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Evaluation of fertilization of hydroponically cultivated castor bean (*Ricinus communis* L.)

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ABSTRACT

Objective: To determine the influence of fertilization on the growth and yield of five accessions of castor bean (*Ricinus communis* L.) cultivated in a hydroponic system.

Design/Methodology/Approach: Five outstanding accessions of the castor bean collection at COLPOS-Campus SLP were established: El Orito (EO), Encarnación de Díaz (ED), Salinas (SA), Ranchería de Guadalupe (RG) and San Luis (SL). The NPK (ppm) fertilization levels tested were: low (LL; 140, 50, 150), medium (ML; 210, 80, 250); high (HL; 280, 110, 350) and a control (NF; No fertilizer). The experimental design was a randomized block, with a 5×4 factorial arrangement (accession × fertilizer level).

Results: The differences in grain production were only significant (α=0.05) between the NF control (31 g plant^{-1}) and the three levels of fertilization (1103, 973 and 967 g plant^{-1}, for LL, ML, and HL, respectively, with no differences among them). Regarding accessions, no differences were observed among them, having ED the highest yield (681 g plant^{-1}). In the case of plant height, NF treatment reached 60 cm, while the other levels had an average height of 170 cm, with HL being the highest (180 cm). The highest oil content (38.4%) was obtained with the ML fertilization.

Study Limitations/Implications: The present study had no obvious limitations.

Findings/Conclusions: For seed yield, significant differences were found only between not fertilizing and fertilizing at any level. Between fertilized levels, however, the differences were not significant, as well as among accessions.

Keywords: yield, oil content, production systems, plant nutrition.

INTRODUCTION

In Mexico there are plant species with bioenergetic potential, among which the following stand out: Mexican pine nut (*Jatropha curcas* L.), castor bean (*Ricinus communis* L.), sweet sorghum (*Sorghum bicolor* (L.) Moench) (SAGARPA, 2017), and prickly pear cactus (*Opuntia* spp) (Amante *et al*., 2013), among others.

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Castor bean (*R. communis*) is a species of tropical origin, with a wide adaptation and distribution in the world. It is an important non-edible commercial oilseed crop that tolerates drought and has a good productive behavior in arid and semi-arid regions (Babita *et al*., 2010). Currently, it is used in the chemical industry known as ricinochemistry; the oil produced in its seed is the only one in nature that is soluble in alcohol, and also has a high density and viscosity. Castor bean seeds are a source of ricinoleic acid, which confers interesting industrial properties for the production of various products, including: inks, medicines, varnishes, synthetic polymers, hydraulic fluids, fuel additives, plastics, lubricants, cosmetics, low molecular weight aviation fuels, and biodiesel (Caupin, 1997; Beltrão *et al*., 2001; Comar *et al*., 2004; Velasco *et al*., 2005; Ogunniyi, 2006; Cardona *et al*., 2009). After detoxification, the seed residues can be used to produce animal feed supplements or as organic fertilizer (Jiménez *et al*., 2016).

According to Severino *et al*. (2006), castor bean is a demanding crop in terms of soil fertility, when high productivity is sought. In turn, Magalhães *et al*. (2002) mentioned that low potassium levels affect growth and vegetative reproduction, while the lack of micronutrients is mainly expressed in production. In general, there is limited information on castor bean responses to chemical fertilization with nitrogen, phosphorus and potassium (NPK). In this regard, Franklin *et al*. (2012) emphasize that an efficient fertilization program is required to generate high seed yields, which could allow determining the response curve in relation to the combination of N, P and K, for their adequate supply, in order to reduce the production costs.

The agricultural sector faces important challenges in the production of species for bioenergy purposes. In this sense, production systems that allow higher yields of raw material for use as biofuels must be sought; such is the case of hydroponic systems, where nutrients are dissolved in water to enter the plant more easily, making nutrition more efficient for plant growth, development, and yield.

Based on the above described, this study aims to determine the effect of different fertilization doses on growth, yield and oil content of five castor bean accessions grown in hydroponics.

MATERIALS AND METHODS

The study was conducted in the ejido Diego Martín (22° 43′ 50.6″ N, 101° 42′ 33.1″ W), municipality of Salinas, San Luis Potosí, with an approximate altitude of 2,038 m.a.s.l., a dry temperate climate, with mean annual temperature of 16 to 18 °C, and mean annual precipitation of 300 to 400 mm (INEGI, 2009).

