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Jatropha curcas performance in intercropping with forages grass and grain crops species

João Alfredo Neto Da Silva[1], Cesar José Da Silva[2], Cristiano Márcio Alvez De Souza[1], Luiz Alberto Staut[2] and Ademar Pereira Serra[3*]

[1]Universidade Federal da Grande Dourados (UFGD), Post Graduation Program in Agronomy – Vegetable Production Department, City of Dourados, State of Mato Grosso do Sul, Brazil.
[2]Brazilian Agricultural Research Corporation (EMBRAPA Western Agriculture), City of Dourados, State of Mato Grosso do Sul, Brazil.
[3]Brazilian Agricultural Research Corporation (EMBRAPA Beef Cattle), City of Campo Grande, State of Mato Grosso do Sul, Brazil.

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The intercropping system has been accomplished with the objective to supply demand for foods through limited resources by smallholders conditions, associated with worries about improvement of land use efficiency. This study was carried out with the aim to assess the biometric and productive traits of *Jatropha curcas* in intercropping with species of forage grass and grain crops. The experiment was carried out in the district of Itahum, city of Dourados, state of Mato Grosso do Sul, Brazil. The treatments were *J. curcas* monocrop intercropping of *J. curcas* with *Stylosanthes* species, *Brachiaria ruziziensis*, *B. ruziziensis* + *Stylosanthes* spp., *Brachiaria humidicola*, *Panicum maximum* cv. Massai, *Cajanus cajan*, *Crotalaria spectabilis*, crop rotation system-1 (peanut/*Crambe abyssinica*/cowpea/maize), crop rotation system-2 (maize off-season/*C. abyssinica/soybean/peanut*) and crop rotation system-3 (cowpea/radish/maize/cowpea). The species in intercropping with *J. curcas* did not affect its biometric traits. *J. curcas* reaches higher seed yield in intercropping with crop rotation system-2 (maize off-season/*C. abyssinica*/soybean/peanut) and crop rotation system-3 (cowpea/radish/maize/cowpea) in comparison to the other species evaluated in intercropping. *J. curcas* seed yield is lower in intercropping with forage grass species.

Key words: Sustainability, cropping rotation, biodiesel, leguminous, oleaginous perennial.

INTRODUCTION

There are almost 200 species of oleaginous plants and Palmaceae with potential for biodiesel, as soybean, peanut, sunflower, sesame, turnip-fodder, castor oil, palm oil and *Jatropha curcas* (Ghosh, 2014). In this scenario,

*Corresponding author. E-mail: ademar.serra@embrapa.br.

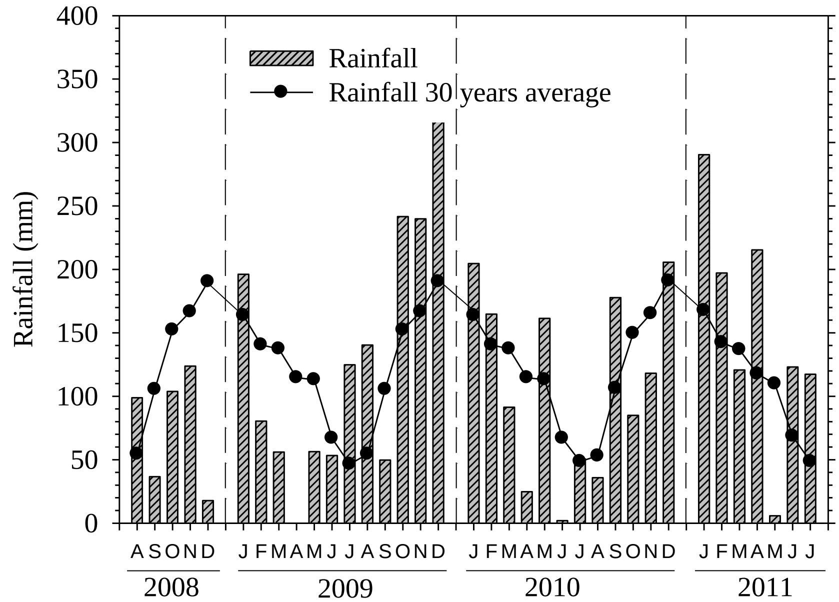

Figure 1. Monthly rainfall in 2008/2009, 2009/2010 and 2010/2011 growing seasons in comparison to the historical precipitation averages of 30 years. Source: Weather Station at Embrapa Western Agriculture Center, Dourados-MS, Brazil.

the challenge is to regionalize agricultural practices to be possible in the recommendation of adequate cropping system and adequate recommendation to improve cropping practice for these potential oil seed crops for biodiesel production.

