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RESEARCH ARTICLE

Effect of pruning and organic fertilization over productive parameters of four mexican provenances of *Jatropha curcas* L.

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ABSTRACT

The performance of Mexican provenances of Jatropha curcas L. under different agropractices has not been very widely investigated in their center of origin. The purpose of this study was to determine the flowering, fruit and seed production performance of four Mexican provenances of J. curcas to pruning and organic fertilization. The evaluated provenances were obtained from the municipalities of Actopan, Tamiahua, Papantla and Amatlán located in southeastern, Mexico. The experimental design considered two factors: provenance and treatment. The treatments were bokashi, vermicompost, pruning, and the control, each one with five individuals per provenance (80 plants). Plants were monitored every week during one productive cycle (April 2016 to January 2017), starting with the development of inflorescences until the harvesting of mature fruits. The seeds obtained from the fruits were dried and weighted to determine plant productivity. The analysis of variance was performed with a significant level of 0.05. Results indicated statistically significant differences between treatments and provenances, but there was no interaction between provenances and treatments. Application of bokashi and vermicompost was statistically similar and allowed the highest productivity, Actopan had the highest productivity (436 g of dried seed by plant), which was 26 % over the control, pruning allowed the highest fruit mooring, but it delayed production by two months, which reduced the total seed productivity (297 g by plant), being statistically similar to the control. We conclude that Mexican provenances have a positive response to organic fertilization and pruning, but pruning reduces its productive period.

Keywords: Floral characteristics; Fruit production; Seed production; Sustainable agropractices

INTRODUCTION

Jatropha curcas L. is an oily species from the euphorbiaceous family, which has its origins in the Mesoamerican region (Rao et al., 2008). This plant has a wide variety of uses as pesticide, medicinal, fertilizer, biodiesel and food (Kumar and Sharma, 2008). However, studies over the species have found a low level of domestication (Ovando-Medina et al., 2011), thus, it has a high phenotypic and morphologic variability among its populations (Kant and Wu, 2011). This represents a challenge for its establishment with productive purposes. Although, other characteristics are considered very valuable for its cultivation, such as its high resistance to drought and the ability to survive in arid soils (Maes et al., 2009; Pérez-Vázquez et al., 2013). Nevertheless, plant growth and productivity will depend on soil fertility, water availability and plant density, among other factors (Behera et al., 2010). Hence, we estimate that agronomic practices can improve plant performance to obtain higher production. In this regard, conventional fertilizers have been applied to *J. curcas* to increase its productivity with certain improvements (Behera et al., 2010; de Lima Gurgel et al., 2011; Mat et al., 2015). Although, organic fertilizers should be considered the best alternatives to lower the negative environmental impacts of conventional agriculture. These types of fertilizer also contribute to improving the physical and chemical characteristics of the soil, when it is deteriorated by the excess of agrochemicals (Nieto-Garibay et al., 2002). Among the organic fertilizers, bokashi and vermicompost are widely known and applied

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due to their low cost and the fact that organic left-overs, such as manure and agricultural residues, can be used to prepare these fertilizers (Nieto-Garibay et al., 2002; Morales-Munguía et al., 2009; Portillo et al., 2011).

Another sustainable agronomic practice is pruning, which aims to increase the number of branches, providing more opportunities for the development of more inflorescences to increase productivity (Guerrero Pinilla et al., 2011).

For Jatropha, productivity is highly linked to the number of female flowers and their degree of success to reach mature fruits, as well as the number and weight of dry seeds by fruit. In this regard, some reports indicate high variability in the floral characteristics of *J. curcas* (de Lima Gurgel et al*.,* 2011; Rao et al., 2008). However, its response to different agronomic practices indicates that the species have higher development and production with organic fertilizers (Behera et al., 2010; Jingura, 2011), while pruning still needs longer investigations (Negussie et al., 2016).

Since Jatropha may have had its origins in Mexico, Mexican provenances can represent a wider source of genetic diversity (Salvador-Figueroa et al., 2015), which is considered very low among populations around the world (Sanou et al., 2015). Besides this, Mexico has some provenances with very low or not detected phorbol ester toxins and higher genetic diversity than other toxic Mexican genotypes (Vandepitte et al., 2019). Some Mexican provenances are characterized by naturally producing heavier (640-870 mg) and oilier seeds (55-57 % oil in kernels) (Cruz Rubio et al., 2015; Martínez-Herrera et al., 2006) than plants disseminated in other continents like Asia and Africa (with 200-750 mg seed weight and less than 35 % oil in kernels) (Borah et al., 2018; Kaushik et al., 2007). However, for the Mexican provenances, their reproductive phenology in combination with their response to sustainable agronomic practices, such as the use of organic fertilizers or pruning needs to be investigated. Therefore, it is important to determine how these provenances response to sustainable agronomic practices in their natural environment.

