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Phytosociology and interference of weeds in upland rice in Maranhão State, northeastern Brazil

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The objective of this research was to identify the weed species and to determine the critical periods of weed interference in upland rice in Maranhão State, northeastern Brazil. The experiment was laid out in a randomized complete block design with 16 treatments and four replications in two growing seasons. Treatments were increasing periods of control and coexistence of the crop with weeds, for every 10 days. Weeds were sampled with a 0.5 × 0.3 m metal rectangle which was randomly thrown four times in each plot. Phytosociological parameters computed were Density, Frequency, Dominance and Importance Value Index of each species. The more important families in both growing seasons were Poaceae and Cyperaceae. *Cyperus* spp., *Phyllanthus niruri* L., *Alternanthera tenella* Colla and *Digitaria* spp. reached higher values of relative importance than the other species. Coexistence of weeds with rice during the whole crop cycle in both growing seasons decreased rice grain yield by 83.4 and 72.0%, respectively. Taking into account 5% tolerance in yield reduction in cropping seasons 2010/2011 and 2011/2012, the periods before interference (PBI) were 15 and 13 days after emergence (DAE), the total periods of interference prevention (TPIP) were 25 and 45 DAE and the critical periods of interference prevention (CPIP) were from 15 to 25 and from 13 to 45 DAE, respectively. It was concluded that the weed control in upland rice must be carried out from 13 till 45 DAE to promote weed free development since the crop has low natural competitive capacity.

Key words: Competition, critical period, *Oryza sativa* L., weed community.

INTRODUCTION

Rice is an annual crop of great socio-economic importance in Brazil because it is a staple food and it is grown in all over the country. According to CONAB (2014), Brazilian rice production in the growing season

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2002/2003 was 11,819.7 thousand tons. Major rice regions in terms of production are the South (9,132.9 thousand tons) followed by Center-West (770.8 thousand tons) and Northeast with (588.2 thousand tons). Maranhão State was the major producer in the Northeast region contributing with 66.33% of the total rice production.

Weeds are the major biological constraint for rice farmers in Maranhão State because they are favored by local climatic conditions. According to Silva and Durigan (2006), weeds are the most sensitive factor affecting upland rice growth, development and yield since they compete for light, space, nutrients and water, which results in qualitative and quantitative yield reductions, besides increasing operational costs of harvest, drying and grain processing.

Uncontrolled weed growth is reported to cause grain yield losses in upland rice in the range of 66-100% (Silva and Durigan, 2006; Silva and Durigan, 2009; Chauhan and Johnson, 2011; Toure et al., 2013). This shows that it is necessary to implement weed control practices to avoid yield losses and associated economic damages.

The first step to develop a weed management program in any crop is the identification of the weed species present in the agroecosystems, particularly those that are more important, taking into account phytosociological parameters such as Frequency, Density and Dominance. These parameters enable a decision making about more suitable control method whether it is cultural, mechanical, physical, biological, chemical or an integrated weed management program (Oliveira and Freitas, 2008).

According to Pitelli (2000), phytosociological parameters permit comparisons of weed populations in a certain time in the weed community thereby revealing the impacts of some cultural practices over weed community growth and space occupation in cropping fields. The weed species controlled by cultural practices tend to decrease their relative importance, while indifferent or favored weed species tend to increase. The most affected component analysis (Density, Frequency or Dominance) may provide evidences about the mode of action of the environmental pressure agents against weed populations.

Knowledge of time and extension of periods which weed coexistence with the rice affect crop yield is crucial for weed management in rice. These periods were defined by Pitelli and Durigan (1984), as period before interference (PBI), the total period of prevention interference (TPIP) and the critical period of interference prevention (CPIP). The PBI corresponds to the period of time starting from planting that the crop can coexist with weeds before its yield or other biological characteristics are negatively affected. The TPIP is the period starting from emergence or planting which the crop must be kept free from weeds to its quality and yield and other characteristics are not adversely altered. The CPIP is the period of time which weed control must be compulsory to prevent weed interference in yield or other crop characteristics.

