Weed management in a low-input cropping system in the Peruvian Amazon region

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A weed-control study in a five-crop sequence [rice–rice–cowpea–rice–cowpea] following forest clearing of a Typic Paleudult in the Peruvian Amazon had the following objectives: (1) to determine the magnitude of the weed problem during the transition from secondary forest to continuous cropping; (2) to measure the effect of weed infestation on crop yields; and (3) to test cultural practices that could form the basis of a weed-management programme for a continuously cropped, low-input system. Tillage and residue mainplot treatments were: (1) rototill with previous crop residues incorporated; (2) rototill with residues mulched; and (3) no-till with residues mulched. A factorial arrangement of two crop planting densities (high and low) and three weed control practices (hand weed, herbicide and no control) comprised the subplot treatments. Tilled plots had more weeds than untilled in the first crop but fewer in the fifth. Mulching residues had little weed-controlling effect, and crop yields were always higher when residues were incorporated. High planting density reduced weed levels and increased crop yields. Herbicides were as effective as hand weeding in controlling weeds, but herbicide costs sharply limit their use in low-input systems. Rice yields fell by 54–100% in the absence of weed control but were reduced by less than 30% for cowpea. Sedges comprised 84% of the weeds in the first crop following forest clearing, but grasses dominated (79%) in the fifth crop.

Keywords: Weed management; Herbicides; Mulches; Planting density; Shifting cultivation; Forest clearing; Peruvian Amazon

Forest fallow performs two essential functions under shifting cultivation: (1) it restores soil fertility so that one or two food crops can be grown without the addition of soil nutrients; and (2) it disrupts the invading weed community, allowing farmers to grow at least one crop with little or no weed control. Replacing shifting cultivation with continuous cropping requires other measures for maintaining soil fertility and controlling weeds.

Previous work has established that continuous cropping systems in the Peruvian Amazon are viable alternatives to shifting cultivation if appropriate amounts of lime and fertilizers are supplied (Nicholaides *et al.*, 1985). Herbicides have provided effective but costly weed control in these intensively managed (high-input) systems (Mt Pleasant *et al.*, 1990).

Low-input systems are based on acid-tolerant cultivars and rely on moderate amounts of fertilizers and careful recycling of crop residues to maintain soil fertility (Nicholaides *et al.*, *ibid*; Sanchez and Salinas, 1981; Sanchez and Benites, 1987). But weed control in this management system poses special problems. Complete reliance on herbicides is unacceptable because of the cost, and hand labour is often unavailable.

Weed control in a low-input system must focus on cultural practices that increase the crop's ability to compete with weeds and thereby eliminate some of the costly control measures needed to maintain yields. Timely fertilization (Ahmed, 1981; Kang *et al.*, 1980; Moody, 1978), increased crop planting density (Ahmed and Hogue, 1981; Akobundu and Ahisson, 1985; Ghafar and Watson, 1983; Moody, *ibid.*, Nangju, 1978; Tosh *et al.*, 1981), use of mulches (Lal, 1975, 1978; Liebl and Worsham, 1983; Shilling and Worsham, 1983; Shilling *et al.*, 1986), tillage methods and the use of appropriate cultivars (Akobundu and Ahisson, *ibid.*; Burnside, 1972; McWhorter and Hartwig, 1972; Minotti and Sweet, 1981; Moody, *ibid.*; Nangju, *ibid.*) are all examples of such practices. They have been used successfully in a variety of cropping systems in both temperate and tropical environments to provide effective weed control.

The objectives of this experiment were: (1) to determine the magnitude of the weed problem during the transition from secondary forest to continuous cropping; (2) to measure the effect(s) of weed infestation on crop yields and to identifv weed species or weed groups posing the greatest problems; and (3) to test cultural practices for a weed-management programme in a continuously cropped, low-input system in the humid tropics.

