SCIENTIFIC NOTE

Effect of the use of pre- and post-emergence herbicides on nodulation and production of cowpea (*Vigna unguiculata* L.) in the Amazonian savannah

Efecto del uso de herbicidas pre- y post-emergentes en la nodulación y productividad del frijol caupí (*Vigna unguiculata* L.) en la sabana amazónica

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ABSTRACT

As a control measure against weeds, the use of herbicides is an effective and inexpensive alternative. However, there are no products recommended for the cultivation of cowpea in Brazil, making it necessary to search for alternative solutions. The objective of this study was to evaluate the effect of herbicides applied in the pre- and post-emergence on cowpea nodulation and production under conditions of the Amazonian savannah. Two experiments were carried out in a randomized block design with four replicates, using the cowpea cultivar BRS Aracê subjected to the pre-emergence herbicides: Metribuzin, Sulfentrazone, S-metolachlor, Pendimethalin, Oxadiazon, Alachlor, Metribuzin + Pendimethalin, Metribuzin + Alachlor and Quizalofop-p-ethyl, Bentazon, Fomesafen, Imazethapyr, Imazamox + Bentazon, Quizalofop-p-ethyl + Imazethapyr, Quizalofop-p-ethyl + Imazamox and Quizalofop-p-ethyl + Bentazon, and post-emergence herbicides: Quizalofop-p-ethyl, Bentazon, Fomesafen, Imazethapyr, Imazamox + Bentazon, Quizalofop-p-ethyl + Imazethapyr, Quizalofop-p-ethyl + Imazamox, and Quizalofop-p-ethyl + Bentazon. The number of nodules in each plant, the dry matter of nodules, dry matter of roots and the grain yield were evaluated. According to the results obtained, the management of weeds in pre- or post-emergence according to the herbicide used affects the nodulation and productivity of cowpea under the conditions of the Amazonian savannah. The herbicides Metribuzin in pre-emergence, and Fomesafen and the mixture of Quizalofop-p-ethyl + Imazethapyr in post-emergence are not recommended for weed control in cowpea. The application of Oxadiazon, Alachlor, and Pendimethalin in pre-emergence can be considered interesting because they do not inhibit the development of the root system or the nodulation of cowpea which provides a greater grain yield. Regarding weed control strategies at post-emergence, the application of the herbicide Imazethapyr and the combination of the herbicides quizalofop-p-ethyl + imazamox, Quizalofop-p-ethyl + Bentazon and Imazamox + Bentazon allow satisfactory levels of grain yield, root system development and nodulation of cowpea.

Key words: chemical control, nitrogen fixation, weeds.

RESUMEN

Como medida de control contra las malezas, el uso de herbicidas es una alternativa efectiva y asequible. Sin embargo, no hay productos recomendados para el cultivo de frijol caupí en Brasil, por lo que es necesario buscar soluciones alternativas. El objetivo de este estudio fue evaluar el efecto de herbicidas aplicados en pre- y post-emergencia sobre la nodulación y productividad del frijol caupí bajo las condiciones de la sabana amazónica. Se realizaron dos experimentos en bloques al azar con cuatro repeticiones, utilizando el cultivar de frijol caupí BRS Aracê sometido a los herbicidas pre-emergentes: Metribuzina, Sulfentrazona, S-metolaclor, Pendimetalina, Oxadiazón, Alaclor, Metribuzina + Pendimetalina, Metribuzina + Alaclor y Quizalofop-p-etil, Bentazona, Fomesafen, Imazetapir, Imazamox + Bentazona, Quizalofop-p-etil + Imazetapir, Quizalofop-p-etil + Imazamox y Quizalofop-p-etil + Bentazona, y herbicidas post-emergentes: Quizalofop-p-etil, Bentazona, Fomesafen, Imazetapir, Imazamox + Bentazona, Quizalofop-p-etil + Imazetapir, Quizalofop-p-etil + Imazamox, Quizalofop-p-etil + Bentazona. Se evaluaron el número de nódulos por planta, la masa seca de nódulos, la masa seca de raíces y el rendimiento de grano. Según los resultados obtenidos en este estudio, el manejo de malezas en pre o post-emergencia de acuerdo con el herbicida utilizado afecta la nodulación y el rendimiento de grano de frijol caupí bajo condiciones de la sabana amazónica. Los herbicidas Metribuzina en pre-emergencia, y Fomesafen y la mezcla de Quizalofop-p-etil + Imazetapir en post-emergencia no se recomiendan para el control de malezas en frijol caupí. La aplicación de Oxadiazón, Alaclor y Pendimetalina en la pre-emergencia puede considerarse interesante porque no inhiben el desarrollo del sistema radicular o la nodulación de frijol caupí lo que proporciona un mayor rendimiento de grano. En lo relacionado con las estrategias de control de malezas posteriores a la emergencia, la aplicación del herbicida Imazetapir y la combinación de los herbicidas Quizalofop-p-etil + Imazamox, Quizalofop-p-etil + Bentazona e Imazamox + Bentazona permiten niveles satisfactorios de rendimiento de grano, desarrollo del sistema de raíces y nodulación de frijol caupí.