Silva and Durigan (2006) found critical interference periods between 12 and 42 DAE for the IAC 202 variety. Conversely, the said period was between 26 and 29 DAE for the variety Caiapó (Silva and Durigan, 2009). However, for upland rice varieties in Africa, Moukoumbi et al. (2011) observed that the critical interference period was between 30 and 60 days after seeding (DAS). However, for three new upland rice varieties in Africa, the critical period was between 14 and 42 DAS and between 28 and 42 DAS for *Oryza glaberrima* (Toure et al., 2013). This shows that rice varieties behave differently in their competitiveness to suppress weeds under different weed communities and climate conditions, therefore weed control should be regionalized (Pitelli, 2014).

The objective of this research was to identify the major weed species and to determine their critical interference periods on upland rice in the Center-West region of Maranhão State to provide a better definition of the weed control time.

MATERIALS AND METHODS

The experiment was carried out in the growing seasons from January till May 2011 and 2012 in the Farm School of the Maranhão State University at São Luis (2°31′47″ S; 44°18′10″ W). The climate in the region, according to Thornthwaite classification, is type B_1WA'a, humid (B_1), with moderate water deficit in winter (between June and September), megathermal (A'), that is, with average monthly temperature always above 18ºC, annual rainfall ranging from 2,400 and 2,800 mm and annual relative humidity above 82% (GEPLAN, 2002). During the two growing seasons rainfall and temperature varied according to Figure 1.

The soil in the experimental area is classified as Alfisol. The rice cultivar used was BRS Seraneja which was developed based on multiple cross carried out in 1993, at EMBRAPA Arroz and Feijão (Brazilian Research Corporation for Rice and Beans), involving lines and cultivars (Carajás // IAC 165²/ Labelle //// Três Marias / IAC 25³ /// A8-204-1 / Guarani // IRAT 216). This cultivar is characterized by vigorous plants, medium height, moderately tillered and resistant to lodging (Breseghello et al., 2006).

Fertilization and seeding were performed manually in the same day. Seeding density was 70 seeds per running meter in rows with fertilizers placed at five and seeds placed at three cm deep respectively simulating mechanical sowing. Basal fertilization was made with the application of 30 kg of N, 60 kg of P_2O_5 and 50 kg of K_2O h^{-1} in the form of ammonium sulfate (20% N), triple superphosphate (43% P) and potassium chloride (60% K). Top dressing was made with 60 kg N ha^{-1} in the form of urea at 30 days after emergences (DAE).

The experiment was laid out in a randomized complete block design with 16 treatments and four replications. Plots contained five rows with five meters each; row spacing was 0.45 cm. Useful plot size was three central rows discarding two rows in borders and 0.50 cm at each end totalizing 5.40 m^2.

The treatments were control and coexistence of weeds in increasing time periods of crop cycle starting from crop emergence. The initial periods of control and coexistence with the weeds were: 0 – 10; 0 – 20; 0 - 30; 0 - 40; 0 - 50; 0 - 60; 0 - 70; 0 – 120 DAE. In addition, season long weedy and weed free checks were included