J. curcas belongs to Euphorbiaceae family; this species shows large agricultural potential, highlight for seed yield, oil quantity and quality, aiming to biodiesel production (Tiwari et al., 2007; Castillo et al., 2014). The cultivation of *J. curcas* shows several advantages in relation to oil production: it is perennial, rustic, easy management, reaching 37.49% oil seed content, and high oil quality for biodiesel (Singh et al., 2016). *J. curcas* may be adequate for intercropping with other species because it is a shrubby plant and associated with wider space between rows the planting of other crops might be feasible (Silva et al., 2012).

The need to supply the demand for foods by means of scarce resources through smallholders is increasingly the adoption of intercropping systems for crop production (Machado, 2009). The intercropping has been used for many smallholders in Brazil, even more in relation to farmers who search higher land use efficiency and greater economic return (Veronesi et al., 2014), besides the generation of viable alternative to increase food offer. Nevertheless, seed yields obtained by stallholders in some locations in the world are limited because of feasible agricultural practice adopted (Liyama et al., 2013).

In relation to *J. curcas* production traits, oil yield depends on the vegetable features as number of branches, crown projection, plant height and crown volume, and production features; seed yield, seed weight, shell mass and seed oil content (Rao et al., 2008). The management adopted may result in negative or positive influence of crops in intercropping for production of the major crop; the positive effects may be related to improvement of soil chemical and physical properties, and negative ones might be due to possible water, light and nutrients competition (Tjeuw et al., 2015).

To improve positive interaction in intercropping, knowledge on the features of the crops associated is necessary, because without this information the farmers are going to commit many mistakes before achieving higher economic returns. This study was carried out with the aim to assess the biometric and productive features of *J. curcas* in intercropping with forage grass and grain crops species.

MATERIALS AND METHODS

Site description and soil

The experiment was carried out in the district of Itahum, city of Dourados, state of Mato Grosso do Sul, Brazil, at the coordinates 22°05'44" S and 55°18'48" W, enabled by a partnership between Brazilian Agricultural Research Corporation (Embrapa Western Agriculture) and Paraíso Farm. The soil is classified as Typic Haplortox (Santos et al., 2013), with average clay content of 200 g kg^{-1}. Long-term monthly rainfall averages, as well as actual rainfall recorded during the trial is presented in Figure 1.

J. curcas was sown in November 2006, on Paraíso Farm using a no-till system, by depositing three seeds per hill. After emerging, only the most vigorous seedling was left in each hill. Planting rows were spaced at 3 m and plants were spaced at 2 m within the row. In 2006/2007 and 2007/2008 growing seasons the usual

Table 1. Treatments of crop management systems in intercropping with *J. curcas* evaluated in the research.

Treatments	Abbreviation	Crop management system in intercropping with *J. curcas*
1	JM	*Jatropha curcas* in monocrop
2	IJS	Intercropping of *J. curcas* with *Stylosanthes* spp.
3	IJB	Intercropping of *J. curcas* with *U. ruziziensis* cv. Ruziziensis
4	IJBS	Intercropping of *J. curcas* with *U. ruziziensis* cv. Ruziziensis and *Stylosanthes* spp.
5	IJBH	Intercropping of *J. curcas* with *U. humidicola* cv. Humidicola
6	IJP	Intercropping of *J. curcas* with *Panicum maximum* cv. Massai
7	IJCC	Intercropping of *J. curcas* with *Cajanus cajan*
8	IJCS	Intercropping of *J. curcas* with *Crotalaria spectabilis*
9	IJCR-1	Intercropping of *J. curcas* with crop rotation system-1 (peanut/*Crambe abyssinica*/cowpea/maize)
10	IJCR-2	Intercropping of *J. curcas* with crop rotation system-2 (maize off-season/*Crambe abyssinica/soybean/peanut*)
11	IJCR-3	Intercropping of *J. curcas* with crop rotation system-3 (cowpea/radish/maize/cowpea)

management practices were applied to the field.