This study aims to evaluate the effects of two organic fertilizers (vermicompost and bokashi) and pruning over flowering, fruit development and seed productivity of four Mexican provenances of *J. curcas*.

MATERIALS AND METHODS

Experimental site

This study was performed at the facilities of the Colegio de Postgraduados, *Campus* Veracruz (CPV), located in the municipality of Manlio Fabio Altamirano (19° 11 ´ 14.92 ´´ N, 96° 20 ´ 47.03 ´´ W; 19 m above sea level (masl)), in the Mexican state of Veracruz. The climate in this region is considered warm sub-humid, with dry winters and two rainy seasons during summer (Table 1). The average temperature, environmental humidity, and accumulative precipitation during the experimental period were obtained from the local meteorological station.

Biological material

The four studied provenances were selected from a germplasm bank consisting of 19 *J. curcas* provenances collected from native trees located in different sites in the state of Veracruz. All these provenances were sown by cuttings during July and August 2012, with 20 repetitions per provenance, which were randomly distributed in the field with an arrangement of 3 x 2 m between plants. Plants were labeled by keywords for their identification and left to grow under natural conditions, without irrigation or any other amendment, except by removing weeds. The four provenances for this study were selected by their high oil content and by their lower phorbol esther contents (Table 2). The characteristics of the experimental site and the sites where the selected provenances were collected are presented in Table 1.

Experimental design and application of the treatments

The experiment was initiated in middle February 2016, when plants were in their period of dormancy in the experimental site. The experimental design was completely random with five plants by treatment, making 20 individuals per provenance, being a total of 80 plants distributed along the width and length of the plot. The treatment 1 (T1) consisted in the application of 10 liters (l) of bokashi per plant, treatment 2 (T2) consisted in the application of 10 l of vermicompost per plant, based in previous non-published experiences. Treatment 3 (T3) consisted of pruning all the branches of the plants at a height of 1.3 m above ground level; and the control treatment 0 (T0), which consisted of plants without any amendment or pruning.

Table 1: Climatic conditions in the experimental site and the original sites of the provenances

Site and identification	Altitude (masl)	Average temperature (°C)	Average annual accumulative precipitation (mm)	Soil texture
Experimental site[a]	12	26	1200	Loamy clay
Actopan (02)	30	23	2500	Loamy sand
Tamiahua (19)	108	26	1425	Loamy clay silt
Papantla (26)	690	24	2250	Loamy clay sandy
Amatlán (45)	19	25	1239	Loamy clay

[a] Colegio de Postgraduados-Campus Veracruz germplasm bank. The number in parenthesis corresponds to the provenance's field number

For the application of treatment 1 and 2, a ditch of 10 cm of depth was made 50 cm around the stem of each plant, the fertilizer was distributed along the ditch and covered with the same soil. This procedure was repeated every three months during two more times, for a total of 30 l of organic fertilizer per plant, ending in late August, when plants were bearing fruits. All the plants were left without irrigation or any other amendment during the experimental period to avoid the interference of other factors.

Flowering development was monitored from April to June, which corresponds to the highest flowering period of this species at the experimental site according to Palacios-Wassenaar et al. (2016). For each treatment, three plants were randomly selected, and per each plant, four inflorescences were randomly selected and tagged to be monitored every week, following the method used by Kaur, Dhillon and Gill (2011). The variables recorded were the number of flower buds, the number of male flowers, the number of female flowers, the number of initial fruits and the number of mature fruits.

The productivity of the plants for each provenance and treatment was estimated by collecting the total number of mature fruits per plant, and the number and weight of seeds per fruit. Fruits were considered mature when they turned yellow, to ensure the maturity of the seeds (Achten et al., 2008; Osuna-Canizalez et al., 2015; Zavala-Hernández et al., 2015). The total productivity was obtained by multiplying the number of fruits from each plant by their average number of seeds per fruit, the dry seed weight and the plant density (1666 plants ha^{-1}). A random sample of 20 seeds from each provenance was sent to the company JatroSolutions GmbH for their chemical analysis, which is presented in Table 2.