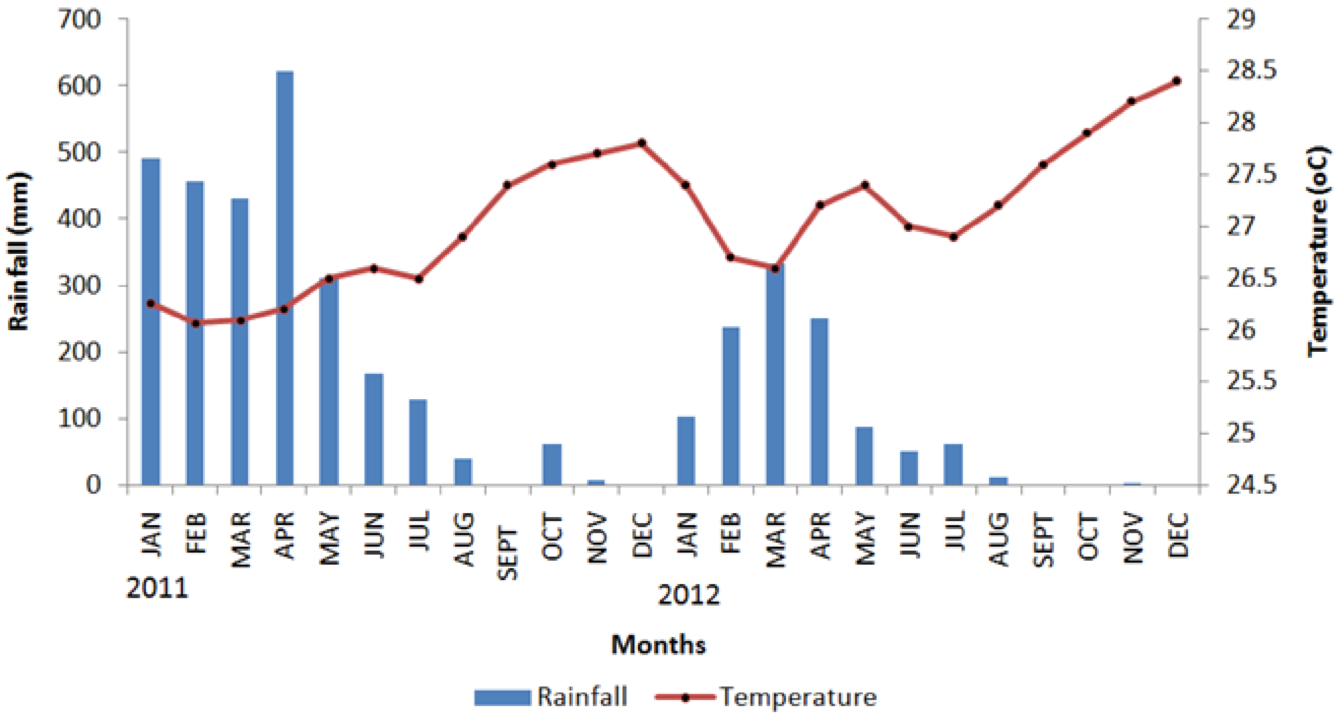


Figure 1. Rainfall and temperature in 2011 and 2012, in São Luís, Maranhão State, northeastBrazil. Source: INMETRO (2013).

as controls. Weed samplings were performed at the end of the coexistence time periods and weed control was performed by means of hand weeding every 10 days.

Four weed samples per plot were taken by means of a 0.50 × 0.30 cm open metal rectangle which was randomly placed in the plot area. Weeds species were cut at the ground level, identified by species, counted and oven dried at 65-70°C till constant weights were obtained to determine weed dry weight. Data on weed density, weed dry weight and frequency of each species present in the weed community were used to compute the following phytosociological parameters: Relative Density, Relative Frequency, Relative Dominance, Importance Value Index (IVI) and Relative Importance (RI) according to methodology suggested by Pitelli (2000).

The crop was manually harvested at 120 DAE from 5.40 m area kept for yield estimation in each plot. Yield data were expressed in kg ha^{-1} and were subjected to regression analysis by the Sigmoidal Boltzmann Model (Kuva et al., 2000) by means of the software ORIGIN 8.0 (Originlab Corporation, 2002). This Model follows the equation: Y= A2 + [(A1-A2)/(1-exp (x-xo)/dx)], where y is rice yield in percentage; X in the superior limit of the coexistence period or control; A1 and A2 are the curve asymptotes; Xo is the superior limit from coexistence or control which corresponds to the inflexion point of the curve and dx indicates velocity of losses or production gains (tg α in the point Xo). Based on regression equations, we determined the time periods of weed interference for arbitrary levels of 5% decrease in rice grain yield with respect to the treatment kept weed free.

