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Response surface applied to mixtures of castor bean hull and presscake for organic fertilization of castor bean plants

Superfície de resposta aplicada a misturas de casca e torta de mamona para adubação orgânica de plantas de mamona

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Abstract . Castor bean presscake and hull are the two sub-products resulting from the extraction of castor bean oil. Their use as organic fertilizers has aroused interest of producers who wish to aggregate value to these products and use them rationally. The growth of castor bean plants of the BRS Energia cultivar in substrates composed of mixtures of two organic materials (castor bean presscake and hull) associated to soil was evaluated in this paper. The experiment was carried out at the Embrapa Algodão greenhouse, in the city of Campina Grande, in Paraíba, Brazil, from February 2010 to June 2010. Five treatments with four replications were evaluated. The treatments were composed of soil, varying from 80 to 100%, and castor bean hull and presscake varying from 0 to 10%. In order to identify the best mixture to promote growth of the plants, the extreme-vertices experimental design was used in a simplex sub-region, due to the restrictions of some components of the mixture. The classification of the best mixture was made based on the following variables: plant height, leaf area, and total dry weight of the plant. These measurements were evaluated by mixture modeling, performed in the MATLAB® computer system. For all of the analyzed variables, the best mixture was composed of 10% of castor bean presscake, 10% of castor bean hull, and 80% of soil.

Keywords. Organic fertilizing, *Riccino communis* L, simplex

Resumo. A torta e a casca de mamona são os dois subprodutos resultantes da extração do óleo de mamona. Sua utilização como fertilizante orgânico tem despertado o interesse dos produtores que desejam agregar valor a estes produtos e utilizá-los de forma racional. Objetivou-se com este trabalho avaliar o crescimento de plantas de mamoneira, da cultivar BRS Energia, em substrato composto por misturas entre dois materiais orgânicos (torta de mamona e casca de mamona), associados ao solo. O experimento foi conduzido em casa de vegetação pertencente à Embrapa Algodão, Campina Grande-PB, Brasil, entre fevereiro e junho de 2010, onde foram avaliados cinco tratamentos, com quatro repetições. Os tratamentos foram compostos por solo, variando de 80 a 100%, misturado com doses de torta e de casca de mamona, ambas variando de 0 a 10% (v/v). Foi utilizado o planejamento experimental extreme-vertices para a identificação da mistura que promovesse maior crescimento de plantas, sendo o espaço experimental uma sub-região simplex, devido às restrições de alguns componentes da mistura. A classificação da melhor mistura foi feita com base nas seguintes variáveis: altura da planta, área foliar e matéria seca total das plantas. Essas medidas foram avaliadas por meio de modelagem de mistura no sistema computacional MATLAB®. Para todas as variáveis analisadas, a melhor mistura foi composta por: 10% de torta de mamona, 10% de casca de mamona e 80% de solo.

Palavras-chave. Adubação orgânica, *Riccino communis* L, simplex

Introduction

The castor bean plant is an oilseed that has social and economic importance. The oil extracted from castor bean seeds can be widely used in industrial products as well as for biodiesel production. The farming of castor bean can be performed in almost all Brazilian territory. However, castor bean farming is quite promising in the semi-arid of the northeast region, where its production cost is low and has easy handling (Fracetto et al., 2012). Nevertheless, in general, the semi-arid region soil presents low content of organic matter. In this way, organic fertilization is a good option for semi-arid.

Organic fertilization is very efficient in providing nutrients to plants, as its action is slower than the mineral fertilizers, which permits the plants to absorb the nutrients more efficiently (Maia et al., 2008). Generally, organic fertilization is obtained by combining different organic materials, with varied indexes of nutrients to formulate complete fertilizer that will meet the nutritional needs of the plants. In these cases, the identification of the proportions of the components in the fertilizers can be properly obtained by means of mixture modeling.

Mixture is a special class of experiments of the “Response Surface” type, in which the product under investigation is composed by several components that determine its proportions (Scheffé, 1958). However, the proportions of many components of a mixture are not independent. The sum of all of them always has to be equal to 100% (Cornell, 1990).

