

Ecological weed control in rice and maize using *Orbygnia phalerata* with focus on the weed seedbank in the soil

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Abstract

The aim of this study was to evaluate the effect of mulching with dry leaves of babassu palm (*Orbygnia phalerata* Mart.) on germination of weed seed bank on rice tiller number and on grain yield of rice and maize in Maranhão state, northeastern Brazil. In the field the experimental design was a split plot in a randomized complete block with 15 replications. Rice, maize and rice intercropped with maize were allocated to the main plots and mulching treatments with unprocessed whole dried palm leaves (0 and 23 t ha⁻¹) to the subplots. Germination of the weed seed bank was assessed after crop harvest in the greenhouse by means of a collection of three soil samples per subplot (n = 270) with an open metal device of 25 cm in length x 16 cm in width x 3 cm in height as sampling unit. Soil samples were placed in aluminum trays in the greenhouse and irrigated daily. The germinated weed species were identified and counted every fifteen days. The results showed that mulching can reduce germination in the weed seed bank up to 55% and promoted a significant increase in rice tiller number from 63 to 95 m⁻², grain yield of rice from 1,077 to 2,251 kg ha⁻¹ and grain yield of maize from 1,137 to 2,293 kg ha⁻¹. Therefore, mulching can be recommended for weed control in smallholder farming of rice and maize crops.

Keywords: Allelopathy; Biological Invasion; Competition; Floristic.

Abbreviations: APG_Angiosperm Phylogeny Group.

Introduction

Weeds are a major biological constraint in smallholder farming. They interfere with crop growth and development by allelopathy and competition for water, nutrients, light and space. Uncontrolled weed growth can reduce grain yields by 68% in maize (Murungu et al., 2018), and by 96% in rice (Chauhan and Johnson, 2011a, b). Adoption of ecological control methods reduce seedling of weed species from the soil seedbank. Alteration in competitive relations for the benefit of the crop and gradual reduction in the weed seed bank size may contribute to regulate weed populations and reduce the negative impact of weeds on crop production (Chauhan and Johnson, 2011 a, b). Considering that the greatest component weeds present in any agricultural field comes from seeds previously deposited in the soil, the definition of strategies that prevent weed seed germination is of fundamental importance for weed control (Rao et al., 2017).

The soil seed bank is a dynamic system with inputs and outputs. The entrances occur through seed rain, as a result of efficient mechanisms of dispersion, and the exits, through germination, predation and deterioration or death of the seeds. These factors determine the amount of viable seeds present in the soil (Garwood, 1989). The diversity of species

may vary depending on the management practices (Ikeda et al., 2008; Ricci et al., 2008). In smallholder farming in the state of Maranhão, northeastern Brazil, there is an enormous lack of knowledge about weed management techniques that consider soil conservation, reduction in slash and burn practice to prepare the land, promotion of nutrient recycling and other techniques that help to recover and maintain environmental sustainability. In this region the system of agricultural exploitation prevails the slash and burn of vegetation, particularly the dry leaves that fall down from babassu palm trees. Therefore, leaves of babassu palm trees are zero-cost, easily accessible material in smallholder farmer communities. Instead of usual burning of leaves they can be used as dead mulching to control weeds in agricultural fields. According to Ranaivoson et al. (2018), the use of mulch reduces the weed germination up to 80%. According to these authors, this occurs because the soil cover blocks the incidence of light on the soil surface and acts as a direct physical impediment in the germination and emergence of many weed species. The effect of using mulch as a strategy for weed management in rice and maize was carried out by several authors (Moraes et al., 2009; Moura et al., 2009; Bunna et al., 2011; Chauhan and Abugho, 2013;

Kumar et al., 2013; Nuemsi et al., 2018; Ranaivoson et al., 2018). However, none of the authors evaluated the effect of mulching on the germination of the soil seed bank and there are no reports on application of babassu palm leaves, which is a dominant autochthonous species in the secondary vegetation in the agricultural fields of the state of Maranhão, in weed management programs.

In this context, mulching made from dried babassu leaves can reduce weed populations in smallholder cropping fields and, consequently, reduce fires and costs in a sustainable way.

The objective of this research was to evaluate the effect of mulching made from dried leaves of babassu palm on the germination of the weed seedbank in the soil, number of rice tillers and grain yield of rice and maize monocrop and intercropped in smallholder farming the state of Maranhão, northeastern Brazil.