Palabras clave: control químico, fijación de nitrógeno, malezas.

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Introduction

Cowpea (*Vigna unguiculata* L. Walp.; Fabaceae) is a widely adapted legume tolerant to water stress (Yadav *et al*., 2017; Oparaeke *et al*., 2018). Because of this, this crop has become very important socioeconomically and is widely cultivated in the northern, northeastern and mid-western regions of Brazil (Dias *et al*., 2019).

Historically, in Brazil, cowpea has been cultivated in areas of insufficient and poorly distributed rainfall and low fertility soils. It is mainly cultivated by small producers using low technology such as manual harvesting, low quality seeds, and inefficient control of pests, diseases and weeds (Costa *et al*., 2017). Because of this, average crop productivity in Brazil is between 300 and 400 kg ha^{-1}, considered low compared to its productive potential of at least 1000 kg ha^{-1} when grown with advanced technologies (Mancuso *et al*., 2016).

One of the main problems faced by producers in the northern parts of Brazil is weed interference (Costa *et al*., 2017). Since sowing is carried out using wider spacing, crops show slow initial growth, allowing weeds to compete directly with cowpea for space, water, light and nutrients (Lamego *et al*., 2011; Linhares *et al*., 2014), and consequently, reduce the crop yield by more than 66% (Gonzaga *et al*., 2018).

Although manual weed removal is a proven effective method of weed control, labor unavailability and its very high cost limit its use. Thus, integrated weed management could be a better approach for reducing yield losses in cowpea because of weeds (Gupta *et al*., 2016). Chemical weed control (i.e. use of herbicides) has proven to be the most practical, effective and economical way to control accessible or inaccessible plants or harmful weeds (Yadav *et al*., 2017). There are no registered herbicides for cowpea in Brazil, which prevents recommendations; however, 27 and 55 herbicides are registered for crops belonging to the same botanical family (Fabaceae) such as the common bean (*Phaseolus vulgaris* L.) and soybean (*Glycine max* L.), respectively (Gonzaga *et al*., 2018).

Herbicides are products that interfere in the biochemical and physiological processes of weeds and can kill or significantly retard their growth (Fontes *et al*., 2010; Monteiro *et al*., 2012). However, their effects on soil microorganisms, especially nitrifying bacteria, can be adverse due to the large number of environmental factors involved in this process, which can be harmful, beneficial or null (Reis *et al*., 2010). Diseases usually occur due to nitrifying microorganisms that share biosynthetic routes similar to those of the host plant (Santos *et al*., 2006).

The action of herbicides on microorganisms can occur mainly by the indirect absorption of endosymbionts in plants treated with these substances. Absorption via soil solution is less expressive, since the inactivation of some molecules in this environment is fast (Reis *et al*., 2010). However, the main mechanism for dissipating herbicides in the soil is through microbial degradation. Procópio *et al*. (2015) report that herbicides can affect the formation and growth of root hairs and this affects the process of infection by nitrifying bacteria.

The mechanisms of dissipation, persistence and transformation of herbicides in the environment and in the plant are complex and deserve special attention since they affect directly and indirectly the nodulation of plants of the family Fabaceae. Thus, knowledge about the tolerance of bacteria to herbicides and the effects of these substances on cowpea nodulation should be studied to support the use of efficient weed control techniques in this crop (Fontes *et al*., 2010; Rodrigues and Almeida, 2017).

Therefore, the objective of this study was to evaluate the effect of herbicides applied in the pre- and post-emergence on cowpea nodulation and production under the conditions of the Amazonian savannah.