Rice grain yield data were subjected to the Analysis of Variance with F test and means were tested for significant differences using the Tukey test at 5% probability. Statistical analyses were carried out by means of the software Assistat 7.7 (Silva and Azevedo, 2009).

RESULTS AND DISCUSSION

For the first growing season (2010/2011), 52 weed species from 18 families were identified. The families with higher species richness were Poaceae and Cyperaceae with 25 and 21.5%, respectively. In contrast only 37 species from 17 families were identified in the second growing season (2011/2012). Poaceae and Cyperaeae were again the families with higher species richness with 41 and 47%, of the species total, respectively (Table 1). Therefore lower weed species diversity was noted in the second growing season, even though higher percent values for species of the Poaceae and Cyperaceae families were observed.

The lower diversity might be due to the amount of rainfall in the second growing season which favored more species from families of Poaceae and Cyperaceae that possess the more aggressive weed species to the rice crop. Species of these families were also identified competing with upland rice by Silva et al. (2014) in the Pré-Amazônia Maranhense, region in Brazil and in Punjab, Pakistan by Rabbani et al. (2011). According to Lorenzi (2008) many species from Poaceae and Cyperaceae produce great number of propagules thereby facilitating dissemination and occupation of ecological niches in many environments, even in those considered unfavorable for plant growth.

Table 1. List of families and weed species identified in upland rice crop in the Farm School of São Luís from the Maranhão State University at São Luís, Maranhão State, northeast Brazil in the growing seasons 2010/2011 and 2011/2012.

Families	Species	
	Growing season 2010/2011	**Growing season 2011/2012**
Asteraceae	*Blainvillea rhomboidea* Cass.	---------------------------
	Emilia coccinea (Sims). G.Don.	*Emilia coccinea* (Sims). G.Don.
	Emilia fosbergii Nicolson	---------------------------
	Tridax procumbens L.	---------------------------
	Synedrella nodiflora (L.) Gaertn.	---------------------------
	Siegesbeckia orientalis L.	---------------------------
	---------------------------	*Galinsoga quadriradiata* Ruiz & Pav.
Amaranthaceae	*Alternanthera brasiliana* (L.) Kuntze	*Alternanthera brasiliana* (L.) Kuntze
	Amaranthus spp.	*Amaranthus* spp.
	Alternanthera tenella Colla	*Alternanthera tenella* Colla
Brassicaceae	---------------------	*Cleome affinis* DC
Cyperaceae	*Cyperus sphacelatus* Rotttb.	*Cyperus sphacelatus* Rotttb.
	Cyperus rotundus L.	*Cyperus rotundus* L.
	Cyperus flavus (Vajl) Nees	*Cyperus flavus* (Vajl) Nees
	Cyperus lanceolatus Poiret	*Cyperus lanceolatus* Poiret
	Cyperus brevifolius (Rottb.) Hassk	------------------------
	Fimbristyllis spp.	*Fimbristyllis* spp.
	Bulbostilys capillaris (L.) C.B. Clarke	*Bulbostilys capillaris* (L.) C.B. Clarke
	Cyperus iria L.	*Cyperus iria L.*
	Cyperus diffusus Vahl	*Cyperus diffusus* Vahl
	Pycreus polystachyos ((Rottb) P.Beauv.)	------------------------
	Pycreus decumbens T. Koyama	-----------------------
	------------------------	*Rhynchospora corymbosa* (L.) Britton
Commelinaceae	*Commelina benghalensis* L.	*Commelina benghalensis* L.
Convolvulaceae	*Ipomoea* spp.	*Ipomoea* spp.
	Ipomoea asarifolia (Desr.) Roem. & Schult	*Ipomoea asarifolia* (Desr.) Roem. & Schult
	------------------------	*Ipomoea purpurea* (L.) Roth
Euphorbiaceae	*Chamaesyce hirta* (L.) Millsp.	-----------------------
	Croton lobatus L.	*Croton lobatus* L.
Fabaceae	*Calopogonim mucunoides* Desv.	-----------------------
	Mimosa pudica L.	*Mimosa pudica* L.
	Senna obtusifolia (L.) Irwin & Barneby	-----------------------
	Indigofera hirsuta L.	-----------------------
Lamiaceae	*Marsypianthes chamaedrys* (Vahl) Kuntze	*Marsypianthes chamaedrys* (Vahl) Kuntze
Loganiaceae	*Spigelia anthelmia* L.	*Spigelia anthelmia* L.
Malvaceae	*Sida* spp.	*Sida* spp.