The response surface methodology has been widely used for optimizing experiments (Bezerra et al., 2008; Yuan et al., 2008; Lenth, 2009; Raissi & Farsani, 2009; Silva & Garcia-Cruz, 2010; Lizotte et al., 2012.) as well as for evaluating and optimizing mixtures in various areas of knowledge (Souza & Menezes, 2008; Gomes et al., 2010; Silveira & Leite, 2010; Karaman et al., 2011; Costa et al., 2012). According to Dias (2006), experiments with mixture can be vastly applied in agriculture. However, despite all the importance of organic fertilization, methods based on mixture modeling to identify organic fertilizers to provide nutritional demands of castor bean plants are still very hard to find in literature.

Organic fertilization improves soil properties because aside from making nutrients available to the crops, it actuates in cation retention, complexation of toxic elements and micronutrients, water retention and aeration (Pires et al., 2008; Primo & Menezes, 2011). In relation to castor bean plant organic fertilization, materials such as castor bean presscake and hulls have being greatly used for presenting significant quantities of nutrients, such as phosphorus and nitrogen (Lima et al., 2011). However, the plants may present nutritional lack when the fertilizing components are not used in balanced proportions. The proportion of castor bean presscake and hull which results in the best development of the castor bean plants can be identified by means of mixture modeling. Therefore, this paper evaluates the proportion of organic materials (castor bean hull and presscake) with soil in order to evaluate the growth of castor bean plant, BRS Energia cultivar, by using experiments with mixture.

Material and Methods

The trial was conducted in a greenhouse belonging to the National Center of Cotton Research (Centro Nacional de Pesquisa de Algodão, CNPA/EMBRAPA), from February to June 2010, in the city of Campina Grande, Paraíba, Brazil, situated in the arid meso-region of Paraiba state, in the eastern portion of the steeper highlands of the Borborema Sierra. Aside from this, this region has a vastly hilly topographic relief, with hill levels varying between 500 m and 600 m above average sea level. The geographic coordinates are 7º 13' 50'' S latitude, 35º 52' 52' W longitude.

According to climate classification by Köppen, the climate of this region is AWi, which is characterized by rainy tropical climate (mega thermal), with a total average annual rainfall (P) around 750 mm, a monthly average air temperature (in all months) superior to 18ºC, and whose dry season happens from autumn into winter.

The trial was performed in plastic vases with a capacity of 20 L. As substrate, a grayish dystrophic ultisol with a sandy texture was used, collected in São José da Mata, municipality of Campina Grande, at a depth of 0-20 cm. The chemical attributes of this soil analysis are described in Table 1. Aside from soil, two organic materials were used: castor bean hull and presscake. The chemical composition of the two organic materials is presented in Table 2.

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Table 1. Chemical attributes of the soil utilized in the trial.

pH	P	k^+	Ca^{+2}	Mg^{+2}	Na^+	Al^+	H^++Al^{+3}	SB	CEC	V	MO
H_2O (1:25)	Md dm^{-3}	....			$cmol_c$ dm^{-3}		....			%	g kg^{-1}
5.46	1.79	0.08	0.25	0.25	0.04	0.55	2.48	0.57	3.06	18.95	2.99

Analyses performed at the Soil Chemistry and Fertility Laboratory at CCA/UFPB.

Table 2. Chemical composition of organic materials.

Substrate	N	P	K	Ca	Mg
	……………………………		%	....	
Castor bean hull	1.86	0.26	4.50	0.67	0.38
Castor bean presscake	7.54	3.11	0.66	0.75	0.51

Analyses performed by the Embrapa Algodão Soil Laboratory.

The Trial was conducted in a design of randomized blocks with five treatments, produced from mixtures obtained with four replications and one plant per portion.

The treatments were composed by mixtures of castor bean presscake (x_1) and castor bean hull (x_2), both varying from 0 to 10%, aside from the soil (x_3) varying from 80 to 100%, with the total sum always equal to 100% (condition to performing experiments with mixture).

$$x_1 + x_2 + x_3 = 1 \quad (1)$$

High doses of castor bean presscake can provoke phyto-toxicity due to the excess of nitrogen it contains (Lima et al., 2008b). The proportions of castor bean presscake and hull present restrictions of 10% ($x_1 \leq 0.1$ and $x_2 \leq 0.1$), resulting in:

$$0.8 \leq x_3 \leq 1.0 \quad (2)$$

The quantities of the materials used in the mixtures are found in Table 3.

Table 3. Combinations of mixtures composed by earth, castor bean presscake, and hull.