Experimental site and design

The treatments were installed in experimental plots comprised of four rows of *J. curcas* with six plants per row (144 m^2 per plot), the treatments are shown in Table 1. In order to evaluate plant height, crown diameter, stem diameter, and number of branches, the experimental was laid out in randomized complete block design with four repetitions, in a joint analysis in factorial scheme 11 × 2 (11 crop management system and two growing seasons). To assess 100-seeds weight, seed yield and seed oil content, factorial scheme 11 × 3 (11 crop management system and 3 growing seasons) was performed.

J. curcas fertilizer rate was applied annually with 32 kg N ha^{-1}, 80 kg P_2O_5 ha^{-1} and 80 kg K_2O ha^{-1}, through the formulation of 08-20-20 (400 kg ha^{-1}). The fertilizer was carried out manually close to the planting row. The fertilizer was divided in two applications for each growing season (2008/2009 and 2009/2010) (50% in October and 50% in January). In addition, 50 kg N ha^{-1} using urea as N source was applied in January 2009 and January 2010. Fertilizer rates recommendation followed the suggestion of Laviola and Dias (2008). The treatments with crop rotation (9, 10 and 11) were managed and fertilized according to recommendations for each crop. The remainder of the treatments did not receive any fertilizer rate. Intercropped forage grass and cover crops species were managed by mowing according to management height indicated by the research for each species. The resulted stubble was uniformly distributed on soil within the plot for mulching (Silva et al., 2012).

Variables assessed

In *J. curcas* trees, stem diameter was determined with the assistance of digital caliber in six plants in each experimental plot; this measurement was accomplished in plant collar. Plant height and crown diameter were determined with graduated ruler in six plants in each experimental plot that was measured from soil surface to the top branch of *J. curcas*. The crown diameter was measured transversely to the row, at the ends of the largest side branch of the plant. The number of branches from the most vigorous plants were determined by counting the vertical direction (from root to shoot) when the data were recorded and then filled in the final harvest of each growing season. In order to determine *J. curcas* seed yield, six plants in each experimental plot were harvest manually. Five harvesting time were conducted from December to July in each growing season (2008/2009, 2009/2010, and 2010/2011).

After harvesting, ripe and dried fruits in each experimental plot was stored in paper bags and naturally ventilated until constant weight. After the fruits dried, it was accomplished the threshing and weighted of the dried seed, and determined the seed yield and 100-seeds weight. The analysis of seed oil content in *J. curcas* grains were accomplished following the method of Soxhlet extraction, according to Lara et al. (1985).

Statistical analysis

The database were submitted to analysis of variance (ANOVA) and in case of significant difference ($p<0.05$) the means were compared by Tukey test of means with the assistance of the statistical software SISVAR.

RESULTS AND DISCUSSION

Biometric traits of *J. curcas* in intercropping system with forage grass and grain crops

The crop management systems evaluated in this study did not affect ($p>0.05$) biometric traits as plant height, crown diameter, stem diameter and number of branches of *J. curcas* on average of 2008/2009 and 2009/2010 growing seasons (Table 2). These results guide to an opportunity to integrate *J. curcas* in intercropping with grass and crops. Intraspecific and interspecific plant competition in intercropping is a challenge to be overcome to implement a profitable production system. The natural increment of plant height form 2008/2009 to 2009/2010 growing season was 19%, which was predictable since *J. curcas* reached its adult height in the fourth year after planting; this way in three years after planting the plants were in vegetable development. In the first growing season, *J. curcas* height did not differ among the crop managements evaluated, which may be due to the initial development of the grain crops and forage grass species

Table 2. Plant height (cm) of *Jatropha curcas* in intercropping with forage grass and seed crops.