Results and Discussion

Effect of mulching on germination of the weed seedbank in the soil

Mulch reduced weed seed germination in the soil seed bank in all treatments with a significant effect on the rice crop ($P < 0.05$), where there was a reduction of 55% in weed germination density (Table 1).

As the evaluation time increased, seed germination density in the mulch treatment decreased, showing a quadratic response in the rice crop area (Figure 1).

The reduction of weed seed germination in the soil was occurred because the mulch probably prevented the penetration of light in the soil or blocked certain wavelengths of the light spectrum that are necessary for seed germination of many weed species (Batlla and Benech-Arnold, 2014). In addition, the physical barrier formed by straw may have contributed to the mortality of germinated seedlings of seeds located on the soil surface, whose reserves were not sufficient to overcome the mulch (Gomes and Christoffoleti, 2008; Gardarin et al., 2010).

Similar results have been reported for rice and maize crops elsewhere in the tropical region. For example in India, Singh et al. (2007), evaluated wheat (*Triticum aestivum* L.) straw as mulch and observed a 54% reduction in the weed density at 30 days after rice planting. In the Amazon region, Moura et al. (2009), observed that the cut of the legumes *Acacia mangium* Willd. and *Leucaena leucocephala* (Lam.) De Wit, used as mulching, resulted in 89% decrease in the weed biomass in the maize crop after five years of an alley cropping study. In the state of Rio Grande Sul, southern Brazil, Moraes et al., (2009) reported that mulching with dry parts of *Azevém* (*Lolium multiflorum* L.) resulted in an increase of 80.72% in maize grain yield.

In total, we sampled 28,499 individuals from 23 families, 49 genera and 71 species in the weed seedbank in the soil (Supplementary Table 1).

The families Cyperaceae and Poaceae had the largest number of species, with 11 each, followed by Malvaceae, with eight; Asteraceae, with seven, Amaranthaceae, with six; Fabaceae and Rubiaceae, with four; Phyllanthaceae, with three; Onagraceae, Lamiaceae, Commelinaceae and Convolvulaceae with two and the others with one species each. The genera that stood out most were *Sida*, with six

species, *Cyperus* with five, *Amaranthus* with four, and *Phyllanthus*, *Fimbristylis* and *Digitaria*, with three species each.

The mulching treatment changed the floristic composition of the soil seed bank, with the disappearance of species of the families Lamiaceae, Loganiaceae and Nyctaginaceae of the area planted with rice, Lamiaceae and Turneraceae of the maize area; and Turneraceae, Brassicaceae and Lamiaceae from the rice intercropped with maize.

In the rice area, based on the record of occurrence of soil seed bank germination, mulching was effective in controlling the species *Amaranthus retroflexus*, *Eclipta alba*, *Mimosa pudica*, *Hyptis suaveolens*, *Spigelia anthelmia*, *Sida urens*, *Boerhavia erecta*, *Ludwigia leptocarpa*, *Phyllanthus corcovadensis*, *Phyllanthus orbicularis* *Digitaria horizontalis* and *Urtica dioica*. The blocking of light penetration on the soil surface seems to have been the main mechanism responsible for this result, since some of these species produce seeds that are positive photoblastic; thus, they need light to germinate such as those in *Eclipta alba* (Chauhan and Johnson, 2008), *Hyptis suaveolens* (Mandal et al., 2008), *Digitaria horizontalis* (Mondo et al., 2010) and *Urtica dioica* (Jankowska-Blaszczuk and Daws, 2007).

In maize, the species *Ageratum conyzoides*, *Commelina diffusa*, *Fimbristylis autumnalis*, *Schoenoplectus juncooides*, *Scleria lithosperma*, *Calopogonium mucunoides*, *Mimosa pudica*, *Urena lobata*, *Richardia brasiliensis* and *Turnera subulata* were eliminated by mulching. Among these species, two also produce positive photoblastic seeds, *Ageratum conyzoides* (Caton et al., 2010; Sun et al., 2012) and *Fimbristylis autumnalis* (Caton et al., 2010).

In the rice intercropped with maize, mulching was effective in controlling the species *Cleome affinis*, *Ipomoea ramosissima*, *Cyperus aggregatus*, *Cyperus meyenianus*, *Desmodium adscendens*, *Hyptis suaveolens*, *Sida glaziovii*, *Phyllanthus corcovadensis*, and *Turnera subulata*. Among these, *Cyperus aggregatus* only germinates in the presence of light (McIvor and Reid, 2011).