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Table 1 Chronology of weed-control measures and rate(s) of herbicide applied during five cropping cycles under two tillage regimes, Yurimaguas, 1983–1985

Crop No.	Tillage	Weed control*	Herb. rate (kg ha^{-1})	Chronology DAP⁺
1 Rice	Rototill	Hand weed	–	24
		Propanil (band)	2.9	9
	No-till	Hand weed	–	24
		Glyphosate + propanil (band)	2.3, 2.9	Preplant, 9
2 Rice	Rototill	Hand weed	–	32
		Oxadiazon + propanil	1.0, 4.3	0, 45
	No-till	Hand weed	–	32
		Paraquat + 2, 4-D	0.5, 1.0	Preplant
		+ propanil	4.3, 3.6	25, 45
3 Cowpea	Rototill	Hand weed	–	24
		Metolachlor	2.3	1
	No-till	Hand weed	–	24
		Paraquat + metolachlor	0.5, 2.3	Preplant
4 Rice	Rototill	Hand weed	–	31, 49
		Oxadiazon + propanil	0.8, 4.0	1, 50
	No-till	Hand weed	–	31, 43
		Paraquat + oxadiazon	0.5, 0.8	Preplant
		+ propanil	4.0	50
5 Cowpea	Rototill	Hand weed	–	29
		Metolachlor	2.3	1
	No-till	Hand weed	–	28
		Paraquat + metolachlor	0.5, 2.3	1

* Each crop × tillage combination also has a 'No control' treatment
⁺ DAP, Days after planting
Oxadiazon (3-[2, 4-dichloro-5-(1-methylethoxy) phenyl]-5-(1, 1-dimethyl)-1, 3, 4-oxadiazol-2-(3*H*)-one)
Metolachlor (2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methylethyl) acetamide

Methods

The study was initiated in October 1983 at the Yurimaguas Research Station in eastern Peru (5° 45′ S, 75° 5′ W, 182 m above sea level) on a fine-loamy, siliceous, isohyperthermic Typic Paleudult. Mean annual temperature is 26°C with little monthly or daily variation. Average annual precipitation is 2100 mm, with a distinct dry season from June through August when average monthly rainfall drops to about 100 mm.

The environment allows three short-cycle crops to be grown in one year. A low-input management system using acid-tolerant cultivars of rice (*Oryza sativa* L.) and cowpea (*Vigna unguiculata* (L.) Walp.) has proved successful under local conditions (Nicholaides *et al.*, *ibid.*). Two consecutive upland rice crops are grown during the rainy season that begins in September. The second rice crop is followed by cowpea, which must be harvested in the dry season to avoid crop loss from diseases. We studied weed control in this management system in a five-crop sequence of rice–rice–cowpea–rice–cowpea, identified in this Paper as Crops 1, 2, 3, 4 and 5.Total elapsed time was 21 months.

The experimental design was a split-plot arrangement. Tillage and residue management whole-plot treatments were: (1) rototill, with previous crop residues incorporated; (2) rototill, with residues mulched; and (3) no-till, with residues mulched. A factorial arrangement of two planting densities (high and low) and three weed control practices (hand weed, herbicide and no control) comprised the sub-plot treatments.

Vegetation (brush, shrubs and trees) in a ten-year-old secondary forest was cut three months before the first crop was planted. It was burned accidentally six weeks before the scheduled planting date so glyphosate (*N*-(phosphonomethyl)glycine) at 2.3 kg ha^{-1} was applied to all no-till main plots to approximate the effect of fire in removing vegetation just before planting. Tillage operations removed existing vegetation in the other main plots.

Main-plots with tillage were rototilled about 12 cm deep with a tractor-mounted rototiller. After crop harvest, standing vegetation was cut by hand, chopped, and removed from all plots. When the field was ready to be replanted, residues were incorporated with the rototiller prior to planting, or spread as mulch after planting, as dictated by treatment.

All crops were planted by hand with a planting stick. The rice cultivar was 'Africano Desconocido'. Because of a seed shortage, two cultivars of cowpea (Vita 6 and Vita 7) were planted in Crop 3 but Vita 7 alone was used in Crop 5. Rice was planted at 81 600 (35 × 35 cm) and 57 100 hills ha^{-1} (35 × 50 cm) to give the two crop planting densities. There were 6–10 seeds per hill. Cowpea populations were planted at 114 200 (25 × 35 cm) and 57 100 hills ha^{-1} (50 × 35 cm) with 2–3 seeds per hill.