Table 2: Chemical characteristics of the kernels of the seeds from four native Mexican provenances

Provenance	Phorbol ester contents (mg/g kernel)[a]	Oil contents (%)[b]	Moisture (%)
Actopan (02)	1.122	57.168	7.139
Tamiahua (19)	0.050	58.585	7.038
Papantla (26)	0.026	60.00	6.863
Amatlán (45)	0.079	58.977	7.203

[a] Estimation according to Davapp and Becker (Devappa et al., 2010), [b]estimations using an NMR apparatus. The number in parenthesis corresponds to the provenance's field number

The weight of the seeds was obtained as follows: the mature fruits were manually peeled by separating the pericarp from the seeds, then the seeds were placed over baskets and left to dry outdoors under a shadow place at environmental temperature (22 °C) until constant weight. One hundred seeds per plant were randomly selected and each one was weighted with an analytic balance (Ohaus, 0.0001 g of precision).

These data were recorded from May to December, which corresponds to the normal productive period of this species at the experimental site (Palacios-Wassenaar et al., 2016)

The number in parenthesis corresponds to the provenance's field number.

Physical and chemical characteristics of the soil and the organic fertilizers

Previous to the experiment, a mixed sample of the experimental soil was collected according to the Official Mexican Norm, which establishes the specifications soil sampling and analysis (SEMARNAT, 2002). Additionally, one sample of bokashi and one sample of vermicompost were randomly obtained before their application. All the samples were sent for their analysis of texture, pH, organic matter, macronutrients (N, P, and K) and micronutrients (Ca and Mg) to the Soil Laboratory of the National Institute of Ecology. The characteristics of the experimental soil and the organic fertilizers are shown in Table 3.

To evaluate the effects of the organic fertilizers over the soil, at the end of the experimental period, four plants from each treatment were randomly selected (12 plants). For each plant, two samples of soil were taken, one by the north and other by the south, at a distance of 40 cm around the trunk and 30 cm deep. The samples from each plant were combined and analyzed separately to estimate organic matter, assimilable N, pH and conductivity.

Statistical analysis

All data was stored in Excel files, where their basic statistics were estimated (maximum, minimum, average, standard deviation, and standard error). The statistical analysis was performed by a two way ANOVA, with provenance and treatment as factors. The differences between paired groups of provenances and treatments were determined

Table 3: Physical and chemical characteristics of the experimental soil and the organic fertilizers applied in the experiment

Sample	pH	%			(mg Kg^{-1})			Cmol(+)Kg^{-1}		
		Clay	Silt	Sand	OM	N	P	K	Ca	Mg
Experimental soil	4.26	51.6	21.6	22.0	30.30	1.70	7	0.41	10.28	4.93
Bokashi	8.23	21.26	33.6	44.7	170.80	9.50	26	18.68	34.47	14.5
Vermicompost	5.12	27.6	19.6	52.7	415.10	27.90	292	9.76	31.28	17.74

OM= Organic matter

by *post hoc* tests using the Tukey method, with a level of significance of 5 %. The Sigmaplot v10 program was used for all the analyses.

RESULTS

Floral display

Statistical analysis found that the number of flower buds had statistical significant interaction between treatments and provenances (P=0.003) (Table 4).

The provenances from Actopan and Amatlán had an average of 47 % more flower buds than Tamiahua and Papantla. Regarding the treatments, only pruning produced 30 % more flower buds than the control and there were no statistical differences between vermicompost and bokashi (Table 5).

Male and female flowers had a significant interaction between treatment and provenance (P=0.002 for male flowers and P=0.004 for female flowers) (Table 3). Actopan and Amatlán on average produced 71 % more male flowers than Papantla and Tamiahua, but treatments had no significant effects over the number of male flowers (P=704). Actopan and Amatlán produced on average 64 % more female flowers than Tamiahua and Papantla; while the organic fertilizers increased the number of female

Table 4: Mean square values and statistical significances obtained in the analysis of variance for the floral display of *Jatropha curcas* L. to different provenances and treatments

Source of variation	DF[a]	Flower buds	Male flowers	Female flowers	Initial fruits	Mature fruits
Treatment	3	22978.28**	1078.27	350.51**	389.44**	82.90**
Provenance	3	78060.84**	54324.40**	306.47**	42.23*	9.20**
T x P [b]	9	14412.08**	7229.81**	50.09**	44.21**	5.59
Error	112	3132.89	2298.57	17.03	10.30	3.31

[a]Degrees of freedom; [b]Treatment by provenance; *significant with P<0.05; **significant with P<0.01

Table 5: Comparisons of means of provenances and treatments for the number of flower buds, male and female flowers, and initial and mature fruits per floral cluster of *Jatropha curcas* L.