Materials and methods

Two experiments were carried out at the Agricultural Sciences Center of the Federal University of Roraima, Cauame Campus, Boa Vista, Roraima, Brazil (2°52'15.49" N, 60°42'39.89" W, and 85 m a.s.l., with annual mean precipitation of 1678 mm). One of the experiments used pre-emergence herbicides and the other used post-emergence herbicides.

The soil of the experimental area was classified as Yellow Udox Soil (EMBRAPA, 2018), clayey texture, with the following physical and chemical attributes (depth 0 to 0.2 m): pH (H_2O) = 5.4; Ca^{2+} = 0.50 cmol$_c$ dm^{-3}; Mg^{2+} = 0.3 cmol$_c$ dm^{-3}; K^+ = 0.02 cmol$_c$ dm^{-3}; Al^{3+} = 0.8 cmol$_c$ dm^{-3}; (H + Al) = 2.62 cmol$_c$ dm^{-3}; P_2O_5 = 30 mg dm^{-3}; sum of bases (SB) = 0.40 cmol$_c$ dm^{-3}; base saturation (V) = 14%; clay = 185 g kg^{-1} (18.5%); silt = 50 g kg^{-1} (5.0%), and sand = 765 g kg^{-1} (76.5%). Based on the interpretation of the chemical analysis, the soil was amended using 1,500 kg ha^{-1} of limestone, 50 kg ha^{-1} of FTE BR 12 (Nutriplant®, Barueri, Brazil), 90 kg ha^{-1} of P_2O_5 in the form of simple superphosphate and 60 kg ha^{-1} of K_2O in the form of potassium chloride.

The experiment was carried out in a randomized design with four replicates. The treatments consisted of ten weed control strategies, with the application of eight pre-emergence herbicides or eight post-emergence herbicides on cowpea, in addition to the plots with and without weed control (Tab. 1). Each experimental plot consisted of six rows of 5 m of length, spaced 0.5 m apart, in which the ten central rows were considered as the useful area.

The cowpea cultivar used in the experiments was BRS Aracê, indicated for cultivation in the State of Roraima. It shows a semi-pruned growth, with an average yield of 1,246 kg ha^{-1}. A mechanized planter was used for sowing in a no-tillage system, adjusting the planting density to 10 bean seeds per linear meter. Before seeding, the seeds were inoculated with 500 g of inoculum for 50 kg of seeds moistened with a sugar solution (10%), with a minimum concentration of 108 cells g^{-1} of *Bradyrhizobium* BR 3262, a strain recommended for the State of Roraima by Zilli *et al.* (2006).

The pre-emergence herbicides were applied one day after planting and the post-emergence herbicides were applied 14 d after sowing when the cowpea plants had formed the third clover and the dicotyledon weeds had three to five pairs of leaves. Applications were performed using two Turbo TeeJet® (TT) 110.02 nozzles spaced 0.5 m with a pressure of 2 bars and a syringe volume of 170 L ha^{-1}. Both herbicides were applied in the evening, between 17:00 and 18:00 h, due to the lower temperature and higher humidity of the air and soil at that time. Weeding was performed in the weed-free plots, while the control plots with weeds (weedy check) were maintained in cohabitation with weeds throughout the cycle.

TABLE 1. Herbicides used in pre-emergence as a strategy to control weeds in cowpea, their modes of action, and the crops for which they are registered (MAPA, 2019).