Weed control treatments and their times of application in each crop are listed in Table 1. Dependent on the severity of weed infestation, hand-weeded plots were weeded once or twice to prevent yield losses. Herbicide treatments were selected to provide a moderate level of weed control and were adjusted according to the intensity of weed infestation. In Crop 1, propanil (*N*-(3, 4-dichlorophenyl)propanamide) was banded between the rice rows to minimize phytotoxicity problems due to an unsuspected contamination with paraquat (1, 1′-dimethyl-4, 4′-bipyridinium ion). Uncontaminated propanil was applied broadcast to rice in Crops 2 and 4. Herbicides were applied with a CO_2 back-

Table 2 Mean total weed weight (g m^{-2}) for each treatment in five consecutively-planted crops. Yurimaguas, 1983–1985

Treatment				Crop				
Tillage	Residue Mngmt.	Planting density	Weed control	1 Rice	2 Rice	3 Cowpea	4 Rice	5 Cowpea
No-till	Mulched	Low	No control	48	207	133	399	280
			Herbicide	10	29	4	90	84
			Hand weed	0	2	22	135	25
		High	No control	76	204	72	541	262
			Herbicide	15	12	7	70	43
			Hand weed	3	63	8	104	17
Rototill	Mulched	Low	No control	538	169	115	507	186
			Herbicide	180	15	4	84	65
			Hand weed	34	5	23	40	4
		High	No control	454	128	50	563	54
			Herbicide	251	31	9	68	33
			Hand weed	32	8	7	42	3
Rototill	Incorporated	Low	No control	–	228	209	591	125
			Herbicide	–	16	49	170	72
			Hand weed	–	5	19	48	4
		High	No control	–	162	99	509	83
			Herbicide	–	8	15	33	15
			Hand weed	–	8	9	5	3

pack sprayer through a four-nozzle boom with T-Jet 8003 nozzles on 0.5 m spacing. Spray volume was 305 l ha^{-1} at 21 kPa.

No fertilizer was applied to rice in Crop 1. Soil samples were taken prior to each harvest and the analyses were used to determine fertilizer needs in succeeding crops. Although P may have been limiting in Crops 4 and 5, none was applied because it could not be incorporated uniformly in both rototilled and no-till plots. A split application of broadcast potash fertilizer (80 kg ha^{-1}) was made in Crop 2; potassium levels were adequate for crop growth throughout the rest of the experiment. Nitrogen, as urea, was broadcast in split applications to rice in Crops 2 and 4 (70 and 50 kg ha^{-1}, respectively).

Weeds were sampled approximately six weeks before crop maturity in Crops 1 and 2, and one week before harvest in Crops 3 through 5. Sample size was 0.25 m^2 in Crops 1 and 2, and 0.5 m^2 for the remainder of the experiment. Two samples were taken from each plot and composited. Weeds were cut at ground level, separated by species, and weighed after drying for one week at 70°C. Weeds were grouped as sedges, broadleaf weeds, grasses or dayflower (*Commelina* spp.) for statistical analysis.

Treatments were replicated three times. Location of treatments within replications was randomized at the onset of the experiment and then maintained through all five cycles. Plot size was 6 × 6 m. Crops were harvested from 9 m^2 in the centre of each plot.

Analysis of variance was at first performed crop by crop (i.e. five separate analyses). Since there was no residue management variable in Crop 1, this crop was then dropped and Crops 2 through 5 were combined and analysed as a single experiment. Planned single-degree-of-freedom contrasts were made for the crop-by-crop and combined analyses. Blocks are considered to be random effects, while treatments are fixed. In addition, regression analyses were used to relate total weed weight and relative crop yield for each crop.

