CROP ROTATION REDUCES WEED COMPETITION AND INCREASES CHLOROPHYLL CONCENTRATION AND YIELD OF RICE[1]

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ABSTRACT - Crop rotation is an essential practice in sustainable agricultural systems, because its effects on soil fertility and other benefits including reduction on weed competition. A field experiment was carried out at the UEMA experimental station, São Luís, Maranhão State, Brazil, to evaluate the effect of crop rotation on weed population, leaf chlorophyll concentration and yield of rice (*Oryza sativa* L. cv. Guarani). The rice was cultivated with and without N application, and in rotation with cowpea (*Vigna unguiculata* (L.) Walp.), hyacinthbean (*Crotalaria paulina* Schrank) and velvetbean (*Mucuna aterrima* Piper & Tracy). First crop legume residues were highest in hyacinthbean, less in velvetbean and least in cowpea. They were left at soil surface as mulch for the second crop, which was cultivated in a minimum tillage system without using herbicides. At the second crop, weed biomass, weed cover, and weed density were lower in the hyacinthbean and velvetbean rotation than in continuous rice. Leaf chlorophyll concentration was greater in the hyacinthbean-rice sequence than in control plots. Rice yield was greater when rotated with hyacinthbean or velvetbean than in continuous crop with or without N application. It was concluded that legume in rice rotation reduces weed competition and improves the yield of rice.

Index terms: *Vigna unguiculata*, *Crotalaria paulina*, *Mucuna aterrima*.

A ROTAÇÃO DE CULTURA REDUZ A MATOCOMPETIÇÃO E AUMENTA O TEOR DE CLOROFILA E A PRODUTIVIDADE DO ARROZ

RESUMO - A rotação de culturas é uma prática importante em sistemas agrícolas sustentáveis pelos efeitos benéficos tanto na fertilidade do solo como na redução da matocompetição, entre outros. Este trabalho foi conduzido no campo experimental da UEMA, em São Luís, MA. Avaliou-se o efeito da rotação de culturas na incidência de plantas invasoras, nos teores de clorofila e na produtividade do arroz (*Oryza sativa* L. cv. Guarani). Cultivou-se o arroz com e sem adubação nitrogenada, bem como em rotação com caupi (*Vigna unguiculata* (L.) Walp.), crotalária (*Crotalaria paulina* Schrank) e mucuna (*Mucuna aterrima* Piper & Tracy). No primeiro ciclo a cobertura morta das leguminosas, deixada sobre o solo para a safra seguinte, foi máxima na crotalária, intermediária na mucuna e mínima no caupi. No segundo ciclo, cultivado em plantio direto sem uso de herbicidas, a rotação com mucuna e crotalária reduziu a biomassa, a cobertura e a densidade das invasoras. O teor de clorofila foi maior na rotação com crotalária do que na testemunha. A produtividade do arroz foi maior na rotação com crotalária e mucuna do que no arroz em cultivo sucessivo com ou sem N. Concluiu-se que a rotação do arroz com leguminosas aumenta a produtividade do arroz e reduz a matocompetição.

Termos para indexação: *Vigna unguiculata*, *Crotalaria paulina*, *Mucuna aterrima*.

INTRODUCTION

Crop rotation, the old practice of growing a sequence of plant species on the same land, is different from intercropping, which consists of cultivating two or more crops at the same time on the same area, or from continuous monoculture, which is the practice of growing a single species repeatedly on the same land. The positive effect of long-term rotations on crop yields has been recognized and exploited for centuries. During the last few decades, however, its benefits in terms of yield seem to have been ignored by many farmers (Crookston, 1984). It is now evident that crop rotation increases yield and that the practice is essential in sustainable agricul-

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tural systems (Mitchell et al., 1991); thus, the yield of barley in the traditional barley-soybeans rotation increased by including other winter crops in the rotation (Santos et al., 1993). In general long-term rotation is no longer included in crop production systems. Several factors have been related to reduced use of extended rotations, like the introduction of chemical fertilizer and pesticides (Crookston, 1984), mechanization, and improved crop varieties (Power & Follett, 1987). At present, short-term rotations and continuous cropping systems are commonly used in substitution to extended rotations. These cropping systems have been economically successful, unfortunately with some negative consequences, among which are the decrease in soil organic matter, increased soil degradation and erosion, and increased use of external input (Bullock, 1992).