Crop management system in intercropping with *J. curcas*	Growing season		
	2008/2009	2009/2010	Average of growing seasons
	Plant height (cm)		
J. curcas in monocrop	244.00^{Ab}	310.00^{ABa}	277.00^{A}
Stylosanthes spp.	259.25^{Ab}	306.00^{ABa}	282.63^{A}
B. ruziziensis	272.00^{Ab}	301.75^{ABa}	286.88^{A}
B. ruziziensis + *Stylosanthes* spp.	254.75^{Ab}	296.25^{Ba}	275.50^{A}
B. humidicola cv Humidicola	263.50^{Ab}	309.00^{ABa}	286.25^{A}
P. maximum cv. Massai	259.75^{Ab}	301.00^{ABa}	280.38^{A}
C. cajan cv. Anão	261.25^{Ab}	309.75^{ABa}	285.50^{A}
C. spectabilis	258.00^{Ab}	314.50^{ABa}	286.25^{A}
Crop rotation system-1	269.75^{Ab}	319.25^{Aa}	294.50^{A}
Crop rotation system-2	258.50^{Ab}	313.50^{ABa}	286.00^{A}
Crop rotation system-3	250.25^{Ab}	308.50^{ABa}	279.38^{A}
Average	259.18^{b}	308.14^{a}	-

Mean in each line followed by the low case letter compare growing seasons and mean in each column followed by capital letter compare the cropping management systems. Mean in each column or line followed by the same letter is not significantly different at p≤0.05 according to Tukey test of mean.

Table 3. Crown diameter (cm) of *Jatropha curcas* in intercropping with forage grass and seed crops.

Crop management system in intercropping with *J. curcas*	Growing season		
	2008/2009	2009/2010	Average of growing seasons
	Crown diameter (cm)		
J. curcas in monocrop	232.25^{Ab}	277.50^{Aa}	254.88^{A}
Stylosanthes spp.	234.50^{Ab}	262.75^{Aa}	248.63^{A}
B. ruziziensis	248.00^{Aa}	265.50^{Aa}	256.75^{A}
B. ruziziensis + *Stylosanthes* spp.	227.50^{Ab}	256.00^{Aa}	241.75^{A}
B. humidicola cv Humidicola	232.00^{Ab}	268.50^{Aa}	250.25^{A}
P. maximum cv. Massai	229.50^{Ab}	269.75^{Aa}	249.63^{A}
C. cajan cv. Anão	221.50^{Ab}	252.00^{Aa}	236.75^{A}
C. spectabilis	223.00^{Ab}	270.50^{Aa}	246.75^{A}
Crop rotation system-1	232.50^{Ab}	269.00^{Aa}	250.75^{A}
Crop rotation system-2	224.25^{Ab}	280.25^{Aa}	252.25^{A}
Crop rotation system-3	215.75^{Ab}	282.25^{Aa}	249.00^{A}
Average	229.16^{b}	268.55^{a}	-

Mean in each line followed by the low case letter compare growing seasons and mean in each column followed by capital letter compare the cropping management systems. Mean in each column or line followed by the same letter is not significantly different at p≤0.05 according to Tukey test of mean.

in intercropping with *J. curcas*. In 2009/2010, plant height in crop rotation system-1 differed from *Brachiaria ruziziensis* + *Stylosanthes* species, but in relation to the other treatments, no significant difference in plant height was observed (Table 2). The increase of *J. curcas* height indicated that these species evaluated in intercropping may not compete hardly for natural resources with *J. curcas* that can compromise its development in height. Nevertheless, interspecific competition in inter-cropping of *Jatropha* with crops has already been mentioned by Tjeuw et al. (2015), who found negative effects on *Jatropha* height due to moisture and nutrient competition with maize.

J. curcas intercropping system and monocrop did not affect the crown diameter of *J. curcas* on average of 2008/2009 and 2009/2010 growing seasons (Table 3). With exception of the intercropping of *J. curcas* with *B. ruziziensis* that remained without alterations, the other treatments showed higher crown diameter in the growing season 2009/2010 (Table 3).