Five outstanding castor bean accessions were used: El Orito (EO), from the state of Zacatecas; Encarnación de Díaz (ED), from Jalisco; and Salinas (SA), Ranchería de Guadalupe (RG) and San Luis (SL), from San Luis Potosí. These were established in an open-air hydroponics system, in pots with drip irrigation applied through drip tape lines (fertigation). Sowing was done in plastic containers with a mixture of sand:tezontle:compost (1:1:1), and transplanting to the hydroponics system took place two months later. Nutrient solution was applied using four irrigation heads, each connected to a 0.25 HP pump and a water tank, for each fertilization level used.

Eight irrigations were applied daily (from 10 to 20 minutes each) using an eight-time programmer (Steren model TEMP-08E®). To calculate the volume of water applied, four control drippers and eight drainage trays were installed to quantify the excess. Nutrient solutions, with increasing proportions of NPK, were: no-added fertilizer (NF), and low (LL), medium (ML) and high

Table 1. Nutrient solutions used for each fertilization level.

Fertilizer	Fertilization level (g/1000 L of water)		
	Low (LL)	Medium (ML)	High (HL)
Potassium nitrate	650	800	920
Calcium nitrate	550	750	820
Monoammonium phosphate *	250	310	430
Monopotassium phosphate **	250	310	430
Magnesium sulfate	120	120	120
Iron chelate	11	11	11
Copper sulfate	0.8	0.8	0.8
Zinc sulfate	0.7	0.7	0.7
Boric acid	1.8	1.8	1.8

* Used during vegetative growth. ** Used during seed filling.

(HL) fertilization levels, supplemented with secondary nutrients and micronutrients (Table 1). In order to support seed filling, the potassium concentration in the nutrient solution was increased after 100 DDT, when fruits began to ripen.

A randomized block experimental design was used, consisting of twenty treatments (five accessions and four fertilization levels) and three replications, for a total of n=60 experimental units, with a spacing of 1.5 m between plants and rows.

Between transplanting and 142 days after transplant (DAT), plant height, number of leaves and number of panicles, were evaluated eight times. At harvest time, dry matter production, grain yield, root volume, root dry weight, weight of 100 seeds, leaf area, and oil content were quantified. The last one was quantified using a Soxhlet 1050 oil extractor, following the technique proposed by Loredo *et al*. (2012). Statistical analysis consisted of analysis of variance (ANOVA) and means comparison using Tukey and LSD tests.

RESULTS AND DISCUSSION

Results obtained from the effect of fertilization on the variables evaluated in five accessions of *R. communis* are presented and discussed below.

Plant height

Ricinus communis accessions showed differential behavior with regard to plant height (Table 2). The SA accession presented the greatest height (179 cm), which was significantly different from the others. It was observed that SA and SL presented faster growth at the beginning of the cycle. The ED accession maintained growth until the end of the evaluation, while in the rest of the accessions growth ceased between 100 and 110 days DAT. This may indicate that ED is a plant with a later vegetative development. On the other hand, SL showed a reduction in height from 121 to 142 days DAT, with a loss of leaves, which could be related to this reduction in growth.

Regarding the fertilization levels tested (Table 2), it was observed that the differences in castor bean plant height at 142 DAT were less than 14 cm between the levels with fertilization. In this last evaluation, the addition of fertilizer increased height by more than 100% compared to the control (NF), although the difference was not significant between the three fertilization levels. After 60 DAT, *R. communis* showed the highest height values with the ML fertilization.

In this study, plant hight ranged from 1.27 to 1.79 m. Jiménez *et al*. (2015) and Salazar *et al*. (2014) report heights of 1.64 to 2.76 m for two accessions from Durango and two hybrids of castor bean. In another work, Solís *et al*. (2016) obtained plant heights from 0.68 to 1.11 m, for 11 varieties of castor bean and one unimproved collected seed, which were smaller than the ones found in this study.

As an example of the plant growth during the period evaluated, Figure 1 shows the height of the EO accession, depending on the fertilization levels. It can be seen that there were no significant differences

Table 2. Plant height (cm) by accession and fertilization level, along growth cycle (DAT).