Results

Treatment means (weed biomass and grain yields) for each crop are presented in Tables 2 and 3. Analysis of data from Crop 1 is presented separately, but for the remaining crops only the combined analysis is given. Relative yields are used to compare product yields across crops. Relative yield is defined as the absolute yield divided by potential yield, where potential yield is the highest yielding treatment or group of treatments in each crop. For Crops 2 and 3 potential yield was the mean of all hand-weeded plots (both rototill and no-till) planted at the higher density. For Crops 4 and 5 it was the mean of the rototilled plots which were hand-weeded and planted at the higher density.

Main effects (Figure 1), Crop 1

Tillage

Rototilled plots had nearly ten times the weed weight as no-till plots, but rice yields were not affected by tillage. Poor germination in many no-till plots reduced rice stands. Although no-till plots were relatively weed-free, rice yields were not greater than in rototilled plots which had large weed infestations.

Crop density

Weed biomass was unaffected by planting density, but rice yields were greater at the higher density.

Weed control

Hand-weeded plots had lower weed weights and more rice than plots treated with herbicide. Propanil banded in the row centres was not as effective as hand-weeding, particularly in rototilled plots where sedge infestation was heaviest.

Tillage × weed control interaction

Weed weight was much greater in rototilled plots

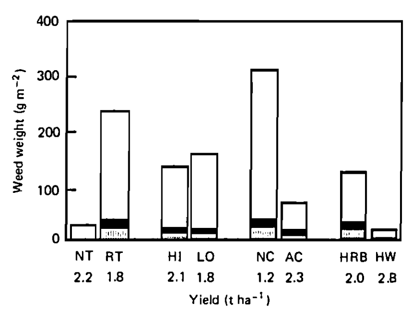
Table 3 Crop yield means for each treatment (t ha^{-1}) in five consecutively-planted crops. Yurimaguas, 1983–1985

Treatment				Crop				
Tillage	Residue Mngmt.	Planting density	Weed control	1 Rice	2 Rice	3 Cowpea	4 Rice	5 Cowpea no-till
No-till	Mulched	Low	No control	1.7	0.3	1.0	0	0.5
			Herbicide	2.0	1.5	1.6	0.9	1.6
			Hand weed	2.1	2.1	1.5	0.7	1.0
		High	No control	1.8	0.7	1.1	0	0.5
			Herbicide	2.6	2.5	1.4	1.4	1.0
			Hand weed	2.8	2.5	1.4	0.9	0.9
Rototill	Mulched	Low	No control	0.7	0.8	1.1	0	0.9
			Herbicide	1.6	1.7	1.3	1.0	0.9
			Hand weed	2.7	2.2	1.1	1.4	0.9
		High	No control	0.6	1.1	1.0	0	1.0
			Herbicide	1.8	2.2	1.3	1.4	0.9
			Hand weed	2.9	2.5	1.4	1.4	1.1
Rototill	Incorporated	Low	No control	–	0.8	0.8	0	0.9
			Herbicide	–	2.5	1.5	1.4	1.1
			Hand weed	–	2.1	1.5	1.4	1.0
		High	No control	–	1.2	1.1	0	1.0
			Herbicide	–	3.0	1.2	1.7	1.0
			Hand weed	–	2.6	1.4	1.8	1.0

Table 4 Significant interactions between tillage, crop density and weed control in Crop 1, Yurimaguas, 1983–1985

Interaction		Weed weight (g m^{-2})			Crop yield (t ha^{-1})		
Tillage × Weed control		Hand weed		Herbicide	Hand weed		Herbicide
			Total weeds			Rice	
	No-till	1		12	2.4		2.3
	Rototill	33		207	2.8		1.7
	P		< 0.01			0.01	
Planting density × Weed control		No control		All control[+]			
			Total weeds				
	Low	342		69	–		–
	High	265		74	–		–
	P		< 0.01				

[+] All control, all treatments with weed control (includes hand weed and herbicide)



	Mean	CV (%)	*P* for each comparison			
Total weeds	147	41	<0.01	0.79	<0.01	<0.01
Sedge	123	52	<0.01	0.68	<0.01	<0.01
Grass	8	298	0.36	0.71	0.29	0.08
Broadleaf	16	122	0.19	0.30	<0.01	<0.01
Rice	1.93	32	0.48	0.04	<0.01	<0.01