Treatments	Proportion of the mixture		
	(x_1)	(x_2)	(x_3)
		%	
T1	0.0	0.0	100.0
T2	5.0	5.0	90.0
T3	10.0	10.0	80.0
T4	10.0	0.0	90.0
T5	0.0	10.0	90.0

According to the methodology of experiments with mixtures, the experimental space (simplex region) of a ternary mixture is an equilateral triangle. However, due to the restrictions considered ($x_1 \leq 0.1$ and $x_2 \leq 0.1$), the simplex region was subdivided into a new region (simplex sub-region), in which the possible combinations of the mixture are found (Figure 1), as described by Silveira & Leite (2010). In this case, there are *extreme-vertices* designs for experiments with mixture.

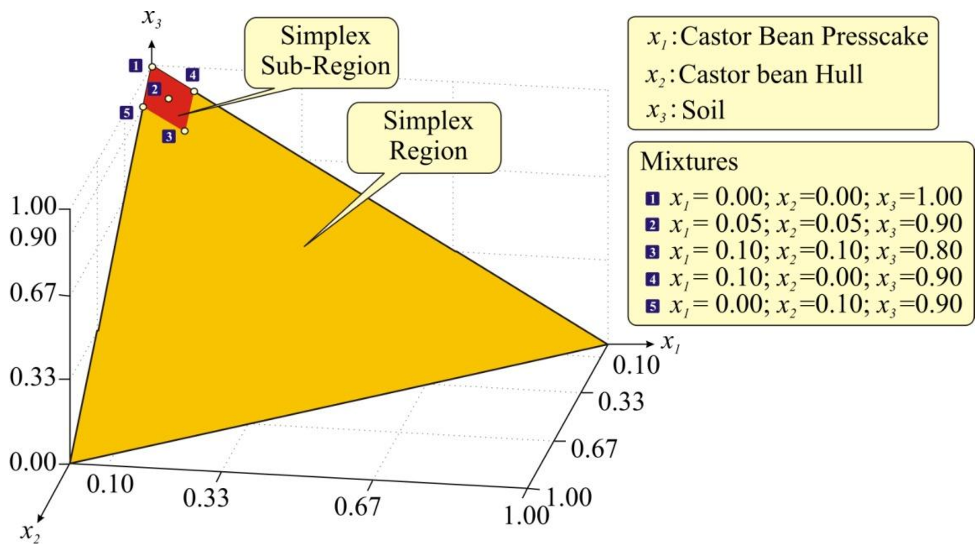

Figure 1. Simplex region and simplex sub-region with proportions of the components of the evaluated mixture.

The plants were irrigated daily with local running water and maintained free of weeds, diseases, and plagues. At 90 days after the emergence of the seedlings, the height and leaf area were evaluated. The leaf area was calculated by using $S = 0.2398 \text{ x } (L + P)^{1.9259}$, were L is the width of the leaf and P is the length of the midrib (Severino et al., 2004). After the collection of leaf eight and area data, the leaves, roots, and stems of the plants were collected for dry weight analysis. This plant material was put in paper bags and then dried in a forced circulation oven at 65^{o} C for 72 h, and later, weighed.

The total dry weight of the plant was obtained by adding the average weights of the dry weight of the leaves, weight of the dry weight of the stems and weight of the dry weight of the roots.

The final value of the height, leaf area, and total dry weight of the plants was obtained by calculating the average of the four replications of each treatment. These measurements were evaluated by means of mixture modeling in the MATLAB® computer system.

The results were submitted to variance analysis and the significance level was determined by the F test.

The adjustment model response used to identify the best mixture was linear, because this is the model that best suits experiments with up to five combinations of mixtures. The quadratic and cubic adjustment models, are better with experimental designs containing at least six and seven distinct mixture combinations, respectively (Hillig, 2003).

Linear adjustment was made considering the following expression:

$$y = \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3, \qquad (3)$$

where: β_1 β_2, and β_3 are constants to be obtained by regression analysis; y is the magnitude in study (height of the plant, leaf area, or total dry weight of the plant).

Results and Discussion

Variance analysis of the growth data was used to evaluate if the differences between the averages of the treatments are significant. Table 4 presents a summary of the variance analyses referring to height, leaf area, and total dry weight of the plants, respectively.

Based on Table 4, the height and total dry weight of the plants were significantly influenced by the organic fertilizer mixed with soil. However, there was not a significant effect of the organic fertilization for leaf area. The plants cultivated in soil without application of organic fertilizers presented greatly inferior leaf area compared to the other plants, which results in a lower rate of photosynthesis in the plant, which consequently affects the accumulation of biomass. Similarly, plants cultivated in soil mixed with only castor bean hull also presented a reduced leaf area.