DAT	Accession					Fertilization level			
	EO	ED	SA	RG	SL	NF	LL	ML	HL
0	15 a	14 a	27 a	17 a	24 a	13 a	13 a	14 a	14 a
22	22 b	23 b	36 a	21 b	34 a	27 a	26 a	27 a	28 a
39	53 c	56 c	75 a	51 c	64 b	36 b	64 b	68 ab	70 a
60	79 c	87 b	108 a	77 c	90 b	50 c	98 b	103 a	103 a
74	94 c	110 b	141 a	97 c	110 b	63 b	117 b	133 a	129 a
92	121 b	135 b	169 a	118 b	128 bc	76 b	152 a	156 a	151 a
106	126 c	143 b	180 a	121 c	131 c	78 b	164 a	162 a	157 a
121	130 c	149 b	179 a	124 c	149 b	78 c	164 ab	172 a	159 b
142	133 b	155 b	179 a	127 b	135 b	77 b	168 a	176 a	163 a

Means with different letters within the same sampling time (DAT) (for either Accession or Fertlization level) are statistically different (Tukey, p≤0.5). Accessions: EO = El Orito, ED = Encarnación de Díaz, SA = Salinas, RG = Ranchería de Guadalupe, SL = San Luis. Fertilization levels: NF = No fertilizer, LL = Low level, ML = Medium level, and HL = High level.

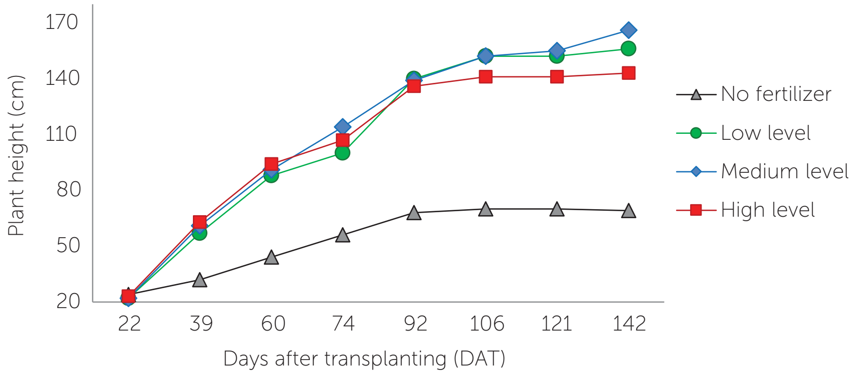


Figure 1. Plant height over time of EO accession in response to fertilization level.

between fertilization treatments, although the NM material presented the highest values, reaching 176 cm at 142 DAT. The NF level showed the lowest heights, registering a maximum value (78 cm) at 106 and 121 DAT. In all the fertilization treatments, similar height values were observed during the first 95 DAT. The same trend was present in the rest of the accessions. In this regard, Silva *et al*. (2003) observed significant differences in plant height at 100 DAT with the use of increasing doses of N (0, 30, 60 and 120 kg ha^{-1}), with 120 kg ha^{-1} being the best treatment.

Number of leaves

For the last evaluation (at 142 DAT), there were significant differences in the number of leaves per plant, both between the accessions and between the fertilization levels. The RG, ED and EO accessions showed the highest leaf production, with 203, 193 and 177 leaves, respectively, which were statistically different from those of SL (131) and SA (118). By fertilization level, there were only significant differences between the unfertilized level (16 leaves) and the low (226), medium (204) and high (204) levels; there were no differences among LL, ML, and HL of fertilization.

In the control treatment (NF), the behavior of the number of leaves (no fertilizer) was very peculiar, since it reached a maximum of 29 at 60 DAT, and decreased to 16 on the last evaluation (142 DAT). In the treatments with fertilization, the number of leaves always increased over time, reaching its highest value in the last evaluation. This result shows that castor bean requires fertilization, as suggested by Magalhães *et al*. (2002), Severino *et al*. (2006), and Franklin *et al*. (2012).

Leaf area

Regarding leaf area (Figure 2), significant differences were observed between the accessions. The Tukey test formed three groups. In the first group, RG was the most productive, with an average of 59.471 cm^2 plant^{-1}; in the second group, EO and ED showed leaf areas of 50.034 and 50.273 cm^2 plant^{-1}, respectively. In the third group, with the lowest leaf area, SA and SLP had 33,577 and 30,364 cm^2 plant^{-1}, respectively.

There were also statistical differences among fertilization levels, and Tukey's test formed three groups: LL was in the first group, which showed the highest production, with 67,199 cm^2 plant^{-1}; in the second group, ML and HL accessions presents leaf areas of 57,450 and 52,371 cm^2 plant^{-1}, respectively. The NF level only produced an average of 1,956 cm^2 plant^{-1}.