Source of variation	Flower buds	Male flowers	Female flowers	Initial fruits	Mature fruits
Treatment					
T0	123.72^{b}	117.50^{a}	6.22^{c}	2.96^{c}	1.59^{c}
T1	129.78^{b}	120.34^{a}	9.44^{b}	4.75^{b}	2.19^{b}
T2	123.25^{b}	114.28^{a}	8.97^{b}	6.06^{b}	2.47^{b}
T3	176.75^{a}	127.88^{a}	14.19^{a}	11.09^{a}	5.22^{a}
Provenance					
02	180.68^{a}	132.22^{b}	13.78^{a}	6.37^{a}	3.38^{a}
19	81.94^{b}	75.19^{c}	6.75^{b}	4.59^{b}	2.34^{a}
26	109.59^{b}	101.63^{b}	7.97^{b}	6.63^{a}	2.47^{a}
45	181.28^{a}	170.97^{a}	10.31^{a}	7.28^{a}	3.28^{a}
Treatment x Provenance					
T0 x 02	133.50^{c}	124.25^{b}	9.25^{cd}	2.25^{c}	1.88^{bc}
T0 x 19	67.50^{e}	63.38^{d}	4.12^{d}	2.25^{c}	1.38^{c}
T0 x 26	97.88^{de}	92.86^{bc}	4.75^{d}	3.88^{c}	1.13^{c}
T0 x 45	196.00^{a}	189.50^{a}	6.50^{d}	3.50^{c}	2.00^{bc}
T1 x 02	173.88^{b}	160.75^{ab}	13.37^{bc}	5.25^{b}	2.88^{b}
T1 x 19	107.13^{de}	97.63^{bcd}	8.25^{cd}	5.25^{b}	2.00^{bc}
T1 x 26	113.00^{d}	106.38^{bcd}	5.63^{d}	4.63^{bc}	2.00^{bc}
T1 x 45	125.12^{c}	117.00^{bc}	7.75^{c}	3.25^{c}	1.88^{bc}
T2 x 02	133.25^{c}	122.25^{b}	11.13^{bc}	4.63^{bc}	2.13^{b}
T2 x 19	94.50^{de}	87.25^{cd}	5.75^{cd}	5.25^{b}	2.88^{b}
T2 x 26	95.50^{d}	88.37^{cd}	5.50^{c}	6.13^{b}	2.00^{bc}
T2 x 45	170.00^{b}	159.38^{ab}	9.88^{bc}	8.25^{b}	2.88^{b}
T3 x 02	282.13^{a}	122.25^{b}	20.63^{a}	13.38^{a}	6.63^{a}
T3 x 19	58.88^{e}	52.50^{d}	5.50^{d}	5.00^{bc}	3.13^{b}
T3 x 26	132.00^{cd}	118.87^{bc}	13.13^{bc}	11.88^{a}	4.75^{b}
T3 x 45	234.00^{a}	218.87^{a}	15.75^{b}	14.13^{a}	6.38^{a}
CV (%)	55.42	51.49	59.93	75.82	81.57
DMSH	18.91	16.95	1.58	1.14	0.65

T0: Control; T1: bokashi; T2: vermicompost; T3: pruning; 02: Actopan; 19: Tamiahua; 26: Papantla; 45: Amatlán; CV: coefficient of variance; DMSH: honest significant difference. Different letters indicate significant differences (P<0.05) flowers by 48 % over the control and pruning increased their number in 128 % over the control.

Initial and mature fruits

There was a significant interaction between treatments and provenances for initial fruits (P<0.001), but not for mature fruits (P=0.099) (Table 3), nor by vermicompost and bokashi (Table 5). Tamiahua was the least productive provenance, with only 32 % of the initial fruits than the average of the other three provenances. In relation with the treatments, organic fertilizers increased the number of initial fruits over the control by 82 %, while pruning increased fruits by 274 %; but, they were effective only in three provenances, because Tamiahua did not respond to any treatment (P=0.089).

The number of mature fruits was similar between provenances. However, the organic fertilizers and pruning increased this number over the control by 46 % and 227 %, respectively.

Total Fruit and seed production

Total fruit production and dry seed weight by plant were different among treatments and provenances, but they had no statistical interaction between provenances and treatments (fruits: P=0.247; dry seed weight: P=0.344) (Table 6).

Between provenances, Actopan had the highest number of fruits per plant, seeds by fruit and total dry seed weight by plant, while Amatlán produced the heaviest seeds, but its total production was 52% of Actopan´s. Treatments with vermicompost and bokashi were statistically similar for all the evaluated variables (Table 7). The average fruit and total dry seed production with these organic fertilizers increased over the control by 69 % and 86%, respectively. Pruning produced the heaviest seeds, but its total production was 32 % below the production with organic fertilizers.