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Table 4. Summary of variance analyses referring to plant height (cm), leaf area (cm^2), and total dry mass of the castor bean plant cv. BRS Energia, submitted to different proportions of soil, castor bean presscake and castor bean hull.

Source of variation	Degree of freedom	Mean Square		
		Height	leaf area	Total dry weight
Treatment	4	5672.4**	93582046.3^{ns}	9084.0**
Residue	15	284.9	57100811.4	1184.2

* significant at 5%,** significant at 1%, ^{ns} not significant by the F test.

The height, leaf area, and total dry weight data of the plants, collected during the trial, were evaluated by means of experiments with mixture. The values obtained for each one of these analyzed variables are summarized in Table 5.

According to the averages obtained for each treatment for the considered growth variables (Table 5), the plants from treatment T1 composed by soil had the lowest performance in all the evaluated growth variables. This possibly occurred due to the chemical attributes of the soil (Table 1). The soil utilized for cultivation of the castor bean plants contained low base saturation (V= 18.95%), considered dystrophic, presenting low indexes of several nutrients (Ca, Mg, K, and P), aside from an acidity considered average (pH=5.46), high saturation of aluminum, which causes serious limitations to the growth of the plants. The value of CEC reflects that this soil has a low capacity of retaining cations. It is formed by low activity clay, which indicates that the presented nutrients can be easily leachate.

Table 5. Growth variables obtained with the combinations of mixtures of soil, castor bean presscake and hull.

Treatments	Proportion of the mixture (%)			Height (cm)	leaf area (cm^2)	Dry weight (g plant^{-1})
	(x_1)	(x_2)	(x_3)			
T1(control treatment)	0.00	0.00	100.00	21.75	235.63	4.073
T2	5.00	5.00	90.00	101.50	3330.36	86.48
T3	10.00	10.00	80.00	118.25	12414.30	119.64
T4	10.00	0.00	90.00	102.25	4354.56	93.81
T5	0.00	10.00	90.00	86.00	827.69	31.57

With regard to the mixture design, Figure 2 (a) depicts a height curve due to the components of the mixture (x_1, x_2, and $x_3 = 1 - x_1 – x_2$), obtained by means of mixture modeling when considering all the treatments. According to Table 5, the plants of treatment T1 (control treatment) presented a much inferior height compared to the plants in the other treatments. Considering that the height regarding to the components of the mixture is obtained by means of linear adjustment model, the utilization of the control treatment results in considered distancing between the curve and the points where there is the greatest height value (coefficient of multiple determinations different from one).

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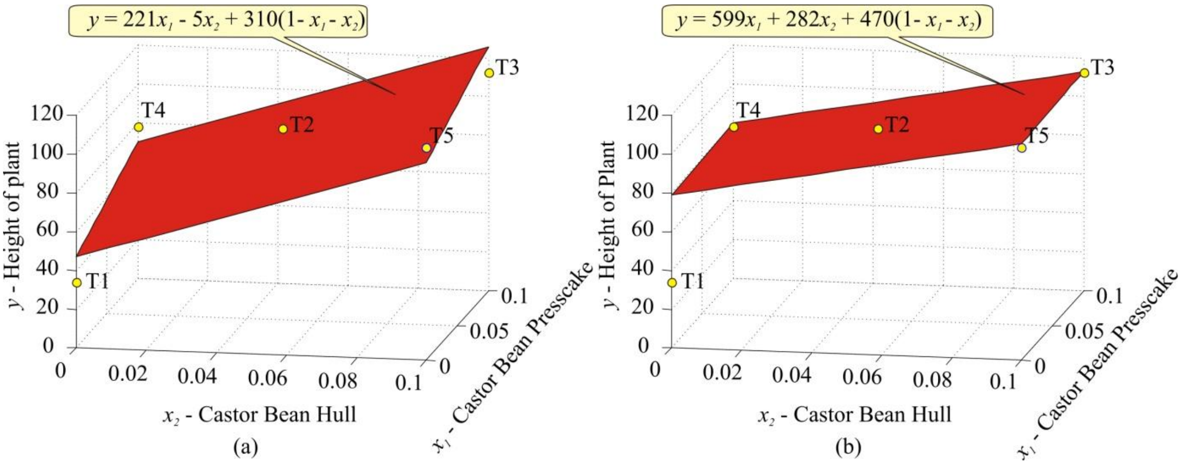

Figure 2. Plant height obtained by means of linear adjustment: (a) with treatment T1; (b) without treatment T1.