Table 1. Contd.

	Sida rhombifolia L.	----------------------------
	Pavonia cancelata (L.) Cav.	----------------------------
	----------------------------	*Sidastrum micranthum* (A. St. –Hil.)Fryxell
Melastomataceae	*Rhynchathera* spp.	----------------------------
Molluginaceae	*Mollugo verticillata* L.	*Mollugo verticillata* L.
Onagraceae	*Ludwigia leptocarpa* (Nutt.) H. Hara	----------------------------
Poaceae	*Digitaria* spp.	*Digitaria* spp.
	Eleusine indica (L.) Gaertn.	*Eleusine indica* (L.) Gaertn.
	Cenchrus echinatus L.	*Cenchrus echinatus* L.
	Coix lacryma-jobi (L.) Sw.	----------------------------
	Dactyloctenium aegyptium (L.) Willd.	*Dactyloctenium aegyptium* (L.) Willd.
	Digitaria bicornis (Lam.) Roem & Schult	----------------------------
	Digitaria horizontalis Wild.	----------------------------
	Eragrostis ciliaris (L.) R. Br	*Eragrostis ciliaris* (L.) R. Br
	Brachiaria brizantha (Hochst. Ex A.Rich.) Stapf	----------------------------
	Brachiaria mutica (Forssk.) Stapf	----------------------------
	Panicum tricoides L.	*Panicum tricoides* L.
	Digitaria ciliaris (Retz.) Koeler	*Digitaria ciliaris* (Retz.) Koeler
	Setaria parviflora (Poir.) Kerguélen	----------------------------
Phyllanthaceae	*Phyllanthus niruri* L.	*Phyllanthus niruri* L.
Plantaginaceae	*Lindernia crustacea* (L.) F. Muell	*Lindernia crustacea* (L.) F. Muell
Rubiaceae	*Hedyotis corymbosa* (L.) F. Muell	*Hedyotis corymbosa* (L.) F. Muell
	Spermacoce latifolia Aubl.	*Spermacoce latifolia* Aubl.
	Spermacoce capitata Ruiz & Pav.	*Spermacoce capitata* Ruiz & Pav.
	Spermacoce verticilata L.	*Spermacoce verticilata* L.
	Staelia aurea K.Schum.	---------------------------
Turneraceae	*Turnera ulmifolia* L.	*Turnera ulmifolia* L.

Cyperus spp. had higher Relative Importance values than the others during the whole coexistence period in the growing season 2010/2011, reaching 35.22% at 50 DAE (Figure 2A). This was probably due to the higher incidence of light on the soil in the initial periods of their coexistence with the crop which favored their growth since they have the C4 carbon fixation cycle. According to Silva et al. (2007) the C4 species can dominate completely the C3 species when growing in environments with high temperatures, high light intensity and even with temporary soil water deficit. In addition, they accumulate two times more biomass per leaf area in the same period of time.

Other relevant species recorded in the weed community in the growing season 2010/2011 were *Phyllanthus niruri* followed by *Alternanthera tenella* and *Digitaria* spp. (Figure 2A). The species *P. niruri* stood out mainly from 10 till 40 DAE, reaching higher Importance Value than the others at 30 DAE with 22.4% of the total. On the other hand, *A. tenella* obtained higher Importance Value than the other species in the weed community at 10 DAE with 19%; maintaining values above 10% from 50 DAE till the last evaluation, while *Digitaria* spp. expressed their higher relevance than the other species