In long-term experiments, Triplett et al. (1993) concluded that crop rotation may affect population of *Rhizobium meliloti*, but not various other soil characteristics such as organic matter, pH, nitrate, phosphorus and potassium. In a four-year experiment, continuous corn (*Zea mays*) produced less grain than corn grown in crop rotation (Peterson & Varvel, 1989). Further, corn following a legume in rotation produced maximum yield with 90 kg/ha of N, while continuous crop required at least 180 kg/ha of N for maximum yield, the rotation effect on soybean seed yield being less pronounced than for cereal crops. Nevertheless, Hesterman et al. (1987) suggested that the N-credit commonly attributed to legumes in crop rotation may be overestimated by as much as 132%. Although many of the beneficial effects of crop rotation are due to its effect on plant nutrient contribution, there are other rotation benefits, called the rotation effect, that cannot be compensated by synthetic chemicals (Baldock et al., 1981; Hesterman et al., 1987). Beneficial, non-N effects of rotation have been reported, including improvements in root activity (Copeland et al., 1993), soil chemical, physical or biological properties (Norton et al., 1995; Pankhurst et al., 1995), reduction in disease (Cook & Haglund, 1991) and nematode incidence (Walters, 1980), and also to a decrease in weed competition (Walker & Buchanan, 1982; Blackshaw et al., 1994).

Crop rotation may be an effective practice for controlling serious weeds because it introduces conditions that affect weed growth and reproduction, which may greatly reduce weed density (Derksen et al., 1993; Blackshaw et al., 1994). In addition, Forcella & Lindstrom (1988) reported that after seven to eight years of weed management the number of weed seeds was about six times greater in continuous crop than in a rotated system. Another benefit of crop rotation may be associated with a smaller chance of selecting troublesome weeds, because crop rotation sequence also determines herbicide use and crop rotation and herbicide can interact to affect weed species (Ball, 1992). Therefore, the practice of rotating crops and herbicides has proved to be successful in influencing weed populations and improving crop production (Walker & Buchanan, 1982), and given the increased attention paid to agroecosystem biodiversity, adopting weed management strategies that promote weed species diversity could be encouraged (Clements et al., 1994). The objective of this study was to evaluate the effect of crop rotation on weed populations, chlorophyll concentrations, and yield of rice.

MATERIAL AND METHODS

A field experiment was carried out at the UEMA experimental station, São Luís, Maranhão State (2°35' S; 44°10' W). The soil type was a Red Yellow Podsol (Oxisol) with sandy texture (25% coarse sand, 55% fine sand, 10% silt, and 10% clay). Soil tests made at the beginning of the study indicated that this soil had a low natural fertility (7 mg/kg of P, and 0.9, 15 and 15 $mmol_c$/kg of K, Ca and Mg, respectively). Means of temperatures and solar radiation were 26°C and 4.000 $kcal/m^2$.day, respectively. Average rainfall during the wet season of the year, from December to July, was 2.100 mm. The experiment was a randomized complete block design with four replications, and 4x5-m plots. The treatments were: rice with N application (26 g/m^2 of N as urea) cultivated after fallow, and rice in rotation with cowpea, hyacinthbean and velvetbean. The control was rice in continuous crop without N application. The rice, cowpea, and hyacinthbean were planted in rows separated 0.4 m at a density of 40 to 50 seeds/m, whereas velvetbean was planted in 1-m row apart and five seeds per meter. The experimental area was tilled conventionally before the first crop season. It received (g/m^2): 1.4 of P as P_2O_5, 3.4 of K as K_2O, and 0.2 of S and

0.5 of Zn as $ZnSO_4.7H_2O$ before planting. The first crop was sowed in July 1995, and cultivated without use of herbicide. At the end of the crop cycle, the plants were harvested, and their biomass left at soil surface, as a mulch for the next crop. Further, during the first cropping period, weed cover and weed biomass were assessed in 0.4x0.4-m samples at 30 days after emergence (DAE), and shoot dry matter accumulation of crops determined at the end of plant cycle.