Soil characteristics at the end of the experimental period

The analysis of the soil found 5 % more organic matter and assimilable N in the samples where bokashi and vermicompost were applied compared to the control (Table 8), while pH increased by 5.8 % in the soils where these organic fertilizers were applied.

DISCUSSION

Floral display

The number of flower buds and male flowers in *J. curcas* is highly dependent on genetic bases, more than on agronomic practices (Nietsche et al., 2015; Pan et al., 2014). In this regard, since the number of male flowers was not affected by any treatment in this experiment, we confirmed that male flowers are associated with genetic factors. The provenances of Amatlán and Actopan are remarkable if they are compared with other provenances in Asian countries, like Malaysia, Philippines and India, which average between 17 to 110 male flowers by inflorescence (Mat et al., 2015), and other American provenances with averages between 80 and 100 male flowers (Nietsche et al., 2015). Although the total number of flower buds in *J. curcas* has a high range of variation, reaching up to 238 by inflorescence, usually their averages are below 120 (Luo et al., 2007). Yet, in the provenances of Amatlán and Actopan, the average number of flower buds were 180. This naturally occurring high number of flowers increases the probabilities of genetic exchange in these plants since their percentage of male flowers is 94 % and pollination in *J. curcas* is outcrossed (Luo et al., 2007).

On the other side, the number of female flowers by inflorescence, which indicates the potential of productivity (Nietsche et al., 2015; Pan et al., 2014), was increased by applying any organic fertilizer, like bokashi or vermicompost, but pruning was the best practice to induce the highest number of female or hermaphrodite flowers in these Mexican provenances. Pruning stimulates hormones like cytokinins, associated with new sprouts, which can increase the number of female and hermaphrodite flowers (Pan et al., 2014). The number of female flowers produced by Actopan, Papantla and Amatlán are located in the upper ranges of American and Asian provenances, which are around 10 to 15 female flowers by inflorescence, while Tamiahua is located in the middle, with 5 to 9 female flowers by inflorescence (Grajales-Conesa et al., 2016; Bhattacharya, Datta and Datta, 2005; Nietsche et al., 2015).

Initial and mature fruits per inflorescence

The flower-fruit ratio of these Mexican provenances was 10:4.7 in natural conditions and increased up to 10:5.9 with organic fertilizers and 10:7.8 by pruning, which is

Table 6: Mean squares values and statistical significances obtained in the analysis of variance for fruits and seed production of *Jatropha curcas* L. to different provenances and treatments

Source of variation	DF[a]	Fruits per plant	Seeds by fruit	Dry seed weight	Dry seed weight by plant
T	3	163971.81**	1.51*	1.19**	1.09**
P	3	67466.55**	0.21	0.31**	0.21
T x P[b]	9	7960.75	0.07	0.17**	0.04
ER	64	6057.54	0.46	0.00	0.04

[a]Degrees of freedom; [b]Treatment by provenance; *significant with P<0.05; **significant with P<0.01

Table 7: Comparisons of means of provenances and treatments for the number of fruits per plant, seeds by fruit, dry seed weight and dry seed weight production by plant of *Jatropha curcas* L.

Source of variation	Fruits per plant	Seeds by fruit	Dry seed weight (g)	Dry seed weight by plant (kg)
Treatment				
T0	139.95^{b}	2.38^{a}	0.68^{c}	0.24^{b}
T1	229.40^{a}	2.40^{a}	0.73^{b}	0.42^{a}
T2	244.90^{a}	2.47^{a}	0.75^{b}	0.45^{a}
T3	134.50^{b}	2.61^{a}	0.78^{a}	0.30^{b}
Provenance				
02	317.60^{a}	2.83^{a}	0.74^{b}	0.69^{a}
19	108.25^{b}	2.23^{b}	0.66^{d}	0.16^{c}
26	154.45^{b}	2.28^{ab}	0.69^{c}	0.24^{c}
45	167.90^{b}	2.52^{ab}	0.84^{a}	0.33^{b}
Treatment x Provenance				
T0 x 02	207.60^{b}	2.84^{a}	0.59h	0.40^{b}
T0 x 19	393.60^{a}	2.80^{a}	0.82^{c}	0.85^{a}
T0 x 26	351.00^{a}	2.82^{a}	0.76^{d}	0.75^{a}
T0 x 45	318.20^{b}	2.86^{a}	0.79^{d}	0.74^{a}
T1 x 02	96.80^{c}	2.23^{b}	0.66^{g}	0.14^{cd}
T1 x 19	142.80^{c}	2.23^{b}	0.65^{g}	0.20^{cd}
T1 x 26	184.20^{c}	2.23^{b}	0.66^{g}	0.27^{cd}
T1 x 45	11.40^{d}	2.22^{b}	0.68^{f}	0.02^{d}
T2 x 02	103^{b}	2.14^{b}	0.68^{f}	0.15^{cd}
T2 x 19	192^{b}	2.13^{b}	0.68^{f}	0.27^{c}
T2 x 26	208.6^{b}	2.32^{ab}	0.74^{e}	0.32^{c}
T2 x 45	114.2^{b}	2.53^{ab}	0.68^{f}	0.20^{cd}
T3 x 02	152.4^{b}	2.32^{ab}	0.80^{d}	0.25^{cd}
T3 x 19	189.2^{b}	2.42^{ab}	0.78^{d}	0.36^{bc}
T3 x 26	235.8^{b}	2.50^{ab}	0.84^{b}	0.47^{b}
T3 x 45	94.2^{c}	2.82^{ab}	0.95^{a}	0.23^{cd}
CV (%)	155.90	27.04	17.44	82.34
HSD	34.81	0.03	0.01	0.09