Considering that the maximum height value is obtained where there is castor bean hull and presscake in the mixture, treatment T1 was discarded for the regression analysis with the linear model. In this case, it was observed that the adjustment was more precise in the region in which the greater values of height are found (Figure 2 (b)).

The representation of the linear adjustment model of plant height y in relation to the quantity of castor bean presscake x_1, castor bean hull x_2, and soil x_3 is found in Figure 3. Plant height was obtained by means of regression analysis, with coefficient of multiple determination $R^2 = 0.79$. With the equation of plant height $y = 372x_1 + 210x_2 + 75x_3$ it was possible to identify the greatest height in the simplex sub-region. Therefore, it was possible to identify the best combination of the ingredients of the mixture. Some isolines whose height values intercepted the simplex sub-region, are also illustrated in figure 3. It is observed that y = 118.25 cm is the highest height found, which corresponds to the combination x_1 = 10%, x_2= 10%, and x_3 = 80%.

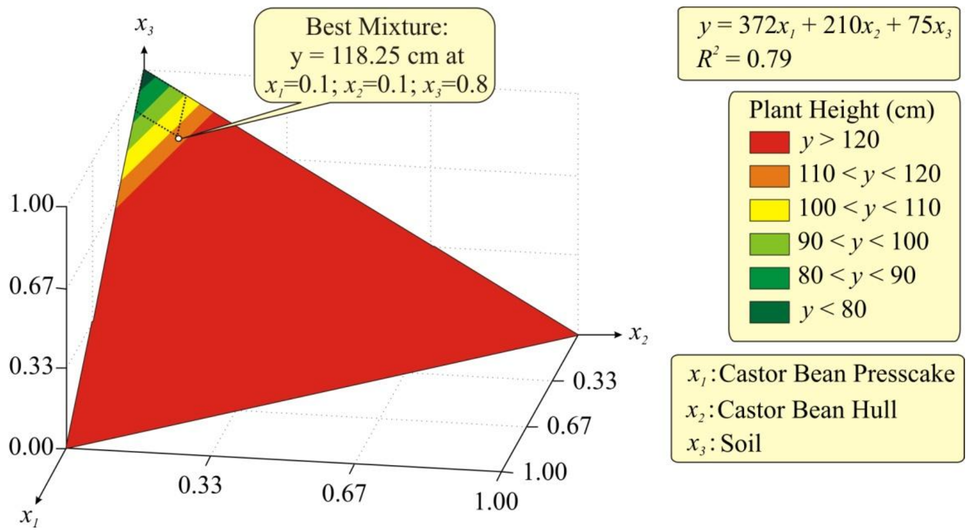

Figure 3. Simplex region containing the isolines for height that intercept the simplex sub-region, obtained by means of linear adjustment.

The equation obtained by the model of linear adjustment for plant leaf area is represented in Figure 4. The leaf area obtained with regression analysis presented the coefficient of multiple determination $R^2 = 0.99$. Figure 4 also illustrates the isolines whose values of leaf area intercept the simplex sub-region, where y = 12414.0 cm^2 is the highest value found for leaf area, which corresponds to the combination x_1 = 10%, x_2= 10%, and x_3 = 80%.

The equation obtained by the linear adjustment model for the total dry weight of plant y is represented in Figure 5. In this case, similar to the others, the best mixture was composed by x_1= 10% castor bean presscake, x_2 = 10% castor bean hull, and x_3 = 80% soil, in which the highest value obtained for the total dry weight of the mixture was y = 119.64 g/plant. The equation of the total dry weight of the plant obtained by means of regression analysis presented the coefficient of multiple determination R^2 = 0.73.