The second crop was planted in January 1996 in a reduced tillage system, without use of herbicides. No synthetic fertilizer was used during this experimental period, except for the rice plus N treatment. Density and biomass of weeds (0.16-m^2 samples) and weed cover were also evaluated at 40 DAE of rice. Weed cover was assessed by using a 50-cm string placed at 20 cm above the tallest weeds. All weed canopies projected over the line string were tallied and in this way, total weed cover determined. At sampling time, weeds were severed at soil surface, identified, and separated into species groups. Shoot of weeds were oven-dried at 72°C until reaching constant mass (about 72 hours), and weighed. At 60 DAE, rice leaf area in ten randomly selected plants was measured (Licor 3100 A, area meter), and at the same sampling time, leaf chlorophyll concentration was determined. For chlorophyll determination, five 9-mm diameter discs were taken from the third upper leaf of three randomly selected plants. The discs were immediately weighed, and chlorophyll extracted in 80% acetone, and its concentration determined according to Lichtenthaler (1987). At harvest, the following yield components in the central rows were determined: number of panicles, spikelets per panicles, 100-seed biomass, and dry weight of grain (14% humidity). To homogenize variance, data derived from weighing and counting were transformed to log(Y+1) and $(Y+0.5)^{0.5}$, respectively, before conducting analysis of variance.

RESULTS AND DISCUSSION

In the first crop cycle there was no effect of crop plants on weed populations, dry matter accumulation and weed cover at 30 DAE (Table 1), which may suggest that these crops did not affect either weed seed germination or weed growth and development. Total crop dry matter residues at harvest was greater in either hyacinthbean (1,460 g/m^2) or velvetbean (997 g/m^2) than in rice, which produced only 412 g/m^2 of residues (Table 1).

A total of 35 weed types were recorded in the second crop. The most abundant weeds were *Cyperus* spp., *Spigelia anthelmia* L. and *Turnera ulmifolia* L. Less common species, grouped as "other species" for statistical analyses, included *Indigofera hirsuta* L., *Mollugo verticillata* L., *Panicum hirtum* Lam., *Borreria verticillata* (L.) Mey, *Brachiaria plantaginea* (Link) Mitchc., *Cenchrus brownii* R. & S., *Centratherum punctatum* Cass., *Chamaecrista nictans* (Chod & Hassl.) Irwin & Barneby, *Cleome affinis* D.C., *Commelina benghalensis* L., *Crotalaria retusa* L., *Croton grandulosus* L., *Croton lobatus* L., *Dactyloctenium aegyptium* (L.) Asch. & Schw., *Digitaria horizontalis* Willd., *Eleusine indica* L. Gaertn., *Emilia sonchifolia* D.C., *Eragrostis ciliares* (L.) R.Br., *Mariscus flavus* Vahl, *Marsypianthes chamaedrys* (Vahl) O. Kuntze, *Mimosa pudica* L., *Mitracarpus* sp., *Panicum cayenense* Lam., *Phyllanthus amarus* Schum., *Phyllanthus orbiculatus* L.C. Rich., *Physalis angulata* L., *Sacciolepis* sp., *Sebastiania corniculata* M. Arg., *Scoparia dulcis* L. *Setaria tenax* (Rich.) Desv., *Sida rhombifolia* L. and *Zornia curvata* Mohl.

Because of the high coefficient of variation observed for weed dry matter accumulation, it was not possible to detect effects of rotation on biomass of individual weed species (Table 2). Frick & Thomas (1992) also observed similar data variability in weed surveys in different cropping systems. Nevertheless, when statistical analysis included data of several weed species the coefficient of variation decreased, becoming evident that hyacinthbean and velvetbean rotation reduced both weed dry matter accumulation and weed cover (Table 2). Weed density of individual weed species showed the same trend as observed for dry matter accumulation. That is, cowpea, hyacinthbean and especially velvetbean reduced weed populations (Table 3). The high variability observed in weed density and mainly in weed dry matter accumulation may be due to weed seed germination physiology, which determines germination rates and weed seedbank over time.