Figure 2 shows the interaction of accessions with the fertilizer levels on leaf area production. In general, it was observed that fertilizers at ML and HL had a negative effect on leaf area, compared to LL. RG had the highest leaf area with LL fertilization; the EO accession with LL was the second highest producer. The NF treatment showed the lowest leaf

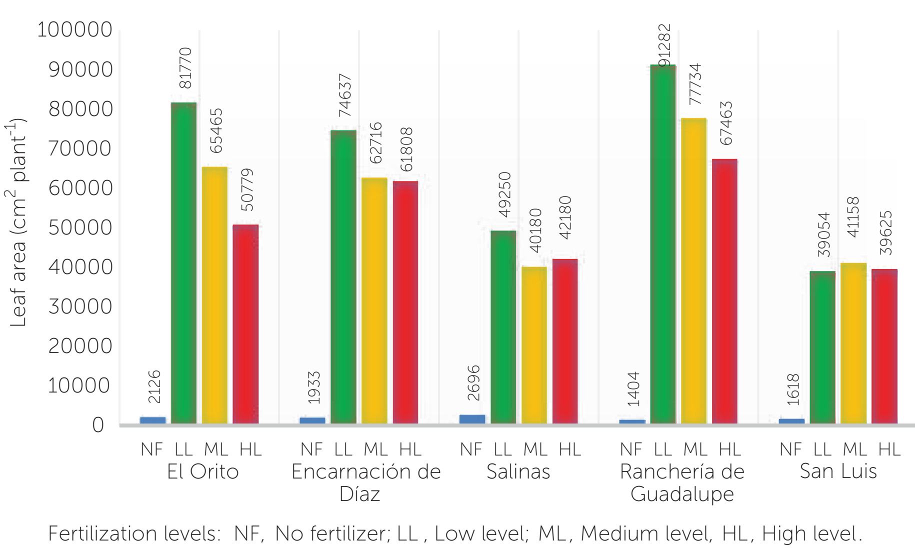


Figure 2. Leaf area accumulation in five castor bean accessions in response to fertilization levels.

area, producing only 5-10% compared to the fertilized levels (LL, ML and HL).

Fertilization levels: NF, No fertilizer; LL, Low level; ML, Medium level, HL, High level.

Table 3. Volume and dry weight of castor bean roots by accession and level of fertilization.

Accession	Root volume (mL plant^{-1})	Root dry weight (g plant^{-1})
El Orito (EO)	2831 bc	298 bc
Encarnación de Díaz (ED)	3505 ab	338 ab
Salinas (SL)	4146 a	405 a
Ranchería de Guadalupe (RG)	3013 bc	312 b
San Luis (SL)	2223 c	218 c
Fertilization level		
No fertilizer (NF)	993 b	67 b
Low level (LL)	3953 a	381 a
Medium level (ML)	3697 a	378 a
High level (HL)	3931 a	430 a

Means with different letters within a variable (for either Accession or Fertlization) are statistically different (Tukey, $p \leq 0.5$).

Root volume and dry weight

There were statistical differences in root volume and dry weight, both between accessions and between fertilization levels (Table 3). By accession, SA showed the greatest volume (4,146 mL plant^{-1}) and dry weight (405 g plant^{-1}), which were not different from those of ED; however both of them were different from the rest of the accessions. As for the level of fertilization, significant differences were only registered between the level without fertilization and those with fertilization for the two variables, with no differences among LL, ML, and HL. These results show that fertilizing castor bean, even at the low level, increases both root volume and root dry weight by about 3.9 and 5.7 times their values, respectively, with implications in the soil exploration area for access to moisture and nutrients.

Number of panicles

There were also significant differences in the number of panicles per plant, both between accessions and between fertilization levels. Among accessions, SL was the highest producer with 27 panicles, followed by ED with 25. The EO and RG accessions showed very similar numbers (18 and 19, respectively), while SA was the lowest producer, with 14 panicles.

Regarding fertilization levels, there were only significant differences between the level without fertilization (NF), with only 2 panicles, and those with fertilization, which presented 24, 27 and 29, with the LL, ML and HL levels, respectively.

Dry matter production

Regarding the dry matter produced (g plant^{-1}), at 142 DAT the highest production was registered in ED, with 841; on the other hand, the EO, SA, and RG accessions produced around 817, with differences of two grams between them. SL produced only 549 g plant^{-1}, being statistically different from the rest. It was observed that accessions showed different physical characteristics, such as very elongated and thick stems in SA, and EO, ED, and RG having more branches and leaves; even so, they had a similarity in terms of dry matter production.