Figure 1 Effect of tillage, planting density and weed control practice on weed infestation and crop yield [crop 1 (rice) of a five-crop experiment], Yurimaguas, 1983. Mean values are given in g m^{-2} for weeds and t ha^{-1} for rice. NT, no-till; RT, rototill; HI, high planting density; LO, Low planting density; NC, no weed control; AC, all treatments with weed control; HRB, herbicide; HW, hand weed. ■, grass; □, sedge; ▥, broadleaf

when weeds were controlled with herbicides, but there was little difference between the two tillage treatments in the hand-weeded plots. Under no-till, herbicide-treated and hand-weeded plots yielded similarly, but rototilled plots that were hand weeded yielded more than those treated with herbicide (Table 4).

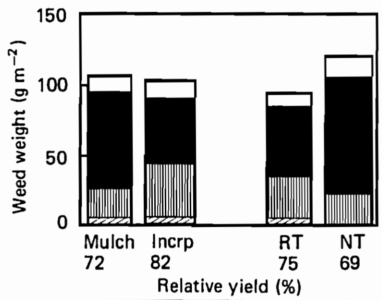
Planting density × weed control interaction

In plots with low weed biomass (those with weed control), density had no effect on weed infestation; but the higher rice density reduced weed biomass in no-control plots where weed levels were much higher (Table 4).

Main effects, Crops 2–5 combined

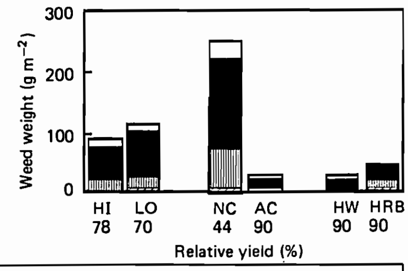
Residue management

There were no differences in total weed weight between mulched and incorporated residues, but relative crop yields were higher when residues were incorporated (Figure 2). Broadleaf weeds comprised 22% of the weeds in mulched treatments, but 39% in plots where residues were incorporated. By contrast, grasses comprised more of the weed population with mulching (64 *vs* 43%).



	Mean	CV (%)	P for each comparison	
Total weeds	106	64	0.68	0.01
Sedge	12	272	0.88	0.06
Grass	62	122	0.07	0.02
Broadleaf	29	165	0.06	0.41
Dayflower	3	341	0.23	0.01
Relative yield (%)	74	32	<0.01	0.03

Figure 2 Effect of residue management and tillage on weed infestation and crop yield in a four-crop sequence (crops 2–5), Yurimaguas, 1984–1985. Incrp, residue incorporated; RT, rototill; NT, no-till. Mean values are given in g m^{-2} for weeds and percentage relative yield for crops. ■, grass; □, sedge; ▥, broadleaf; ▨, dayflower



	Mean	CV (%)	P for each comparison		
Total weeds	106	64	<0.01	<0.01	0.12
Sedge	12	272	0.77	<0.01	0.58
Grass	62	122	0.04	<0.01	0.76
Broadleaf	29	165	0.50	<0.01	0.18
Dayflower	3	341	0.75	0.09	<0.01
Relative yield (%)	74	32	<0.01	<0.01	0.80

Figure 3 Effect of crop density and weed control practice on weed infestation and crop yield in a four-crop sequence (crops 2–5), Yurimaguas, 1984–1985. Mean values are given in g m^{-2} for weeds and percentage relative yield for crop. HI, high planting density; LO, low planting density; NC, no weed control; AC, all treatments with some weed control measure; HW, hand weed; HRB, herbicide. See Figure 2 for symbols

Tillage

No-till plots had larger weed weights and lower relative yield than rototilled plots. Grasses comprised 70% of the weeds in no-till but only 53% when plots were rototilled (Figure 2).

Planting density

There was lower weed biomass and higher yields when crops were planted at the higher density (Figure 3).