Table 4. Stem diameter (mm) of *Jatropha curcas* in intercropping with forage grass and seed crops.

Crop management system in intercropping with *J. curcas*	Growing season		
	2008/2009	2009/2010	Average of growing seasons
	Stem diameter (mm)		
J. curcas in monocrop	105.04^{ABb}	132.77^{Aa}	118.90^{A}
Stylosanthes spp.	111.71^{ABb}	130.76^{Aa}	121.23^{A}
B. ruziziensis	102.79^{ABb}	123.92^{Aa}	113.35^{A}
B. ruziziensis + *Stylosanthes* spp.	107.63^{ABb}	118.09^{Aa}	112.86^{A}
B. humidicola cv Humidicola	107.84^{ABb}	126.52^{Aa}	117.18^{A}
P. maximum cv. Massai	105.18^{ABb}	123.13^{Aa}	114.15^{A}
C. cajan cv. Anão	106.00^{ABb}	126.28^{Aa}	116.14^{A}
C. spectabilis	115.92^{Ab}	131.15^{Aa}	123.53^{A}
Crop rotation system-1	111.42^{ABb}	127.88^{Aa}	119.65^{A}
Crop rotation system-2	97.54^{Bb}	128.59^{Aa}	113.07^{A}
Crop rotation system-3	105.13^{ABb}	124.95^{Aa}	115.04^{A}
Average	106.92^{b}	126.73^{a}	-

Mean in each line followed by the low case letter compare growing seasons and mean in each column followed by capital letter compare the cropping management systems. Mean in each column or line followed by the same letter is not significantly different at p≤0.05 according to Tukey test of mean.

It is possible to infer that the spread of roots in deeper layers for *J. curcas* avoids higher competition for natural resources from soil. As reported by Sánchez et al. (2003), the establishment of roots from grain crops or forage grass species in surface layers and the trees in deeper layers decrease the competition in soil for water and nutrients. The increasing in crown diameter from 2008/2009 to 2009/2010 growing season was 16%, which is quite important due to the energy that the plant needs for growth that comes from the photosynthesis, this way, size of the crown diameter is related to the capacity of assimilate carbon and turn into energy (Larcher, 2004). Thus, the size of crown diameter is associated with the photosynthesize capacity, which is expected that higher crown diameter in relation to higher assimilation of CO_2 may result in increasing grain yield for *J. curcas*.

The crop management system evaluated showed significant difference only in 2008/2009 growing season, which showed depletion of the crop rotation system-2 on the stem diameter in comparison to intercropping of *J. curcas* with *Chrysolopus spectabilis*, the other treatments remained without alteration on stem diameter (Table 4). Nevertheless, this negative effect on stem diameter promoted by crop rotation system-2 was not confirmed in the following growing season (Table 4). In 2009/2010 growing season was observed increment of 19% of stem diameter in comparison to preceding growing season. However no significant difference was observed among the crop management system on average of the two growing seasons (Table 4). Based on stem diameter average of the two growing seasons, these results did not confirm competition for intercropping *J. curcas* with forages grass or grain crops species evaluated in relation to stem diameter of *J. curcas*. The stem diameter is positively correlated to root development (Fakuta and Ojiekpon, 2009), thus, plants with higher stem diameter is expected to have better nutrition and higher tolerance to drought stress due to higher root volume to explore the soil for water and nutrients. The absence of significant difference of crop management system in stem diameter of *J. curcas* pointed out a possibility for further researches to investigate the root development of vegetable species integrated in the production system to assure the absence of root competition through time of plant growth.

Numbers of branches were higher in 2008/2009 growing season for the treatments; intercropping *J. curcas* with *Stylosanthes* spp., *B. ruziziensis*, *Brachiaria humidicola*, *Panicum maximum* cv. Massai, *Cajanus cajan* and crop rotation system-3 (Table 5). Nevertheless, in the following growing season (2009/2010), the crop management system did not affect number of branches (Table 5). The number of branches on average of two growing seasons was not affected by the crop management system evaluated (Table 5).