	Mode of action	Crop	Dose (g ha^{-1} a.i.)
	Pre-emergence herbicides		
Metribuzin (M)	Inhibition of photosynthesis - photosystem II	Soybean	360
Sulfentrazone (S)	Cell membrane disruption - protoporphyrinogen oxidase (PPO) inhibitor	Soybean	600
S-metolachlor (S-m)	Inhibition of very-long-chain fatty acid (VLCFA) (inhibition of cell division)	Soybean, common bean	1200
Pendimethalin (P)	Inhibition of mitosis and cell division, inhibition of microtubule assembly	Soybean	750
Oxadiazon (O)	Inhibition of protoporphyrinogen oxidase (PPO), leading to irreversible cell membrane damage	-	1000
Alachlor (A)	Inhibition of very-long-chain fatty acid (VLCFA) (inhibition of cell division)	Soybean, peanut	2400
Metribuzin + Pendimethalin (M + P)	Inhibition of Photosystem II + Microtubule assembly	Soybean	360 + 750
Metribuzin + Alachlor (M + A)	Inhibition of Photosystem II + Inhibition of very-long-chain fatty acid (VLCFA)	Soybean	360 + 2400
	Post-emergence herbicides		
Quizalofop-p-ethyl (Q)	Inhibition of acetyl CoA carboxylase (ACCase)	Soybean, common bean, peanut	100
Bentazon (B)	Inhibition of photosynthesis (photosystem II)	Soybean, common bean, peanut	720
Fomesafen (F)	Protoporphyrinogen oxidase (PPO) inhibitor	Soybean, common bean	225
Imazethapyr (Ir)	Inhibition of acetolactate synthase (ALS), acetohydroxyacid synthase (AHAS)	Soybean, common bean	100
Imazamox + Bentazon (Ix + B)	Inhibition of acetolactate synthase (ALS), acetohydroxyacid synthase (AHAS) + inhibition of photosynthesis (photosystem II)	Soybean, common bean, peanut	50
Quizalofop-p-ethyl + Imazethapyr (Q+Ir)	Inhibition of acetyl CoA carboxylase (ACCase) + inhibition of acetolactate synthase (ALS) (acetohydroxyacid synthase (AHAS))	Soybean, common bean, peanut	100 + 100
Quizalofop-p-ethyl + Imazamox (Q+Ix)	Inhibition of acetyl CoA carboxylase (ACCase) + inhibition of acetolactate synthase (ALS) (acetohydroxyacid synthase (AHAS))	Soybean, common bean, peanut	100 + 168
Quizalofop-p-ethyl + Bentazon (Q+B)	Inhibition of acetyl CoA carboxylase (ACCase) + inhibition of photosynthesis (photosystem II)	Soybean, common bean, peanut	100 + 720
	Non herbicide treatments		
Weed-free (manual weeding)	-	-	-
Weedy check	-	-	-

The evaluation of the effect of herbicides on nodulation was performed 30 d after planting (DAP). At the time, the plants were harvested with the roots using a straight blade and then the roots were washed using a stream of water. After that, the roots were separated from the shoot by a cut at the base of the stem; the nodules were removed and counted to determine the number of nodules. The nodules and roots were dried in a forced air circulation oven (TE-394/5-MP, Tecnal®, Piracicaba, Brazil) for 72 h at 65°C until reaching a constant mass for the determination of the dry matter of nodules and roots.

To estimate grain yield, the pods were harvested and threshed manually according to maturity; then, the dry matter of the beans was weighed to determine the yield, expressing the values in kg ha^{-1}.

The results were subjected to the Shapiro-Wilk normality test; the visual control evaluation data were arcsine square root-transformed and presented with mean separation based on transformed values. The data were subjected to an ANOVA and when the variances were significant, the averages were compared by the Tukey's test at $P \leq 0.05$. The Pearson correlation matrix was also applied using the R software (R Development Core Team, 2018).

Results and discussion

The use of pre-emergence and post-emergence herbicides in the cowpea crop significantly interferes with the characteristics evaluated in this research.

In the case of pre-emergence herbicides, we observed a higher mean number of nodules in the weed-free and weedy check treatments, and with alachlor, pendimethalin and oxadiazon application which did not differ statistically from each other (Tab. 2). All the plants died in the metribuzin treated plots and, therefore, did not show a number and dry matter of nodules, dry matter of roots or yield (Tab. 2). According to Souza Cruz *et al.* (2018), metribuzin and

TABLE 2. Mean values of number of nodules (Nn) per plant, dry matter of nodules (DMn), dry matter of roots (DMr) and grain yield (Y) in response to the application of pre- and post-emergence herbicides in cowpea plants with weed-free and weedy check treatments.