Effect of mulching on rice tiller number and grain yield of rice and grain yield of maize

The mulching treatment had a significant effect ($P < 0.05$) on the increase in the number of rice tillers and grain yield of rice and maize. In the rice crop, there was an increase of 50.7% in the number of tillers and 109% in the grain yield. In the maize crop, there was a grain yield increase by 101% (Table 2). This was due to the decrease in competition for nutrients, space, water and light which altered competitive relations in favor of the crops.

The hypothesis of this research is that mulching, made from low cost material and easy access in the farmer communities, can reduce the germination of the weed seedbank in the soil, constituting a management strategy for weed control in smallholder farming in the state of Maranhão, besides providing other benefits to the soil. This is because mulching prevents light from penetrating the soil surface or blocks certain wavelengths of light spectrum that are required for the seed germination of most weed species. In addition, it forms a physical barrier that prevents germination and/or emergence of many weed species.

Table 1. Germination density in the weed seedbank in the soil grown with rice and maize monocrop and intercropped with and without mulching in the state of Maranhão, northeastern Brazil.

Treatments	Weed seed germination density (plants m ⁻²)		
	Rice	Maize	Rice intercropped with maize
Without mulching	6113 a	2466 a	2330 a
With mulching	2781 b	1131 a	1012 a

Means followed by the same letter in the column do not differ by the Tukey test at 5% probability.

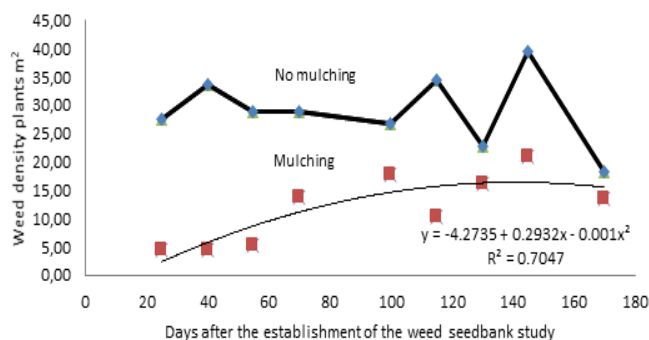


Fig 1. Weed germination density in the weed seedbank in the soil in a rice field without and with mulching made with unprocessed whole dried leaves of babassu palm in the state of Maranhão, northeastern Brazil according to the time (days) of evaluation.

Table 2. Number of rice tillers and grain yield of rice and maize with and without mulching in the state of Maranhão, northeastern Brazil.

Treatments	Rice		Maize
	Tillers (n m ⁻²)	Grain yield (kg ha ⁻¹)	Grain yield (kg ha ⁻¹)
Without mulching	63 b	1077 b	1137 b
With mulching	95 a	2251 a	2293 a

Means followed by the same letter in the column do not differ by the Tukey test at 5% probability.

In fact, in the experiment using 23 tons ha⁻¹ of unprocessed whole dried leaves of the babassu palm placed on the soil, we verified a reduction of 55% in the germination density of the weed soil seed bank in the soil of areas grown with rice and maize monocrop and intercropped in the state of Maranhão (Table 2), confirming the hypothesis proposed. The reduction in the weed seed germination altered the competitive relations in favor of the crops resulting in an increase in the rice tiller number and the grain yield of rice and maize (Table 4), which corroborates the hypothesis.

Other works described in the literature confirm that the proposed hypothesis is also applicable to the use of mulch with other materials. In fact, rice straw (Murungu et al., 2011; Chauhan and Abugho, 2013), wheat residue mulch (Kumar et al., 2013), *Stylosanthes guianensis* and a mixture of maize and *Dolichos lablab* (Ranaivoson et al., 2018) and dead vegetation cover (Nuemi et al., 2018) showed a similar response in the weed control in rice and maize.

Throughout the discussion, mulching with babassu palm dry leaves can be used as a strategy to weed control in areas of smallholder farming in the state of Maranhão.

Materials and Methods

Study site

This research was carried out in the villages of Boa Esperança (04°12'42,7"S - 44°41'30,5"W); Jussaral (04°06'03,4"S - 44°56'42,9"W) and Encruzilhada

(04°23'34,8"S - 44°37'19,8"W) located, respectively in the municipalities of Bacabal, Lago Verde and São Luís Gonzaga, in the state of Maranhão, northeastern Brazil.