Weed control

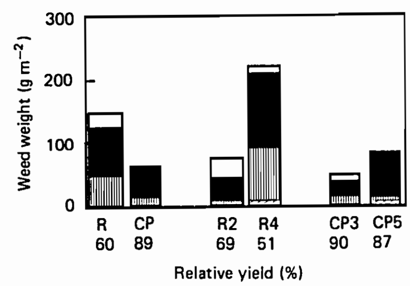
Plots with weed control had lower weed biomass and higher crop yields than plots with no weed control, but there were no weed or crop yield differences between plots which were hand weeded and those which received herbicide (Figure 3).

Crop species

Rice had higher weed weights and lower relative yields than cowpea. The composition of the weed population was also distinctly different in the two crops. Broadleaf weeds comprised more than 30% of the weed population in rice but only 19% in cowpea. Grasses were 69% of the weeds in cowpea and 54% in rice; sedges comprised 12% of the weeds in rice but only 5% in cowpea (Figure 4).

The two rice crops also showed distinct differences. Crop 2 rice had lower weed biomass and higher relative yields than Crop 4 rice. Composition of the weed population was different in the two rice crops. Crop 2 rice had more than 40% sedges but these species comprised just 3% of the weeds in Crop 4. Broadleaf weeds represented 11% of the weeds in Crop 2, but increased to 38% in Crop 4. Grasses were 49% of the weeds in Crop 2 and 56% in Crop 4.

Cowpea crops also differed. Crop 5 cowpea had more weed biomass than Crop 3 cowpea, but there were no differences in relative yields between the two crops. Broadleaf weeds comprised 36% of the weed population in Crop 3 cowpea but only 9% in Crop 5 cowpea. Grasses increased from 47% of total weeds in Crop 3 to almost 80% in Crop 5.



	Mean	CV (%)	P for each comparison		
Total weeds	106	64	<0.01	<0.01	0.1
Sedge	12	272	0.02	0.01	0.56
Grass	62	122	0.03	<0.01	0.06
Broadleaf	29	165	0.01	<0.01	0.52
Dayflower	3	341	0.95	0.06	0.07
Relative yield (%)	74	32	<0.01	0.06	0.78

Figure 4 Between-species and within-species comparisons of weed infestation and relative crop yield in a four-crop sequence (crops 2–5), Yurimaguas, 1984–1985. Mean values are given in g m^{-2} for weeds and percentage relative yield for crops. R, rice; CP, cowpea; R2, crop 2 rice; R4, crop 4 rice; CP3, crop 3 cowpea; CP5, crop 5 cowpea. See Figure 2 for symbols

Crop species × residue management interaction

Residue management affected crop yields differently, and the direction of the residue effect as well as its magnitude depended on the crop. There were no differences in cowpea yields between plots which were mulched and those with incorporation. By contrast, rice yields were much higher when residues were incorporated (Table 5).

The effect of mulching on weed infestation was not consistent between the two cowpea crops. With mulching, total weed weight was lower in Crop 3 cowpea but higher in Crop 5 cowpea.

Table 5 Significant interactions between residue management, crop, planting density and weed control in combined analysis (Crops 2 through 5). Yurimaguas, 1984–1985

Interactions	Total weeds (g m^{-2})			Relative yield (%)		
A. Crop species × Residue management				Rice		Cowpea
Mulched	–		–	56		88
Incorporated	–		–	73		90
P					0.04	
Cowpea × Residue management	Crop 3		Crop 5			
Mulched	39		94	–		–
Incorporated	67		50	–		–
P		0.04			0.04	
B. Crop species × Weed control	Rice		Cowpea	Rice		Cowpea
No control	349		146	15		73
All control⁺	48		23	83		97
P		< 0.01			< 0.01	
Rice × Weed control	Crop 2		Crop 4	Crop 2		Crop 4
No control	186		511	30		1
All control	78		18	77		89
P		< 0.01			0.04	
Cowpea × Weed control	Crop 3		Crop 5			
No control	111		180	–		–
All control	14		32	–		–
P		0.02				
C. Residue Management × Planting density	Mulched		Incorporated			
Low	111		128	–		–
High	103		79	–		–
P		0.01				

⁺ All control, all treatments with weed control (includes hand weed and herbicide.)