Pre-emergence herbicides	Nn	DMn (g)	DMr (g)	Y (kg ha^{-1})
Metribuzin	0.00 d	0.00 f	0.00 f	0.0 d
Sulfentrazone	128.75 c	0.53 e	6.76 cde	617.0 c
S-metolachlor	234.50 b	1.53 cd	5.79 e	1,315.0 b
Pendimethalin	351.50 a	2.32 b	8.68 ab	1,437.0 b
Oxadiazon	336.50 a	1.71 c	7.91 bc	1,669.0 a
Alachlor	360.50 a	2.44 ab	7.85 bcd	1,377.0 b
Metribuzin + Pendimethalin	266.75 b	0.47 e	6.35 e	396.0 c
Metribuzin + Alachlor	262.25 b	1.63 c	5.89 e	560.0 c
Weed-free	366.00 a	2.72 a	9.36 a	1,682.0 a
Weedy check	364.50 a	1.16 d	6.60 de	566.0 c
VC (%)	8.01	11.03	7.98	21.93
Post-emergence herbicides	Nn	DMn (g)	DMr (g)	Y (kg ha^{-1})
Quizalofop-p-ethyl	339.25 ab	1.60 bcd	7.18 bc	1,405.0 b
Bentazon	347.00 ab	1.97 b	5.96 c	1,139.0 cd
Fomesafen	323.00 ab	1.32 d	6.39 c	1,001.0 cde
Imazethapyr	159.25 c	1.91 bc	11.78 a	1,256.0 bc
Imazamox + Bentazon	364.75 ab	1.74 bcd	11.76 a	1,210.0 bcd
Quizalofop-p-ethyl + Imazethapyr	192.75 c	1.71 bcd	7.15 bc	949.0 de
Quizalofop-p-ethyl + Imazamox	315.25 b	1.93 b	6.63 c	1,453.0 ab
Quizalofop-p-ethyl + Bentazon	199.25 c	1.46 cd	11.29 a	1,404.0 b
Weed-free	375.50 a	2.60 a	8.33 b	1,711.0 a
Weedy check	366.50 ab	2.05 b	6.54 c	916.0 e
VC%	7.91	10.39	7.11	17.10

(VC%) = variation coefficient; means followed by the same letter in the column do not differ from each other according to the Tukey test at 5% probability ($P \leq 0.05$).

all its mixtures are not recommended as pre-emergence weed control strategies in cowpea because they are not selective to this crop. However, Costa *et al*. (2017) report that metribuzin and sulfentrazone are promising for cowpea selectivity; such disagreements may be related to the cowpea cultivars used in the cited works and their differential behavior in relation to the herbicide molecule.

As for the effect of post-emergence herbicides, we also observed the highest number of nodules in the weed-free and weedy check treatments, but these treatments did not differ from the plots with the application of imazamox + bentazon, bentazon, quizalofop-p-ethyl and fomesafen. These results corroborate the studies of Santos *et al*. (2006) in which no harmful effects on nodulation were observed after the application of the herbicides bentazon (14.19 mg L^{-1}), imazamox (0.69 mg L^{-1}) and fomesafen (4.92 mg L^{-1}). Monteiro *et al*. (2012), when evaluating the effect of bentazon on the number of nodules, observed that the herbicide shows low phytotoxicity to cowpea and has little influence on the nodulation of the crop. However, these authors observed a decrease in the number of nodules by the application of the herbicide fomesafen, which was not observed in our study. The lowest numbers of nodules were observed in the plots treated with the herbicides sulfentrazone and metribuzin.

The application of metribuzin resulted in the death of all the plants of the plot, as observed by Fernandes *et al*. (2012) in common bean at the dose of 1440 g ha^{-1}. The effect of the use of the herbicide metribuzin mixed with the herbicides pendimethalin and alachlor was also harmful to cowpea. Herbicide mixtures are common in crops; however, few farmers are aware of the negative effects of this management on microorganisms, especially in cowpea.

Table 2 shows that the weed-free treatment, and alachlor and pendimethalin applied in pre-emergence showed the highest mean dry matter of nodules. Opposite results were obtained with the application of sulfentrazone and metribuzin + pendimethalin that negatively affected nodulation in cowpea. Nodule dry matter was significantly impaired by both weed coexistence and the use of any herbicide in the post-emergence period, since the weed-free treatment was better than all the other treatments.

The highest mean dry matter of roots was verified in the weed-free treatment compared to the pre-emergence herbicides and weedy check treatments. On the other hand, the plots treated with imazethapyr, imazamox + bentazon and quizalofop-p-ethyl + bentazon in post-emergence showed mean dry matter of roots larger than in the weed-free treatment (Tab. 2). This indicates that pre-emergence herbicides possibly caused antagonistic effects, leading to root death. However, the use of herbicides in post-emergence may even inhibit the healthy development of roots, causing them to thicken and to increase their dry mass. However, low yield was still observed due to the decrease of nutrient absorption by root hairs.