These results reassure that intercropping of *J. curcas* with forage grass and grain crop species do not affect the development of *J. curcas* plants. Number of branches is a variable correlated with production capacity of *J. curcas* to develop its breeding structure in new branches growing up in the currently growing season (Dehgan and Webster, 1979; Tjeuw et al., 2015), thus the fruit production depends on number of new branches. The increment in number of branches from 2008/2009 to 2009/2010 growing season was 20%, which increases the capacity of *J. curcas* production under monocrop or intercropping system.

Table 5. Number of *J. curcas* branches in intercropping with forage grass and seed crops.

Crop management system in intercropping with *J. curcas*	Growing season		
	2008/2009	2009/2010	Average of growing seasons
	Number of branches		
J. curcas in monocrop	5.46^{Aa}	6.38^{Aa}	5.92^{A}
Stylosanthes spp.	5.42^{Ab}	6.54^{Aa}	5.98^{A}
B. ruziziensis	4.88^{Ab}	6.13^{Aa}	5.50^{A}
B. ruziziensis + *Stylosanthes* spp.	4.63^{Aa}	5.25^{Aa}	4.94^{A}
B. humidicola cv Humidicola	5.13^{Ab}	6.17^{Aa}	5.65^{A}
P. maximum cv. Massai	5.42^{Ab}	6.54^{Aa}	5.98^{A}
C. cajan cv. Anão	4.71^{Ab}	6.17^{Aa}	5.44^{A}
C. spectabilis	5.21^{Aa}	6.00^{Aa}	5.60^{A}
Crop rotation system-1	5.29^{Aa}	6.19^{Aa}	5.74^{A}
Crop rotation system-2	5.16^{Aa}	6.04^{Aa}	5.60^{A}
Crop rotation system-3	4.92^{Ab}	6.17^{Aa}	5.54^{A}
Average	5.11^{b}	6.14^{a}	-

Mean in each line followed by the low case letter compare growing seasons and mean in each column followed by capital letter compare the cropping management systems. Mean in each column or line followed by the same letter is not significantly different at p≤0.05 according to Tukey test of mean.

Table 6. 100-seeds weight of *J. curcas* in intercropping with forage grass and seed crops species.

Crop management system in intercropping with *J. curcas*	Growing season			
	2008/2009	2009/2010	2010/2011	Average of growing seasons
	100-seeds weight (g)			
J. curcas in monocrop	74.40^{Aa}	69.56^{Aab}	66.16^{ABb}	70.04^{A}
Stylosanthes spp.	74.31^{Aa}	69.92^{Aab}	67.07^{ABb}	70.43^{A}
B. ruziziensis	75.60^{Aa}	66.14^{Ab}	63.30^{ABb}	68.35^{A}
B. ruziziensis + *Stylosanthes* spp.	72.99^{Aa}	66.54^{Ab}	62.19^{Bb}	67.24^{A}
B. humidicola cv Humidicola	75.42^{Aa}	65.34^{Ab}	64.48^{ABb}	68.41^{A}
P. maximum cv. Massai	72.96^{Aa}	64.50^{Ab}	65.80^{ABb}	67.75^{A}
C. cajan cv. Anão	73.78^{Aa}	67.81^{Ab}	69.07^{Aab}	70.22^{A}
C. spectabilis	70.30^{Aa}	66.92^{Aa}	69.26^{Aa}	68.83^{A}
Crop rotation system-1	70.61^{Aa}	71.31^{Aa}	67.52^{ABa}	69.81^{A}
Crop rotation system-2	71.08^{Aa}	69.91^{Aa}	65.86^{ABa}	68.35^{A}
Crop rotation system-3	74.52^{Aa}	68.39^{Ab}	68.41^{ABb}	70.44^{A}
Average	73.27^{a}	67.85^{b}	66.28^{b}	-

Mean in each line followed by the low case letter compare growing seasons and mean in each column followed by capital letter compare the cropping management systems. Mean in each column or line followed by the same letter is not significantly different at p≤0.05 according to Tukey test of mean.