Crop species × weed control interaction

The two crop species also responded differently to weed control treatments. No-control plots in both rice and cowpea had more weed biomass and lower product yields than plots with weed control, but lack of weed control affected rice much more severely. Rice and cowpea plots with weed control had comparable levels of weed infestation and crop yield, but no-control plots in rice had higher weed weights. Weeds reduced rice yields more severely than cowpea yields.

Treatment effects not only differed between crop species, they also differed over crop cycles of the same species. Total weed biomass and rice yields in plots with weed control were similar in Crops 2 and 4, but no-control plots in Crop 4 rice had a much higher weed biomass and more severely reduced product yields than no-control plots in Crop 2 rice.

Cowpea showed a similar pattern: weed weight in no-control plots was much higher in Crop 5 than in Crop 3. In contrast to rice, relative yields in the check plots of the two cowpea crops were similar.

Residue management × planting density interaction

When residues were mulched, planting density had no effect on weed weight; but when residues were incorporated, high density significantly reduced weed infestation. With respect to crop yields, there was no residue management × density interaction: yields were always higher at the higher crop density.

Relationship between weed infestation and crop yield

For each crop (Crops 2 through 5) relative yield was regressed on total weed weight rounded to 10 g intervals. There was a linear relationship but no quadratic effect between cowpea yield and total weed weight (Crops 3 and 5). By contrast, the two rice-crop regressions had both linear and quadratic components. Slopes of the two cowpea-crop regressions were similar as were the rice-crop regressions. For these reasons the data were combined by species. Figures 5 and 6 show the relationship between product yield and level of weed infestation for cowpea and rice.

Cowpea relative yields (Figure 5) declined approximately 1.6% for every 10 g of weeds present. Although high levels of weeds were associated with reduced cowpea yields, there was considerable variation in yield which is not explained by the level of weed infestation ($R^2 = 0.50$).

The effect of weeds on rice yields differed sharply from that of cowpea. In order to show the relationship more clearly, the linear and quadratic portions of the rice regression (Figure 6) have been separated and graphed as a linear-plateau model using a technique described by Anderson and Nelson (1975). When weed levels were above 250 g m^{-2} there was no harvestable grain. This portion of the data represents the quadratic component of the regression. It has been drawn as a line with a slope of zero because there is no biological reason to expect rice yields to begin increasing again at very high levels of weed infestation. Yields remain at zero as weed weights rise from 250 to 650 g m^{-2}. When weed weights are less than 250 g m^{-2} the relationship between weed infestation and rice yield is strongly linear: yields declined 3.6% for every 10 g increase in weed weight. In contrast to cowpeas, most of the variability in rice yields was attributable to the level of weed infestation ($R^2 = 0.86$).

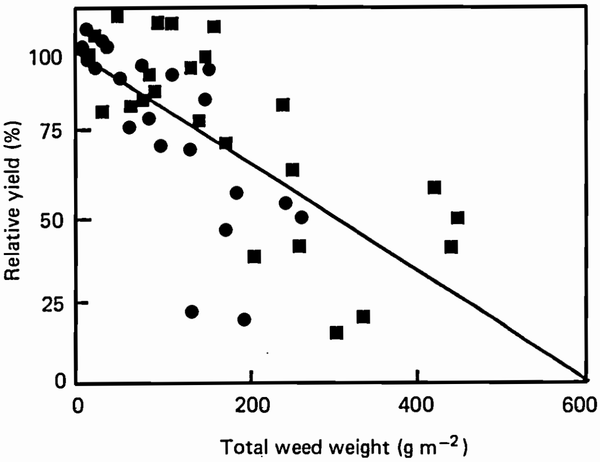


Figure 5 Relationship between weed infestation and cowpea yields (crops 3 and 5 of a five-crop experiment), Yurimaguas, 1984–1985. 100% relative yield, 1.4 t ha^{-1} in crop 3, and 1.1 t ha^{-1} in crop 5. ●, crop 3; ■, crop 5. $Y = 98.42 - 0.1633\,X$, where Y is relative yield and X is total weed wt. $R^2 = 0.50$