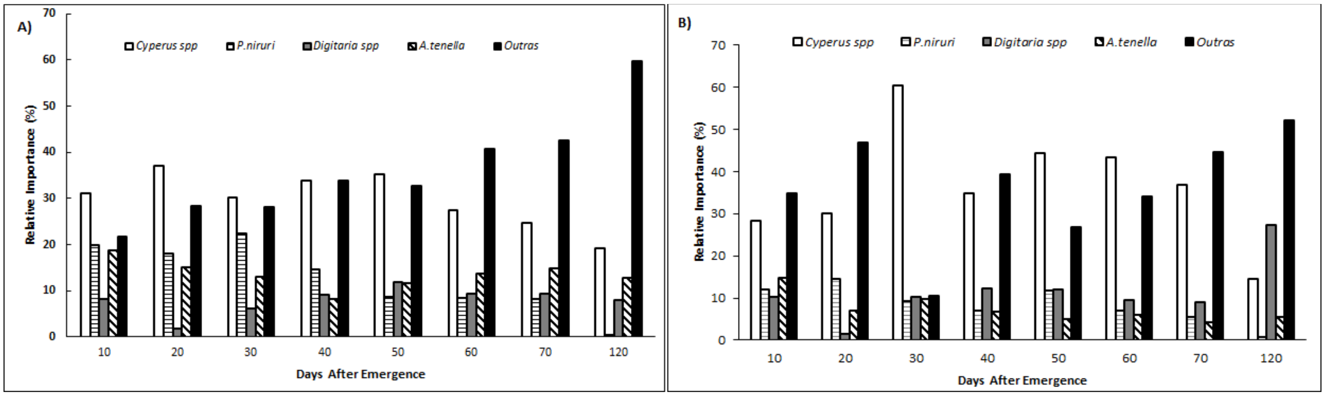


Figure 2. Relative Importance of the main weed species in coexistence with the rice crop variety BRS Sertaneja in the Farm School at São Luis /CCA/UEMA, São Luís, Maranhão State, northeastern Brazil. A) Growing season 2010/2011 and B) Growing season 2011/2012.

in the weed community at 50 DAE, with 12%. At the end of crop cycle the other species corresponded to 60% of the weed community (Figure 2A). Therefore a decrease in the relative importance of *Digitaria* spp. was observed at the end of the crop cycle indicating higher level of interespecific competition.

In the second growing season (2011/2012) species from Cyperaceae family showed higher relevance than species from the other families in the weed community during the whole crop cycle, except at harvest when they were superseded by *Digitaria* spp. with 60% of the total (Figure 2B). These results show that Cyperaceae species may be considered to have higher influence to damage the rice crop at early growth stage. Among Cyperaceae species, *C. rotundus* stood out in the beginning of the crop cycle. It prefers open places with high light intensity. However, by the end of the crop cycle the weed community was dominated by *C. sphachelatus, C. diffusus* and *C. brevifolius* that thrive better in more humid and shaded conditions. According to Moreira and Bragança (2010), Cyperaceae species prefer humid, shaded or open places and tend to form difficult to control communities which compete for space and nutrients. Research results reported by Rabbani et al. (2011) also show that *C. rotundus* is among the most abundant species in rice fields of Punjab, Pakistan.