Productive features of *J. curcas* in intercropping with forage grass and grain crops species

In 2008/2009 growing season, 100-seeds weight of *J. curcas* was 8% higher than the following growing seasons (Table 6). 100-seeds weight showed significant difference through the crop management system only in 2010/2011 growing season, resulting in low 100-seeds weight in intercropping of *J. curcas* with *B. ruziziensis* + *Stylosanthes* spp. in comparison to intercropping with *C. cajan* cv. Anão and *C. spectabilis*. Even with decreasing in 100-seeds weight in intercropping of *J. curcas* with *B. ruziziensis* + *Stylosanthes* spp., the effect of crop management system on 100-seeds weight was not significantly different (Table 6). The average values of 100-seeds weight found in each growing season were above the average found in literature, as the case of Silva et al. (2008), who showed 46.89 g for 100-seeds weight of *J. curcas,* and 25.80 g for 100-seeds weight (Veronesi et al., 2014). These differences obtained in the study in

Table 7. Seed yield (kg ha^{-1} year^{-1}) of *Jatropha curcas* in intercropping with forage grass and seed crops.

Crop management system in intercropping with *J. curcas*	Growing seasons			
	2008/2009	2009/2010	2010/2011	Average of growing seasons
	Seed yield (kg ha^{-1} year^{-1})			
J. curcas in monocrop	229.19^{Ab}	329.72^{Aab}	388.16^{ABCa}	315.69^{AB}
Stylosanthes spp.	196.45^{Ab}	340.20^{Aa}	175.31^{CDb}	237.32^{BC}
B. ruziziensis	195.92^{Aab}	251.61^{Aa}	128.78^{Db}	192.1^{C}
B. ruziziensis + *Stylosanthes* spp.	207.44^{Aab}	317.45^{Aa}	134.83^{Db}	219.91^{BC}
B. humidicola cv Humidicola	214.97^{Aab}	262.87^{Aa}	134.67^{Db}	204.17^{C}
P. maximum cv. Massai	172.62^{Aa}	254.49^{Aa}	158.05^{Da}	195.05^{C}
C. cajan cv. Anão	192.81^{Ab}	339.15^{Aa}	205.56^{CDb}	245.84^{ABC}
C. spectabilis	204.33^{Aa}	311.59^{Aa}	258.93^{BCDa}	258.28^{ABC}
Crop rotation system-1	196.10^{Ab}	321.60^{Aa}	281.68^{ABCDab}	266.4^{ABC}
Crop rotation system-2	156.41^{Ab}	369.79^{Aa}	485.92^{Aa}	337.37^{A}
Crop rotation system-3	187.76^{Ab}	299.71^{Ab}	435.76^{ABa}	307.74^{AB}
Average	195.82^{c}	308.92^{a}	253.42^{b}	-

Mean in each line followed by the low case letter compare growing seasons and mean in each column followed by capital letter compare the cropping management systems. Mean in each column or line followed by the same letter is not significantly different at p≤0.05 according to Tukey test of mean.

comparison to the other results in literature might be due to different weather conditions that may influence on water and nutrients available for *J. curcas*.

The forage grass and grain crop species in intercropping affected the grain yield of *J. curcas* (Table 7). The significant effect of the intercropping was observed just in the third growing season (2010/2011), these results might be attributed to the species in intercropping be older and more established in the soil, which can recycle the nutrients and change in chemical and biological soil properties. Through the three growing seasons evaluated, *J. curcas* seed yield decreases in grain yield due to the intercropping with *Stylosanthes* spp., *B. ruziziensis*, *B. ruziziensis* + *Stylosanthes* spp., *B. humidicola* and *C. cajan* (Table 7), the decreasing may be attributed to water, light and nutrients competition among.

On the other hand, intercropping with crop rotation system-2 and 3 were observed higher seed yield of *J. curcas* in 2010/2011 growing season in comparison to 2008/2009. In growing season 2010/2011, the same treatments referred above showed higher seed yield. In general, in the present study seed yield of *J. curcas* showed values above the results obtained in literature, as the yield of 192 kg ha^{-1} observed by Oliveira et al. (2012) and 83.87 kg ha^{-1} showed by Evangelista et al. (2011). However, the soil properties can affect the seed yield of *J. curcas* (Openshaw, 2000), which can result in high diversity of seed yield in different regions. These observations on terms of seed yield might be an indicative that this intercropping with forage grass and seed crops species show great potential to be insert in intercropping system of *J. curcas* production.

