruiz, J. & Escalante, H. Efecto de la poda y el empleo de un regulador de crecimiento sobre el inicio de la floración en mango. *Rev. Fac. Agron. (LUZ)*. 20 (4):430-442, 2003.

Bharti, Archana; Vidyasagar, M. & Aranganathan, V. Relative efficacy of phytohormones in promoting fruit yield on *Jatropha curcas* for biodiesel production. *Int. J. Adv. Lif. Sci*. 9 (4):445-452, 2016.

Brunet, J. *Caracterización de procedencias de Jatropha curcas L. en la EEPF Indio Hatuey*. Trabajo de diploma para optar por el título de Ingeniero Agrónomo. Matanzas, Cuba: Universidad de Matanzas, 2012.

Campuzano, L. F. Perspectivas de la investigación de *Jatropha curcas* L. en Colombia. Parte I. Componente genético. *Rev. Fac. Nac. Agron. Medellín*. 62 (3):51-63, 2009.

Campuzano, L. F.; Ríos, L. A. & Cardeño, F. Caracterización composicional del fruto de 15 variedades de *Jatropha curcas* L. en el departamento del Tolima, Colombia. *Corpoica Cienc. Tecnol. Agropecu*. 17 (3):379-390, 2016.

Córdova-Mendoza, Eyka S. *Efecto de tres dosis de 6- Benciladenina en el incremento de la floración de piñón blanco (Jatropha curcas L.)-Juan Guerra-San Martín-Perú*. Tesis para optar por el título de Ingeniero Agrónomo. Tarapoto, Perú: Universidad Nacional de San Martín, 2017.

Córdova, L.; Zavala, J. T.; Bautista, E.; Mártinez, María del R. & Hernández, Nancy Y. Producción de semillas de *Jatropha curcas*, L.: elementos clave. En: F. J. Osuna-Canizalez, C. J. Atkinson, J. M. P. Vázquez-Alvarado, E. J. Barrios-Gómez., M. Hernández-Arenas, S. E. Rangel-Estrada y E. Cruz-Cruz, comps. *Estado del arte en la ciencia y tecnología para la producción y procesamiento de jatropha no tóxica*. Publicación Especial No. 60. Morelos, México: Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación, Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias, Centro de Investigación Regional Pacífico Sur, Campo Experimental Zacatepec. p. 39-46, 2015.

Díaz-Hernández, Brenda G.; Aguirre-Medina, J. F. & Díaz-Fuentes, V. H. Rendimiento de *Jatropha curcas* L. inoculada con micorriza y aplicación de composta de caña. *Rev. Mex. Cienc. Agríc*. 4 (4):599-610, 2013.

Edrisi, S. A.; Dubey, R. K.; Tripathi, V.; Bakshi, Mansi; Srivastava, P.; Jamil, Sarah *et al*. *Jatropha curcas* L.: A crucified plant waiting for resurgence. *Renew. Sust. Energ. Rev*. 45:855-862, 2015.

Fé-Montenegro, C. F. de la; Lamz-Piedra, A.; Cárdenas-Travieso, Regla & Hernández-Pérez, J. Respuesta agronómica de cultivares de frijol común (*Phaseolus vulgaris* L.) de reciente introducción en Cuba. *Cultivos Tropicales*. 37 (2):102-107, 2016.

Folegatti, M.; Alves, Patricia; Ferreira, Thais M.; Almeida, C.; Flumignan, D.; Valentim, A. *et al*. *Evapotranspiração e coeficiente de cultivo do pinhão-manso a partir do terceiro ano de cultivo e em função de diferentes tipos de poda. Projeto de pesquisa*. São Paulo, Brasil: Universidade de São Paulo Escola Superior de Agricultura "Luiz de Queiroz", 2013.

García, Florencia; García, E.; Pérez, A. & Ruíz, O. Contenido de aceite en accesos de *Jatropha curcas* L. no tóxica en Veracruz, México. *Rev. Mex. Cienc. Agríc*. 8 (3):635-648, 2017.

González, R.; Juárez, J. R.; Aceves, L. A.; Rivera, B. & Guerrero, A. Zonificación edafoclimática para el cultivo de *Jatropha curcas* L., en Tabasco, México. *Investigaciones Geográficas. Boletín del Instituto de Geografía*. 86:25-37, 2015.

Hernández-Jiménez, A.; Pérez-Jiménez, J. M.; Bosch-Infante, D. & Castro-Speck, N. *Clasificación de los suelos de Cuba*. Mayabeque, Cuba: Instituto Nacional de Ciencias Agrícolas, Instituto de Suelos, Ediciones INCA, 2015.

Huamán, Z., Ed. *Descriptors for sweet potato*. Rome: International Board for Plant Genetic Resources, 1991.