There were no significant differences in dry matter production among LL, ML and HL fertilization levels (831.6, 831.6, 837.2 g plant^{-1}, respectively). However, when no fertilizer was applied, dry matter accumulation was only 32 g plant^{-1}. Thus, it is inferred that fertilizing castor bean, even at a low level, is required to increase dry matter production; in fact, in this study EO, ED and RG accessions produced the highest amount of dry matter with the LL treatment.

Grain yield

There were significant differences in grain yield only between the unfertilized level (31 g plant^{-1}) and the low, medium and high fertilization levels (1103, 973 and 967 g plant^{-1}, respectively), although between the latter three the differences were not significant. In addition, there were no significant differences in seed yield among accessions. ED was the most productive (681 g plant^{-1}), followed by RG, EO, SA and SL (661, 652, 539 and 530 g plant^{-1}, respectively). It was observed that SL was damaged by a severe wind event; some branches were broken, showing a weakness in their basal part, which is accentuated when green, hydrated and heavier panicles are present. This could have influenced yield, due to a possible loss of fruits.

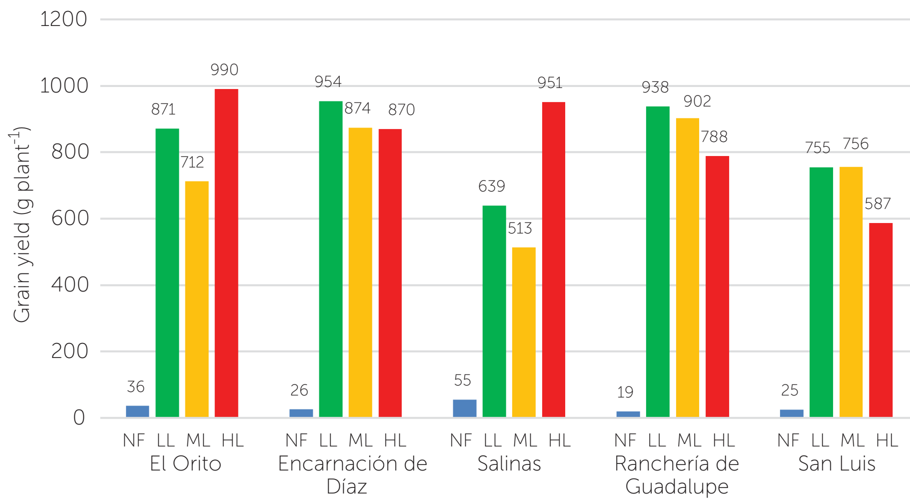
Regarding grain yield per accession as a function of the fertilization level, Figure 3 shows a differentiated response of the accessions to fertilizer application, since some of them, such as EO and SA, reached the maximum yield with HL fertilization, while ED, RG and SL produced more grain with LL fertilization. This indicates that in some cases grain yield was affected as more fertilizer was applied; however, it is very evident that castor bean responds to fertilization, since even with the LL treatment grain yield increased more than 11 times, compared to the NF control level. This confirms what Severino *et al*. (2006) mentioned in relation to the fact that castor bean requires fertile soils in order to ensure high yields.

The results obtained in this study are similar to those obtained by Solís *et al*. (2016) with a seed collected in Estado de México and 10 varieties from Chiapas and Michoacán evaluated in soil, and reporting yields ranging from 0.3 to 1.1 kg plant^{-1}.

Seed oil concentration

The highest oil concentration in castor bean seeds was observed in the ED accession (37%), followed by SA and SL (both with 34%) and RG (33%), while EO had the lowest concentration (32%). With reference to fertilization, the NF and LL levels led to a 32% oil production, while the highest production was obtained with ML (38%), and the lowest with HL (31%). Figure 4 shows the percentage of oil by accession as a function of the fertilization level. The highest concentration was obtained with the SA accession fertilized at ML, followed by the ED accession with the ML and HL levels of fertilization. Something that stands out is that in the SL and EO accessions the highest concentration of oil in the seed was obtained without fertilization.

According to the data, the average castor oil yield with the NF level was 44 kg ha^{-1}, while with the LL, ML and HL levels, production values were 1,568, 1,643 and 919 kg ha^{-1}, respectively.