T0: Control; T1: bokashi; T2: vermicompost; T3: pruning; 02: Actopan; 19: Tamiahua; 26: Papantla; 45: Amatlán; CV: coefficient of variance; DMSH: honest significant difference. Different letters indicate significant differences (P<0.05)

Table 8: Soil characteristics at the study site 11 months after the application of organic fertilizers

Treatment	Organic matter (%)	Assimilable N (%)	Relation C/N	pH	Conductivity dSm^{-1}
Bokashi	1.71	$10.25x10^{-2}$	11.60	5.03	34.34
Vermicompost	1.73	$10.38 x10^{-2}$	11.60	5.04	30.63
Control	1.64	$9.84x10^{-2}$	11.60	4.76	35.31

high compared with Indian *J. curcas* that shows a ratio of 10:1 under natural conditions (Bhattacharya, Datta and Datta, 2005). Our higher number of initial fruits can be attributed to the fact that the experimental site and the sites where these plants were obtained belong to the same geographical area; therefore, their natural pollination insects are present, and they are a major factor to increase the number of initial fruits in *J. curcas* (Rincón-Rabanales et al., 2016), since *J. curcas* mainly depends on open pollination to fecundate flowers.

The higher number of initial fruits obtained with both biofertilizers can be attributed to the high contents of P and K supplied by them to the soil, which was low in these nutrients. Increments of P and K can increase fruit initiation in tropical fruit trees (Pathak and Mitra, 2017); however, pruning helped to eliminate dead and unproductive branches, allowing the new branches to increase their vigor (Dufour, Kerana and Ribeyre, 2019), thus being more productive than non-pruned fertilized plants.

For the number of mature fruits by inflorescence, we consider that the most important factor to increase productivity will depend on the agronomical treatment more than on the provenance because despite the fact that the provenances of Actopan and Amatlán have had the largest number of female flowers, the four provenances obtained statistically similar number of mature fruits. For this situation, we observed a constant decrement in the percentage of fruits to reach maturity when the number of initial fruits is higher in the four provenances and treatments; for example, for the control, 53 % of the initial fruits reached maturity, but for pruning, which has the highest number of initial fruits, only 47 % of these fruits reached maturity (Fig. 1). This behavior indicates that another key factor to increase production consists of reducing the number of losses during fruit development. In this regard, previous investigations considering different agronomic practices in *J. curcas*, such as fertilization and pruning, have not evaluated this relationship, because they reported only the total number of ripe fruits (Díaz-Hernández, Aguirre-Medina and Díaz-Fuentes, 2013); although, in these reports, the number of mature fruits per inflorescence in *J. curcas* is usually found low (lower than six), even with the application of fertilizers. This may be because Jatropha fruits need a long period to ripe (35 to 50 days), which implies that fruits are more susceptible to pests or diseases during their development, causing their loss and reducing the final number of ripe fruits. In this experimental site, all the plants presented problems with phytophagous insects and pathogens, damaging leaves, tender shoots, or even the fruit clusters. This information has been reported in previous research at the experimental place (Noda-Leyva, Pérez-Vázquez and Valdés-Rodríguez, 2015), thus, we consider that pest and disease control needs to be provided to increase fruit production.