Hyacinthbean and velvetbean rotations reduced weed cover, total weed dry matter accumulation and weed density by about 70, 80 and 90%, respectively, in comparison to continuous rice. These reductions may be important in crop production systems since weed competition in rice is considered to be critical during the first weeks of rice growth (Moody, 1993), especially when it is taken into account that no herbicides were used during the experiment. A high correlation (r = 0.98**) between density and dry matter of weeds was observed in the second crop. Since weed dry matter accumulation in this cycle was correlated with dry matter residues left during the

TABLE 1. Effects of rotations on both weed cover and weed dry matter at 30 days after emergence, and total biomass of crops at the end of the first cycle[1].

Treatments	Total weed dry matter (g/m^2)	Weed cover (%)	Total crop dry matter (g/m^2)
Rice - rice	71.77a	70.00a	412.30c
Fallow - rice + N	87.35a	82.32a	-
Cowpea - rice	77.45a	81.75a	606.40c
Hyacinthbean - rice	73.37a	83.50a	1460.10a
Velvetbean - rice	99.46a	74.00a	997.10b
CV (%)	43.20	23.50	44.00

[1] Within columns, means followed by the same letters are not significantly different at $P \leq 0.05$ as determined by the Duncan test.

TABLE 2. Effects of rotations on dry matter accumulation of *Cyperus* spp., *Spigelia anthelmia*, *Turnera ulmifolia* and other weed species, and weed cover at 40 days after crop emergence in the second crop[1].

Treatments	Dry matter accumulation (g/m^2)					Total weed cover (%)
	Cyperus spp.	*S. anthelmia*	*T. ulmifolia*	Other weeds	Total of weeds	
Rice - rice	4.38a	24.00a	5.94a	86.56a	120.88a	88.20a
Fallow – rice + N	5.44a	11.06a	1.56a	60.63ab	78.69ab	62.00b
Cowpea - rice	0.69a	18.25a	0.06a	38.13bc	57.13b	31.20c
Hyacinthbean - rice	1.19a	10.00a	2.25a	20.81b	34.25c	22.20cd
Velvetbean - rice	0.00a	8.88a	1.56a	6.69c	17.13d	13.20d
CV (%)	188.98	57.43	165.73	24.74	8.18	17.00

[1] Within columns, means followed by the same letters are not significantly different at $P \leq 0.05$ as determined by the Duncan test.

TABLE 3. Effects of rotations on density of *Cyperus* spp., *Spigelia anthelmia*, *Turnera ulmifolia*, other weed species, and total weed population at 40 days after crop emergence in the second crop[1].

Treatments	Weed density ($plants/m^2$)				
	Cyperus spp.	*S. anthelmia*	*T. ulmifolia*	Other weeds	Total of weeds
Rice - rice	107.81a	176.56a	15.63a	384.38a	684.38a
Fallow – rice + N	60.94a	53.13ab	15.63a	232.81b	362.51b
Cowpea - rice	7.81a	50.00ab	1.56a	128.13b	187.50c
Hyacinthbean - rice	7.81a	17.19ab	4.69a	101.56c	131.25c
Velvetbean - rice	0.00a	6.25b	4.69a	18.75c	29.69d
CV (%)	98.36	55.98	50.65	26.53	22.55

[1] Within columns, means followed by the same letters are not significantly different at $P \leq 0.05$ as determined by the Duncan test.

first cycle (r = 0.76*), the negative effect of crop rotation on abundance of weeds may be due to the inhibitory effect of legume residues on weed seed germination, either by production of allelochemicals, reduction on light levels at soil surface or directly by acting as a physical barrier impeding weed seedling development. The reduction of weed competition due to crop rotation observed in this experiment is in agreement with previous field investigations in which cropping sequence reduced weed density (Blackshaw et al., 1994; Loeppky & Derksen, 1994). On the other hand, Walker & Buchanan (1982) cited the allelophathic potential of residues on weed control. These results suggest that the use of hyacinthbean and velvetbean rotation in sustainable rice production system may be a useful practice for reducing weed competition in reduced tillage systems.