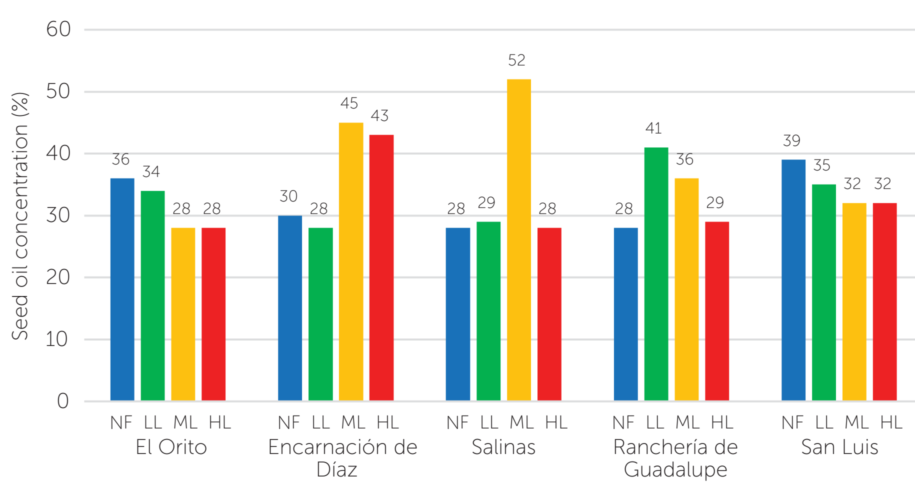
Fertilization levels: NF, No fertilizer; LL, Low level; ML, Medium level; HL, High level.

Figure 3. Seed yield of five castor bean accessions in response to fertilization level.

Oil concentration values in this study (28 to 52%) were higher than those reported by Salazar *et al*. (2014) and Jiménez *et al*. (2015), which ranged from 13.6 to 40.3% for seeds from Durango and some hybrids. Our values are within those reported by Goytia-Jiménez *et al*. (2011) for 151 materials from Chiapas, with oil concentrations ranging from 12.2 to 64.8%. In turn, Martínez *et al*. (2012) reported higher values (between 51.9 to 63.3%) for 10 castor bean varieties.

Weight of 100 seeds

The weights of 100 seeds of castor bean accessions evaluated are shown in Table 4. According to the data, three groups were formed (small, medium and large): small seeds were found in EO and RG (with a 100-seed weight of 9.8 and 13.2 g); the ED accession had medium-size seeds (between 30.2 and 32.5 g); and large seeds were harvested in SA and SL (between 31.7 and



Fertilization levels: NF, No fertilizer; LL, Low level; ML, Medium level; HL, High level.

Figure 4. Seed oil concentration in five castor bean accessions in response to fertilization level.

Table 4. Weight of 100 seeds of five castor bean accessions grown under different fertilization levels.

Fertilization level	Accessions				
	EL Orito (EO)	Encarnación de Díaz (ED)	Salinas (SL)	Ranchería de Guadalupe (RG)	San Luis (SL)
No Fertilizer (NF)	10.6	30.2	40.3	9.8	31.7
Low level (LL)	13.2	32.0	60.5	12.0	46.3
Medium level (ML)	12.4	31.3	57.3	11.0	52.8
High level (HL)	11.7	32.5	53.5	12.0	52.5

60.5 g). Seeds from the SL accession showed more variation among the fertilization levels. Vasco (2014) evaluated the weight of 100 seeds and mentions that EO collection had an average weight of 11 g, ED 21.6 g, SL 52.9, and RG had a weight of 10.1; these values are somehow similar to the ones in this study.

CONCLUSIONS

Castor bean showed a significant response to fertilization, since even with the low level, it increased more than 11 times the grain yield compared to the control treatment. There were no differences among the fertilization levels (low, medium and high). The responses to fertilization were differentiated among accessions, with EO and SA showing the highest yield with HL, while ED and RG had the highest yield with LL. Seed yield per accession ranged from 530 to 681 g plant^{-1}, with no significant differences. The EO accession had the highest yield (990 g plant^{-1}), achieved with the LL of fertilization. ED (45%) and SA (52%) accessions were the highest oil producers, when grown with the LL fertilization. The accessions evaluated showed homogeneous plant heights, ranging from 140 to 180 cm. The RG accession had the highest number of leaves (203) and the largest leaf area (91,282 cm^2 plant^{-1}). SA produced 15 to 25% more roots than the other accessions.

The information reported here serves as a basis for accession management and for considering some traits for genetic breeding.

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