Total Fruits and seed production

Although the analysis of the inflorescences of *J. curcas* found that pruning plants can increase fruit production and enhance seed weight, the total production of fruits was affected by the length of the flowering and fruiting period combined by the biofertilizers. Both fertilizers increased the pH of the soil from strongly acid to moderately acid (SEMARNAT, 2002) and slightly increased the contents of organic matter, facilitating the absorption of the nutrients by the roots of *J. curcas* (Góngora Canul et al., 2018). The statistically similar

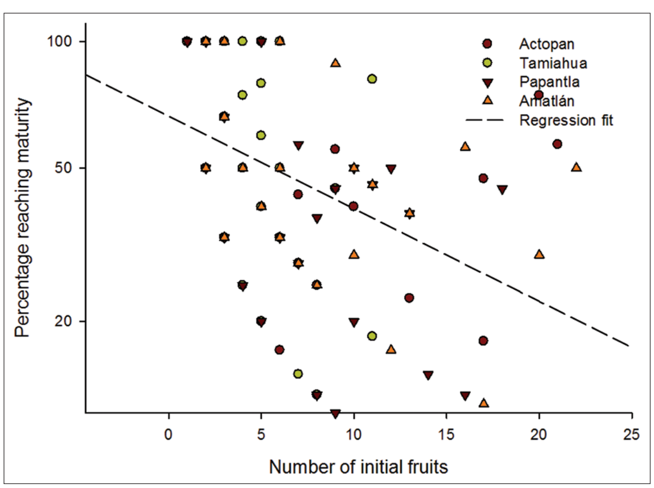

Fig 1. Percentage of fruits reaching maturity in relation to the number of initial fruits in four native Mexican provenances of *Jatropha curcas*

results obtained by these two biofertilizers can be attributed to the fact that both content the amounts of nutrients required by these provenances. Hence, we can recommend any of them to increase their yield. Different studies over *J. curcas* have found that plant nutrient requirements are highly depending on the soil type, such as texture and pH (Achten et al., 2008; Behera et al., 2010; Suriharn et al., 2011; Valdés-Rodríguez et al., 2011), thus we consider that, for these provenances and this soil type, bokashi and vermicompost containing high quantities of N and P supplied the required nutrients to increase plant productivity. Besides this, the high amounts of P and K, combined with a good balance of Mg and Ca in bokashi and vermicompost (SEMARNAT, 2002), contributed to a healthier development of the flowers and their corresponding fruits (Pathak and Mitra, 2017).

By the other side, the major disadvantage of pruning consisted in that it delayed flowering for about two months, even the plants where pruned during their dormancy period; thus, when pruned plants had their highest production peak the environmental temperatures and the number of sunlight hours were 2.6 °C and 1.8 hours lower than at the highest peak of production of the non-pruned plants (Fig. 2), which reduced the amount of photosynthetic energy that the pruned plants could obtain during their fruiting period. According to previous phenological information at the experimental site, average temperatures for fruiting are located above 27.5 °C (García Pérez et al., 2013), while the highest fruiting period corresponds to June up to October, which is the same fruiting period we observed in these experimental provenances. Therefore, we consider that pruning altered the phenological performance of the plants, which by the months of November and December were still delivering fruits, while their non-pruned counterparts were entering in their dormancy period. Similar results were obtained by other researchers who pruned *J. curcas* plants and observed a drastically reduced yield in the immediate growing season after pruning (Ghosh, Chikara and Chaudhary, 2011). In this regard, we consider that pruning can improve the sanitation of *J. curcas*, by eliminating damaged or infested branches, especially in a very dense crop system, and it will also help for an easier harvest by reducing the height of the plants, however, it will be necessary to monitor the plants during longer periodos to determine long term effects of pruning over yields.

Regarding the provenances, the number of fruits by plant obtained by Actopan was 23 % higher than the highest obtained by other Mexican provenances from the state of Morelos in similar clay soils (Pérez et al., 2019), while it is 122% higher than the highest obtained by Malaysian provenances with fertilization ratios of 1912.5, 1832.5