Leaf area was greater in the hyacinthbean rotation (132.26 dm^2/m^2) than in continuos rice (47.88 dm^2/m^2), with intermediate values for rice rotated with cowpea or velvetbean (Table 4). Chlorophyll a and b, and total chlorophyll concentrations were greater in rice treated with N than in rice rotated with the leguminous crops (Table 4). Levels of total chlorophyll ranged from 2.5 mg/g FW in plots treated with N to 1.18 mg/g FW in the cowpea rotation, with no difference among cowpea, velvetbean and the continuous rice. Nevertheless, a greater amount of chlorophyll (1.82 mg/g FW) was observed in the hyacinthbean-rice rotation than in control plots (1.36 mg/g FW), which suggests high levels of N fixation in hyacinthbean plants. Cowpea and velvetbean showed no effect on leaf chlorophyll concentration, which may be due to a low level of N fixation in these legumes. Even when N application accounted for the highest levels of chlorophyll, a parameter highly responsive to nitrogen availability in the soil, leaf area followed a different trend, which shows the importance of other non-N benefit effects of legumes in enhancing plant growth, as reported by Crookston et al. (1991) and Copeland et al. (1993) for the corn-soybean rotation. Yield components of rice grain followed a similar trend as foliage production, greater values being observed in rotation systems than in continuous rice. Panicle number and spikelets per panicle were greater in the hyacinthbean-rice rotation than in the cowpea-rice or velvetbean-rice sequence, whereas individual seed weight was not much affected by crop rotation (Table 5). The yield of grains was greater in the hyacinthbean (117.10 g/m^2) or velvetbean (95.17 g/m^2) rotation than in continuous rice (22.24 g/m^2) with input of N. These results suggest that the use of hyacinthbean or velvetbean may be a good agronomic practice in small farmer rice production systems.

TABLE 4. Effects of rotations on rice leaf area and leaf chlorophyll (chl a, chl b, chl a+b) concentrations at 60 days after emergence in the second crop[1].

Treatments	Leaf area (dm^2/m^2)	Leaf chlorophyll concentrations		
		Chl a (mg/g FW)	Chl b (mg/g FW)	Chl a + Chl b (mg/g FW)
Rice - rice	47.88c	0.94c	0.43b	1.36c
Fallow - rice + N	98.73b	1.83a	0.67a	2.50a
Cowpea - rice	78.16b	0.84c	0.36b	1.18c
Velvetbean - rice	104.79b	1.10c	0.37b	1.47c
Hyacinthbean - rice	132.26a	1.36b	0.46ab	1.82b
CV (%)	18.80	16.80	32.20	13.30

[1]Within columns, means followed by the same letters are not significantly different at $P \leq 0.05$ as determined by the Duncan test.

TABLE 5. Effects of rotations on yield components of rice at harvest time in the second crop[1].

Treatments	Panicles (number/m^2)	Spikelets per panicle	Grain mass (g/m^2)	100-seed dry matter
Rice - rice	32.16b	3.20c	14.08c	2.33b
Fallow - rice + N	34.30b	5.80ab	22.24bc	3.15a
Cowpea - rice	50.04b	4.30bc	35.10b	3.15a
Velvetbean - rice	88.16a	6.87a	95.17a	3.59a
Hyacinthbean - rice	88.39a	7.45a	117.10a	3.17a
CV (%)	32.06	19.22	30.42	11.15

[1]Within columns, means followed by the same letters are not significantly different at $P \leq 0.05$ as determined by the Duncan test.

CONCLUSIONS

1. The use of velvetbean or hyacinthbean reduces weed competition in crop rotation systems.
2. The rotation of rice with velvetbean or hyacinthbean increases the yield of rice.
3. Nitrogen application at a rate of 26 g/m^2 does not substitute the legume rotation effect.
4. Hyacinthbean cultivated in rotation with rice increases rice chlorophyll concentrations.

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