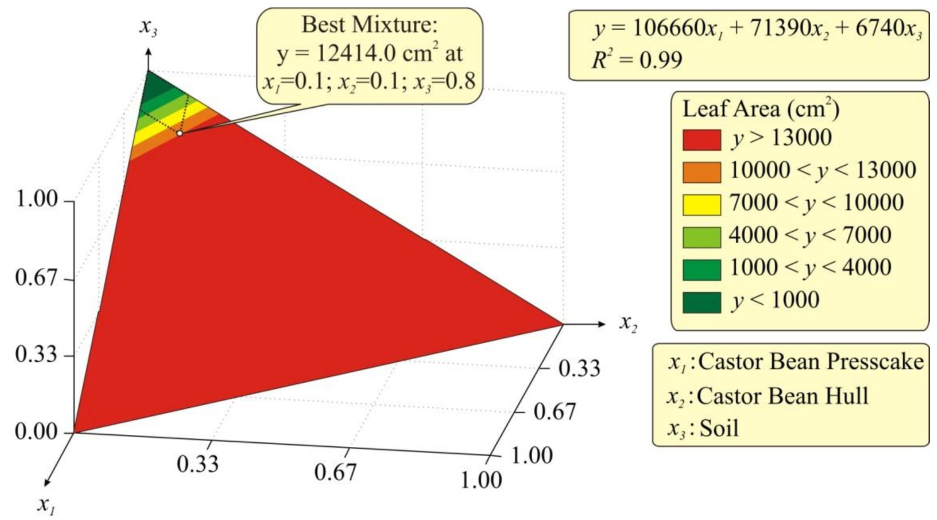

Figure 4. Simplex region containing the isolines of the leaf area that intercept the simplex sub-region, obtained by means of linear adjustment.

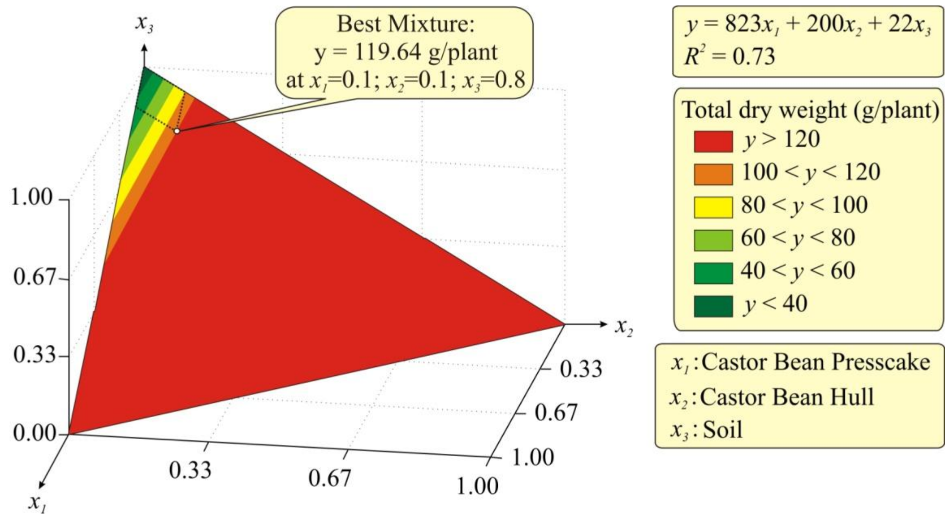

Figure 5. Simplex region containing the isolines of the total dry weight that intercept the simplex sub-region, obtained by means of linear adjustment for dry weight.

It was observed that soil mixtures with only one of the organic fertilizers, castor bean presscake or with castor bean hull, did not promote significant increase in the growth of the plants. This probably occurred due to the excess of nitrogen present in the castor bean presscake, which leads to phyto-toxicity of the plants and to the elevated relation C/N (carbon/nitrogen) of the castor bean hull, which induces the lack of nitrogen (Lima, et al., 2008a). However, it could be observed that the joint use of castor bean hull and castor bean presscake with soil promoted increase in the evaluated growth variables. These results are in accordance with results obtained by Guimarães et al. (2008), who state that the castor bean plant is responsive to fertilization. In addition, the organic fertilizer greatly improved soil structure allowing the plants to develop better in pots where there was organic matter.

According to the used mixture modeling, considering the used growth variables, the mixture that promoted increase in the growth of the plants was composed of 10% castor bean presscake, 10% castor bean hull, and 80% soil.

Conclusion

The adequate combination of the organic materials (castor bean hull and presscake) propitiates improvement in the soil, providing satisfactory amounts of nutrients to the plant growth. The methodology of mixture allowed the identification of the proportions of organic fertilizers which promoted better results in the growth of castor bean in pots, in which the best mixture for all tested growth variables (height, leaf area, dry weight) was 10% of both castor bean hull and presscake and 80% of soil. The maximum value of 10% of castor bean hull and presscake was taken into account to avoid phyto-toxicity.

The applicability of the mixture methodology can be extended to more complete studies, with other combinations of organic materials, to evaluate productivity of castor bean in the field.

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