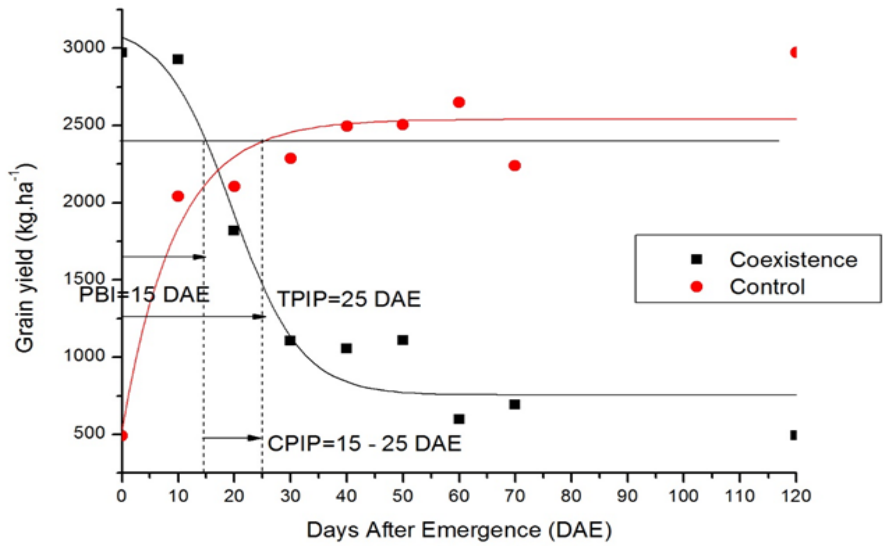
Digitaria spp. were relevant only at the end of the crop cycle but they must be controlled because they are highly aggressive weeds (Kissmann and Groth, 1991). Furthermore *Digitaria* spp. are also potential inoculum sources of the rice blast disease (*Piricularia oryzae* Cav.). In a phytosociological weed survey carried out in upland rice in Maranhão State, Silva et al. (2013) also reported that species from this genus were among the most important in the weed community.

The species *P. niruri* and *A. tenella* reached higher relative importance than the other species at 20 and 10 DAE with 15 and 14.5%, respectively (Figure 2B). These species showed lower values of Relative importance in the second growing season. This suggests that the lower amount of rainfall affected their growth (Figure 2).

Taking into account a 5% yield loss in the variety BRS Sertaneja in the growing season 2010/2011, it was observed that the coexistence time with weeds started to affect the crop (PBI) at 15 DAE, extending up to numerical weed control (TPIP) till 25 DAE (Figure 3). The critical period of interference prevention (CPIP) was characterized by an interval between 15 and 25 DAE. This lower PAI indicates that the crop shows low competitive capacity in the early stage of its growth cycle, thus requiring weed removal so as to not adversely interfere with crop yield. However the TPIP obtained suggests that the crop enhanced weed control by shading the soil. Research results with variety Caiapó in the growing season 2004/05 determined TPIP at 26 DAE, due to the lower incidence of weeds, thereby the crop was able to soon shade the soil (Silva and Durigan, 2009). However, in research carried out by Moukoumbi et al. (2011) in Africa under weeding at 14 DAS, the critical period of competition between weeds and cultivated plants varied between 30 and 60 DAS.

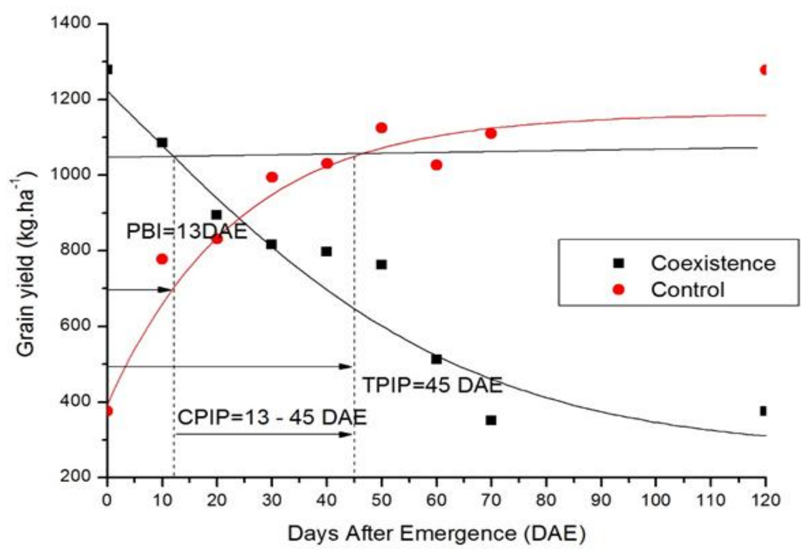
In the second growing season (2011/2012), taking into account the same 5% crop yield loss, it was obtained PBI from 13 DAE and TPBI of 45 DAE. Therefore the CPIP, was between, 13 and 45 DAE (Figure 4). In this year, the variety extended the TPBI for 17 days compared to the first growing season. This suggests that the weed community was more aggressive. Because of this, weeding had to be extended.