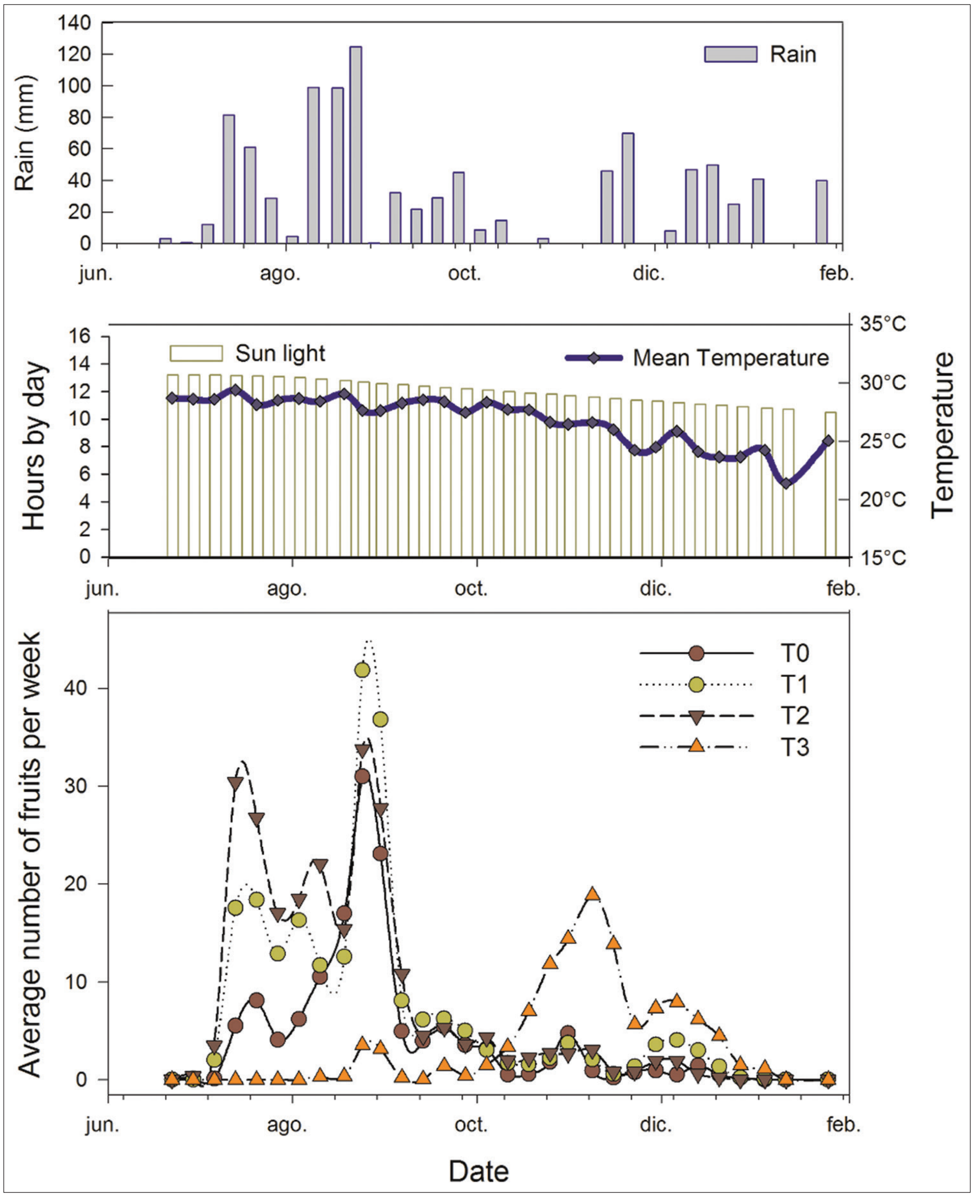

Fig 2. Environmental conditions (number of hours of sunlight and average temperature) registered at the experimental site and their relationship with weekly fruit production in native provenances of *J. curcas* under four agronomic practices; T0: control, T1: vermicompost; T2: bokashi, T3: pruning.

and 382.5 gm^{-2} NPK (Shah et al., 2017). For the total seed production by hectare, research adding 17-17-17 NPK plus mycorrhizae to elite germplasm developed by the Center of Research and Technological Assistance of Jalisco in Mexico (Góngora Canul et al., 2018) was 29 % lower than the yield obtained by the provenance of Actopan with biofertilizers, which registered a total production of 1,331 kg ha^{-1}. These results, together with its high content of oil (57 %) indicate that the provenance of Actopan is an elite germplasm that can be considered for biofuel purposes. The provenance of Amatlán, which has very low phorbol esters contents is more suitable for edible purposes, it has even higher contents of oil (59 %), and its total yield of 683.2 kg ha^{-1} with biofertilizers can be considered as in the middle of good productivity for elite germplasm of Mexican provenances (Góngora Canul et al., 2018).

CONCLUSIONS

Bokashi or vermicompost can significantly increase the yield of Mexican provenances of *Jatropha curcas*, while pruning can improve the number of fruits by inflorescence, however, it delays the development of flowering, and in sites with a winter period, it reduces the final productivity of the plants. Among the four Mexican provenances, the one from Actopan has a remarkable high productivity, which is the highest found in any Mexican provenance.

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Authors' contributions

OAVR: conceptualization, analysis, investigation, writing, review and editing of final document. IGZ: field work, data curation, analysis, investigation and writing of the draft document. OPW: conceptualization, field work, data curation, analysis, review of draf and final document. GQ: field work, methodology, investigation and review of draft document. APV: review of draft, project support and administration.

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