The most damaging effects for the dry mass of nodules and roots in post-emergence herbicide applications were verified for fomesafen and bentazon, respectively. Monteiro *et al*. (2012) evaluated the effect of bentazon on dry mass of roots and nodules and observed that the herbicide showed low phytotoxicity to cowpea and had little influence on nodulation and biomass of the crop, while the herbicide fomesafen caused significant loss of dry matter of nodules, corroborating the results in our study.

The highest grain yields were obtained with the application of the herbicide oxadiazon in pre-emergence and with the post-emergence mixture of quizalofop-p-ethyl + imazamox. However, neither treatment differed from the weed-free treatment (Tab. 2). Similar yield results were obtained by Simplício *et al*. (2016), but the results in this study were significantly higher than in all herbicide-free weeds.

The results for grain yield showed that all treatments were satisfactory when compared to the coexistence of the crop with the weeds that significantly reduced productivity. Similar results were obtained by Gonzaga *et al*. (2018), who observed a 67% reduction productivity in cowpea yield with weeds present. According to Lamego *et al*. (2011), the low yield in some treatments can be explained by the phytotoxicity exhibited by the crop, which reduces growth and causes the death of some plants, affecting productivity.

Bandeira *et al*. (2017) conclude that cowpea cv. BRS Aracê shows tolerance to the herbicide quizalofop-p-ethyl and moderate tolerance to imazethapyr and the formulated bentazon + imazamox. However, in our study, the isolated application of imazetapyr reduced productivity by 26.56% compared to the weed-free treatment and the application of quizalofop-p-ethyl reduced productivity by 17.85%. The application of the herbicide mixture quizalofop-p-ethyl + imazethapyr promoted more severe phytotoxicity effects, reducing yield at the same level as the weedy check treatment and the application of fomesafen.

According to Gupta *et al*. (2016), the mixture of the herbicides quizalofop-p-ethyl + imazethapyr promotes a lower

TABLE 3. Pearson correlation matrix for the number of nodules (Nn), dry matter of nodules (DMn), dry matter of roots (DMr) and grain yield (Y) in cowpea plants with herbicide application in pre- and post-emergency.

	Pre-emergence herbicides				Post-emergence herbicides			
	Nn	**DMn**	**DMr**	**Y**	**Nn**	**DMn**	**DMr**	**Y**
Nn	-	0.354 ^{ns}	-0.448 ^{ns}	0.129 ^{ns}	-	0.775 **	0.864 **	0.700 *
DMn	-	-	-0.082 ^{ns}	0.442 ^{ns}	-	-	0.924 **	0.549 ^{ns}
DMr	-	-	-	0.280 ^{ns}	-	-	-	0.781 **
Y	-	-	-	-	-	-	-	-

** Significant at $P \leq 0.01$, * significant at $P \leq 0.05$, and ^{ns} not significant according to the t test.

dry mass of weeds and is efficient in its control (84%). However, the isolated use of the herbicide imazethapyr shows higher production of cowpea. Nevertheless, there is a lack of information that can assist farmers in the proper use of these mixtures.

The low yields in the fomesafen-treated plots reflect the symptoms of severe phytotoxicity presented by them. These results are similar to those of Linhares *et al.* (2014) in which the herbicide causes intoxication of the cowpea crop, foliar necrosis and consequent loss of productivity. According to Estorninos *et al.* (2010), fomesafen delays cowpea growth and shows low efficiency in the control of weeds in the long term. However, according to Mancuso *et al.* (2016) fomesafen applied at the initial stage of crop establishment is efficient in controlling weeds. In the present study, the phytotoxicity of fomesafen provided yields of grains similar to those obtained with the weedy check treatment.

Pre-emergence mixtures of metribuzin + pendimethalin and metribuzin + alachlor provided better results than the single application of metribuzin, suggesting the need for further studies on the interaction between these active principles.

Although there was no direct correlation between the variables with the pre-emergence application of the herbicides (Tab. 3), there were positive correlations among all variables in the post-emergence application except for the dry mass of nodules and yield. This suggests that the increase of one of the variables directly and positively affected the others, so that the increase in the number of nodules increased the dry matter of nodules and roots and the yield of the crop. The issue of nodules, although directly affecting the matter of the roots, does not affect the yield, and the matter of the roots directly affects the grain yield of cowpea, as observed by Simplício *et al.* (2016), who cited that a larger number of nodules, but of smaller size (matter) is more important for grain yield than a smaller number of nodules with a larger size.

Conclusion

The management of weeds in pre- or post-emergence according to the herbicide used affects the nodulation and productivity of cowpea under the conditions of the Amazonian savannah.