Although lower species diversity was observed in the second growing season when compared with the first, there was a higher amount of species from Poaceae and



Yconv. = 755.21683+(3168.1161-755.21683)/1+exp((x-19.63108)/6.1458)) R2=0.93
Ycoex. = 2540.84647+(-9.5074E6-2540.84647)/(1+exp((x+80.09404)/9.46491)) R2=0.83

Figure 3. Upland rice grain yield (BRS Sertaneja) and data adjustment by the Sigmoidal Boltzmann Model, based on coexistence periods with weeds taking into account a 5% yield loss in the growing season 2010/2011. São Luis, Maranhão State, northeastern Brazil.



Ycoex. = 267.67263+(2062.57116-267.67263)/(1+exp((x+195.97419)/23.46629)) R^2=0.89
Ycontr. = 1163.47834+(-3.26144E6-1163.47834)/(1+exp((x+195.97419)/23.46629)) R^2=0.90

Figure 4. Upland rice grain yield (BRS Sertaneja) and data adjustment by the Sigmoidal Boltzmann Model, based on coexistence periods with weeds taking into account a 5% yield loss in the growing season 2011/12. São Luis, Maranhão State, northeastern Brazil.

Cyperaceae families that have very aggressive weed species to the rice crop (Table 1). With respect to PBI, one difference of three days was observed, confirming the need to perform weed control in the beginning of the crop growth cycle, since emerging weeds negatively affected yield. Silva and Durigan (2006) reported a critical period between 12 and 40 DAE for the variety IAC 202 in the growing season 2003/2004. In Africa, Kolo and Umaru (2012) reported a critical period between 25 and 45 DAE for the variety NERICA 1. Toure et al. (2013) determined the critical period between 14 and 42 DAS for three new rice varieties in Africa. Thus, it is concluded that regardless of the soil and climatic conditions, upland rice does not show great competitive capacity with the weed community.

BRS Sertaneja grain yield in total absence of weed interference in the growing season 2010/2011 was 2,971.8 kg ha^{-1}, while in the growing season 2011/2012 was 1,278.5 kg ha^{-1}. Therefore, there was a 43% yield reduction from the said variety in the second growing season. This fact can be explained by the lower rainfall amount in the time of panicle differentiation. Research conducted by Kolo and Umaru (2012) in Africa showed that the cultivar Nerica 1 had higher grain yield due to less weed competition which favored its higher growth.

The coexistence with weeds during the whole crop cycle resulted in yield losses of 83.4 and 71% in the growing seasons 2010/2011 and 2011/2012, respectively. This highlights the great crop susceptibility to weed interference. These results are similar to those noted by Touré et al. (2013) who reported 85% yield reduction when coexistence with weeds occurred in the whole crop cycle. Harding and Jalloh (2011) reported average yield losses ranged from 22 to 66%. This shows that rice varieties behave differently in their competitiveness to suppress weeds under severe competition. Kolo and Umaru (2012) stated that the drooping leaves and higher tillering ability of NERICA 1 resulted in good canopy formation which contributed to its weed suppressing ability resulting in higher grain yield.

Conclusions

The main families and weed species in coexistence with upland rice crop during the two growing seasons of this study were Cyperaceae and Poaceae, and *Cyperus* spp.*, P. niruri*, *A. tenella* and *Digitaria* spp.

Weed interference must be minimized in the first stage of upland rice crop growth to promote its free development since it has low natural competitive capacity. Weed control in upland rice crop must be carried out in the period starting from 13 till 45 DAE; beyond this period it is not economically recommended for the farmers to continue weeding.

Conflict of Interest

The authors have not declared any conflict of interest.

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