The climate of the region is Aw, according to Köppen's classification, which is tropical hot and humid, with a rainy season from January to June and a dry season, from July to December. The average temperature is 25 °C and rainfall is around 1,800mm annually (NUGEO, 2015). Soils of the study sites are classified as Plintossols with clay texture and vegetation is classified as open ombrophylous forest with Babaçu (*Orbignya phalerata* Mart.) Arecaceae, secondary forest fallow regrowth which had suffered frequent previous slash-and-burn agriculture cycles. (Gehring et al., 2011).

Experimental design

The experiments were established in a randomized complete block design with three treatments and 15 replications, in a split plot arrangement. The treatments were rice, maize and rice intercropped with maize allocated to the plots and the mulch (0 and 23 t ha⁻¹ of dried babassu leaves) in the subplots. The experimental area was composed of 45 plots of 5.0 m x 10.0 m divided in 90 subplots of 5.0 m x 5.0 m. The useful area of each subplot was established in 4.0 m x 4.0 m. Mulching was done before planting in the end of December 2008, with two unprocessed whole dried leaves of the Babassu palm tree (*Orbignya phalerata* Mart.) on top of one another so that the soil was completely covered with the placement of two dried leaves of the Babaçu palm tree

(*Orbygnia phalerata* Mart.) on top of one another so that the soil was completely covered.

Plant materials

Land preparation for planting was done manually at the end of the dry season in November 2008. There was no soil plowing and no corrective and fertilizer applications.

Rice and maize were planted in pits at the beginning of the rainy season in January 2009 with manual planters that opened space in the straw sufficient for planting and seed germination.

The varieties of rice and maize were Bonança and BR - 106, respectively, which are planted regularly by farmers in the region.

For monocrop rice, it was planted in pits with a spacing of 0.40 m x 0.40 m with the consumption of 50 kg of seeds ha⁻¹. Maize was planted in rows with spacing of 1.0 m x 0.20 m with 20 kg of seeds ha⁻¹. In rice-maize intercropping, rice was planted in pits with the same spacing and seed consumption as in monocrop and maize was planted in rows with a spacing of 3.0 m x 0.10 m with a consumption of 7 kg of seeds ha⁻¹.

The manually harvested rice panicles and maize ears were sun dried and were manually threshed and the grains were weighed.

Assessment of rice and maize variables

The crop variables assessed were the number of tillers m⁻² at 30 days after emergence for rice and grain yield for both rice and maize expressed as kg grains ha⁻¹ corrected to 13% moisture.

Assessment of the weed seedbank traits

The effect of mulching on the weed seedbank germination was assessed *ex situ* right after crop harvest. For this, three soil samples were collected per subplot in July 2009 with an open metal rectangle with 25 cm in length 16 cm in width and 3 cm in depth. The rectangle was introduced into the soil. All the material delimited by the internal perimeter was removed.

The samples were placed in black plastic bags, labeled and transported to the School Farm of the Agrarian Sciences Center of the Maranhão State University in São Luis, where they were transferred to a greenhouse protected with 50% shading. Thereafter the soil samples were placed in aluminum trays of 25 cm in length, 16 cm in width and 5 cm in depth in July 2009. The trays were perforated to facilitate drainage and irrigated daily.

Three trays with washed sand were added to a batch of 90 samples to serve as test control. This was done due to the possibility of seed rain contamination of seeds from local weeds. No contamination was observed during the conduction time of the experiment.

The identification, counting and removal of the germinated species from the trays was done every fifteen days, during a period of 130 days, from August 2009 to February 2010. At 60 days, the irrigation was suspended for two weeks and the soil was revolved with the purpose of facilitating the germination of the seeds located in the lower part of the

trays. Seven evaluations were made, four before and three after water stress.

The botanical identification of the species was made by analyzing the external morphology of the vegetative and reproductive parts and the specialized bibliography, by comparison with other species already identified and also by consulting specialists. The species that could not be immediately identified were transplanted into plastic containers and cultivated until they reached the flowering period. The Angiosperm Phylogeny Group IV classification system was used (APG IV, 2016).

Statistical analyses

The weed germination density, the number of rice tillers and the grain yields of rice and maize were analyzed by Analysis of Variance. The means were compared by the Tukey test. Regression analysis was also performed according to the days after seed bank implantation. All analyzes were performed using the SAS / STAT program (SAS, 2011).

Conclusion

The use of mulch with unprocessed whole dried leaves of the babassu palm in one growing season reduced the germination of the weed seed bank by 55% in rice and maize grown in monocrop or in intercropping. Soil mulching with unprocessed whole dried of the babassu palm promotes a significant increase in the number of rice tillers and grain yield of rice and grain yield of maize.

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