Iguarán, C.; Cabrales, R. & Marrugo, J. L. Evaluación agronómica de la calidad del aceite de *Jatropha curcas* en Córdoba. *Memorias III Seminario Internacional de Ciencias Ambientales SUE-Caribe*. Barranquilla, Colombia: Sistema Universitario Estatal del Caribe. p. 217-220, 2017.

INIVIT. *Instructivo técnico del cultivo del Ipomea batata*. Villa Clara, Cuba: Instituto de Investigaciones de Viandas Tropicales, 2007.

IPGRI. *Descriptores para Phaseolus vulgaris*. Rome: International Plant Genetic Resources Institute, 2001.

Kumar, A.; Patil, N. S.; Kumar, R. & Mandal, D. Irrigation scheduling and fertilization improves production potential of Jatropha (*Jatropha curcas* L.). A review. *Int. J. Curr. Microbiol. App. Sci*. 6 (5):1703-1716, 2016.

LaMotte. *Smart3 Soil. Operator´s manual*. Chestertown, USA: LaMotte. http://www.lamotte.com/ images/pdf/instructions/1985-05-MN.pdf. [15/12/2017], 2012.

Machado, R. Caracterización morfológica y productiva de procedencias de *Jatropha curcas* L. *Pastos y Forrajes*. 34 (3):267-279, 2011.

Machado, R. & Suárez, J. Comportamiento de tres procedencias de *Jatropha curcas* en el banco de germoplasma de la EEPF "Indio Hatuey". *Pastos y Forrajes*. 32 (1):29-37, 2009.

MAG. *Aspectos técnicos sobre cuarenta y cinco cultivos agrícolas de Costa Rica*. San José, Costa Rica: Ministerio de Agricultura y Ganadería, 1991.

Moreno, J. G. F. *Experiencias en el manejo del cultivo de jatropha bajo condiciones de riego y temporal en el norte de Sinaloa*. Sinaloa, México: Fundación Produce Sinaloa. https://www.google.com.cu/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=0ahUKEwimw5WN8LLaAhWPt-1MKHRtvBjcQFggmMAA&url=http%3A%2F%2Fwww.fps.org.mx%2Fportal%2Findex.php%2Fcomponent%2Fphocadownload%2Fcategory%2F35-otros%3Fdownload%3D166%3Aexperiencias-en-el-manejo-del-cultivo-de-jatropha-bajo-condiciones-de-riego-y-temporal-en-el-norte-de-sinaloa&usg=AOvVaw1xlir-7m2h5QRgVv44mEawZ. [10/05/2017], 2014.

Rade, Diana Y.; Cañadas, A.; Zambrano, C.; Molina, C.; Ormaza, Alexandra & Wehenkel, C. Viabilidad económica y financiera de sistemas silvopastoriles con *Jatropha curcas* L. en Manabí, Ecuador. *Revista MVZ Córdoba*. 22 (3):6241-6255, 2017.

Raposo, R. S.; Souza, I. G.; Veloso, M. E.; Kobayashi, A. K.; Laviola, B. G. & Diniz, F. M. Development of novel simple sequence repeat markers from a genomic sequence survey database and their application for diversity assessment in *Jatropha curcas* germplasm from Guatemala. *Genet. Mol. Res*. 13 (3):6099-6106, 2014.

Rucoba, A.; Munguía, A. & Sarmiento, F. Entre la jatropha y la pobreza: reflexiones sobre la producción de agrocombustibles en tierras de temporal en Yucatán. *Estudios Sociales. Hermosillo, Son*. 21 (41):115-141, 2013.

Solís, J. L.; Pecina, V.; Reyes, A. L.; Martínez, B. B.; Zamarripa, A.; López, L. J. *et al*. Comportamiento agronómico, energético y emisiones de gases de piñón mexicano (*Jatropha curcas* L.). En: F. J. Osuna, comp. *Estado del arte en la ciencia y tecnología para la producción y procesamiento de Jatropha no tóxica*. Morelos, México: INIFAP. p. 39-46, 2015.

Sotolongo, J. A.; Suárez, J.; Martín, G. J.; Toral, Odalys & Reyes, F. Producción integrada de biodiesel y alimentos: la concepción de una tecnología agroindustrial apropiada para Cuba. *Memorias II Convención Agrodesarrollo 2012*. Matanzas, Cuba: EEPF Indio Hatuey. p. 476-481, 2012.

Wencomo, Hilda. *Evaluación morfoagronómica e isoenzimática y selección de accesiones de Leucaena* spp. *con fines silvopastoriles*. Tesis presentada en opción al grado científico de Doctor en Ciencias Agrícolas. Mayabeque, Cuba: Instituto Nacional de Ciencias Agrícolas, 2008.

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