The seed oil content in *J. curcas* was affected by the intercropping in all growing seasons. In 2008/2009 growing season, the seed oil content extracted from *J. curcas* monocrop and crop rotation system-3 showed lower seed oil content, while intercropping with *B. ruziziensis* showed higher oil content, in comparison to *J. curcas* monocrop, intercropping with *Stylosanthes* spp., *B. ruziziensis* + *Stylosanthes* spp., crop rotation system-1 and 2 (Table 8). In 2009/2010 growing season, the treatment of *J. curcas* intercropping with *B. ruziziensis* and *B. humidicola* showed higher seed oil content differing from the other treatments (Table 8). The average seed oil content were 33.24%, 34.84% and 29.37% in 2008/2009, 2009/2010 and 2010/2011 growing seasons, respectively. These averages are in accordance to Singh et al. (2016), who found 27.68% to 37.49% of crude seed oil content in *J. curcas*. On average of the three growing seasons, *J. curcas* monocrop and in crop rotation system-2 and 3 promoted lower seed oil content among the treatments evaluated.

Conclusions

The species in intercropping with *J. curcas* did not affect its vegetable development. *J. curcas* reach higher seed yield in intercropping with crop rotation system-2 (maize off-season/*Crambe abyssinica*/soybean/peanut) and crop rotation system-3 (cowpea/radish/maize/cowpea) in comparison to the other species evaluated in intercropping. The *J. curcas* seed yield is lower in intercropping with forage grass species due to interspecific competition.

The leguminosae *Cajanus cajan* cv. Anão and *Crotalaria spectabilis* showed intermediary result in terms of seed yield, which was attribute to lower interspecific competition with *J. curcas* and maybe biologic nitrogen fixation available for *J. curcas*.

Table 8. Seed oil content of *Jatropha curcas* in intercropping with forage grass and seed crops species.

Crop management system in intercropping with *J. curcas*	Growing seasons			
	2008/2009	2009/2010	2010/2011	Average of growing seasons
	Oil content (%)			
J. curcas in monocrop (control)	27.19^{Bb}	31.74G^{a}	27.03^{EFa}	28.65^{F}
Stylosanthes spp.	32.85^{ABa}	34.19^{CDEFa}	27.01^{EFb}	31.35^{CDE}
B. ruziziensis	38.42^{Aa}	37.36^{Aa}	32.35^{Bb}	36.04^{A}
B. ruziziensis + *Stylosanthes* spp.	33.02^{ABa}	33.71^{EFa}	31.59^{BCa}	32.77^{BCD}
B. humidicola cv Humidicola	34.83^{Aa}	37.72^{Aa}	28.81^{CDEb}	33.79^{ABC}
P. maximum cv. Massai	33.59^{ABa}	35.19^{BCDa}	35.77^{Aa}	34.85^{AB}
C. cajan cv. Anão	37.03^{Aa}	33.24^{Fb}	30.95^{BCDb}	33.74^{ABC}
C. spectabilis	34.64^{Aa}	35.44^{BCa}	28.01^{DEFb}	32.70^{BCD}
Crop rotation system-1	34.46^{Aa}	35.72^{Ba}	28.91^{CDEb}	33.03^{BC}
Crop rotation system-2	32.31^{ABa}	34.04^{DEFa}	25.16^{Fb}	30.50^{DEF}
Crop rotation system-3	27.28^{Bb}	34.73^{BCDEa}	27.51^{EFb}	29.84^{EF}
Average	33.24 b	34.83 a	29.37 c	-

Mean in each line followed by the low case letter compare growing seasons and mean in each column followed by capital letter compare the cropping management systems. Mean in each column or line followed by the same letter is not significantly different at $p \leq 0.05$ according to Tukey test of mean.

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Conflict of interests

The authors have not declared any conflict of interests.

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