The herbicide metribuzin in pre-emergence, and fomesafen and the mixture of quizalofop-p-ethyl + imazethapyr in post-emergence are not recommended for weed control for cowpea.

The application of oxadiazon, alachlor, and pendimethalin in pre-emergence is interesting because they do not inhibit the development of the root system or the nodulation of cowpea, which provides greater grain yield.

In post-emergence weed control strategies, the application of the herbicide imazethapyr and the combination of the herbicides quizalofop-p-ethyl + imazamox, quizalofop-p-ethyl + bentazon and imazamox + bentazon allow satisfactory levels of yield, roots system development and nodulation of cowpea.

Literature cited

Bandeira, H.F.S., J.M.A. Alves, P.R.R. Rocha, A. Strucker, L.B. Trassato, and A.J. Vieira. 2017. Crescimento inicial do feijão-caupi após aplicação de herbicidas em pós-emergência. Revista Brasileira de Herbicidas 16(2), 112-121. Doi: 10.7824/rbh.v16i2.503

Costa, A.F., L.S. Vale, A.B. Oliveira, J.F. Brito Neto, and G.D. Cardoso. 2017. Selectivity of pre-and post-emergent herbicides for cowpea (*Vigna unguiculata*). Afr. J. Agric. Res. 12(11), 881-887. Doi: 10.5897/AJAR2016.12081

Dias, L.R.C., A.R.B. Santos, E.R. Paz Filho, P.H.S. Silva, and C. Athayde Sobrinho. 2019. Óleo essencial de *Lippia sidoides* Cham (alecrim-pimenta) no controle de *Macrophomina phaseolina* em feijão-caupi. Rev. Cubana Plant. Med. 24(1), 1-17.

EMBRAPA. (2018). Sistema brasileiro de classificação de solos. Embrapa, Brasilia.

Estorninos Júnior, L.E., N.R. Burgos, V.K. Shivrain, E.L. Alcober, T.M. Tseng, P. Sapkota, and D.R. Motes. 2010. Efficacy and safety of herbicides applied pre-plant and pre-emergence on cowpea. pp.169-173. In: Webster, T.M. Proceedings of the 63rd Annual Meeting of the Southern Weed Science Society. 2010, January 24-27, Little Rock, USA. Red Hook, Curran Associates, Inc.

Fernandes, C., A. Braz, S. de O. Procópio, H. de A. Dan, G. Braz, A. de L. Barroso, C.C.E. Menezes, G.A. Simon, and L. Braz. 2012. Seletividade de herbicidas registrados para uso em pré e pós-emergência na cultura da cana-de-açúcar ao feijoeiro-comum. Revista Trópica Ciências Agrárias e Biológicas 5(3), 8-21.

Fontes, J.R.A., J.R.P. Gonçalves, and R.R. Morais. 2010. Tolerância do feijão-caupi ao herbicida oxadiazon. Pesq. Agropec. Trop. 40(1), 110-115. Doi: 10.5216/pat.v40i1.6241

Gonzaga, G.S., A.B. Souza Cruz, J.A.A. Albuquerque, G.X.L. Santos, M.B.B. Soares, P.R. Ribeiro Rocha, J.M.A. Alves, T.S. Castro, T.S. Santos, and D.L. Souza Cruz. 2018. Phytosociology of weed community in culture of cowpea (*Vigna unguiculata* L. Walp) and controlling possibilities with pre-emergent herbicides. Appl. Ecol. Env. Res. 16(5), 5311-5322. Doi: 10.15666/aeer/1605_53115322

Gupta, K.C., A.K. Gupta, and R. Saxena. 2016. Weed management in cowpea [*Vigna unguiculata* (L.) Wasp.] under rainfed conditions. Int. J. Agri. Sci. 12(2), 238- 240. Doi: 10.15740/HAS/IJAS/12.2/238-240

Lamego, F.P., C.J. Basso, R.A. Vidal, M.M. Trezzi, A.L. Santi, Q. Ruchel, T.E. Kaspary, and M. Gallon. 2011. Seletividade dos herbicidas S-metolachlor e alachlor para o feijão-carioca. Planta Daninha 29(4), 877-883. Doi: 10.1590/S0100-83582011000400018

Linhares, C.M.S., F.C.L. Freitas, K.S. Silva, M.F.P. Lima, and J.L.D. Dombroski. 2014. Crescimento do feijão-caupi sob efeito dos herbicidas fomesafen e bentazon+imazamox. Rev. Caatinga 27(1), 41-49.

Mancuso, M.A.C., B.C. Aires, E. Negrisoli, M.R. Corrêa, and R.P. Soratto. 2016. Seletividade e eficiência de herbicidas no controle de plantas daninhas na cultura do feijão-caupi. Rev. Ceres 63(1), 25-32. Doi: 10.1590/0034-737X201663010004

MAPA - Ministério da Agricultura, Pecuária e Abastecimento. 2019. AGROFIT - Sistema de Agrotóxicos Fitossanitários. URL: http://agrofit.agricultura.gov.br/agrofit_cons/principal_agrofit_cons (accessed 30 June 2019).

Monteiro, F.P.D.R., A.F.C. Júnior, M.R. Reis, G.R. Santos, and L.F.B. Chagas. 2012. Efeitos de herbicidas na biomassa e nodulação do feijão-caupi inoculado com rizóbio. Rev. Caatinga 25(3), 44-51.

Oparaeke, A.M., M.C., Dike, and C.I. Amatobi. 2018. Field evaluation of extracts of five Nigerian spices for control of post-flowering insect pests of cowpea, *Vigna unguiculata* (L.) Walp. Plant Protec. Sci. 41, 14-20. Doi: 10.17221/2737-PPS

Procópio, S.D.O., J.B. Santos, R.J. Jacques, M.C.M. Kasuya, A.A. Silva, and R.C. Werlang. 2015. Crescimento de estirpes de *Bradyrhizobium* sob influência dos herbicidas glyphosate potássico, fomesafen, imazethapyr e carfentrazone-ethyl. Rev. Ceres. 51, 294-297.

R Development Core Team. 2018. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna. URL: https://www.r-project.org/ (accessed 28 October 2019).

Reis, M.R., A.A. Silva, J.L. Pereira, M.A.M. Freitas, M.D. Costa, M.C.S. Silva, E.A. Santos, A.C. França, and G.L. Ferreira. 2010. Impacto do glyphosate associado com endossulfan e tebuconazole sobre microrganismos endossimbiontes da soja. Planta Daninha 28(1), 113-121. Doi: 10.1590/S0100-83582010000100014

Rodrigues, B.N. and F.S. Almeida. 2017. Guia de herbicidas. Londrina, Brazil.

Simplício, S.F., A.C.M. Gonçalves, E.C.C. Duarte, W.M.C. Barbosa, J.P.C.S. Rodrigues, B.S. Oliveira, and S.P. Souza Júnior. 2016. Características de crescimento e produção do feijão-caupi (*Vigna unguiculata* L. Walp.) sob aplicação de herbicidas. Revista Agropeária Técnica 37(1), 55-62.

Santos, M.V., F.C.L. Freitas, F.A. Ferreira, R.G. Viana, L.D. Tuffi Santos, and D.M. Fonseca. 2006. Eficácia e persistência no solo de herbicidas utilizados em pastagem. Planta Daninha 24(2), 391-398, Doi: 10.1590/S0100-83582006000200024

Souza Cruz, A.B., P.R.R. Rocha, J.A.A. Albuquerque, J.M.A. Alves, D.L. Souza Cruz, E.L. Finoto, and G.X.L. Santos. 2018. Seletividade de herbicidas aplicados em pré e pós-emergência na cultura do feijão-caupi na Savana Amazônica. Nativa Pesquisas Agrárias e Ambientais 6(6), 625-630. Doi: 10.31413/nativa.v6i6.5732

Yadav, T., K.C. Nisha, N.K. Chopra, M.R. Yadav, R. Kumar, D.K. Rathore, P.G. Soni, G. Manarana, A. Tamta, M. Kushwah, H. Ram, R.K. Meena, and M. Singh. 2017. Weed management in cowpea - A review. Int. J. Curr. Microbiol. Appl. Sci. 6(2), 1373-1385. Doi: 10.20546/ijcmas.2017.602.156

Zilli, J.É., R.R. Valicheski, N.G. Rumjanek, J.L. Simões Araújo, F.R. Freire Filho, and M.C.P. Neves. 2006. Eficiência simbiótica de estirpes de *Bradyrhizobium* isoladas de solo do Cerrado em caupi. Pesq. Agropec. Bras. 41(5), 811-818.