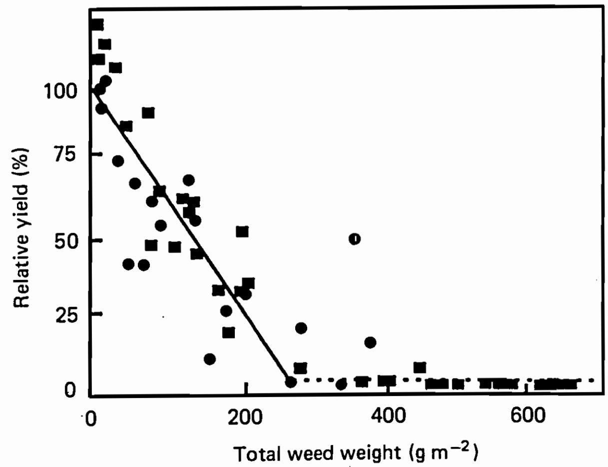


Figure 6 Relationship between weed infestation and rice yields (crops 2 and 4 of a five-crop experiment), Yurimaguas 1984. 100% relative yield, 2.5 t ha^{-1} in crop 2, and 1.6 t ha^{-1} in crop 4. ●, crop 2; ■, crop 4. $Y = 95.24 - 0.36\,X$, where Y is relative yield and X is total weed wt. $R^2 = 0.86$

Discussion and conclusions

Failure to control weeds reduced product yields in both rice and cowpea, but the method of weed control (chemical or manual) had little effect on yield. The two crop species differed substantially in their ability to compete with weeds. Weed levels in rice were much greater than in cowpea, and failure to control weeds had a much greater effect on rice yields. Keeping weeds at moderate levels in rice (Crops 2 and 4) required two hand-weedings or two applications of herbicide. On the other hand, weeds in cowpea (Crops 3 and 5) were easily controlled with only one hand weeding or a single application of a pre-emergence herbicide. Because cowpea establishes quickly, we hypothesize that it covers the row and shades out emerging weed seedlings. Rice, in contrast, is much slower in forming a canopy. With the soil surface left unshaded, weed seedlings in rice quickly become competitors.

Weed infestation was also more severe the longer the field was cropped (Figure 7). Weed levels in Crop 4 rice were much higher than in Crop 2 rice. (Although weed samples in Crop 2 were taken much earlier than in Crop 4, the magnitude of the difference is much more than could be accounted for by time of sampling alone.) The same pattern was seen in cowpea: weed infestation was higher in Crop 5 than Crop 3. Experimental conditions may have biased these results, however. Plots without weed control, which were randomly located across the field, may have served as a seed source, providing a constant supply of invading weeds. In a production rather than experimental situation, it is easier to prevent weed build-up because the entire field receives a uniform control measure; and there are no pockets of weeds to re-infest the field.

The composition of the weed population also changed with time. Sedges were the main weed species in Crop 1; but by Crop 5, grasses accounted for almost 80% of the population (Figure 7). This pattern of early sedge domination, followed by their decline and replacement with grasses, has been observed in other work at the Yurimaguas Research Station (Mt Pleasant *et al.*, 1990). Sedges in Yurimaguas are annuals which are not competitive with grasses. In addition, they are easily controlled with herbicides.

The effect of tillage on weed infestation changed over the course of the experiment (Figure 8). In the first crop, rototilled plots had many more weeds than no-till plots, but there were no differences in weed growth between tillage treatments in Crops 2 through 4. By Crop 5, however, the no-till treatment had many more weeds than the rototill treatment; and when Crops 2 through 5 were analysed as a single experiment, no-till had more weeds and lower relative yields than rototill.

Rototilling in Crop 1 provided an ideal seedbed for weed seed germination. With tillage, sedge seeds were brought to the surface where they germinated in a flush. In contrast, weed infestation in no-till plots in Crop 1 was low. Fire (and glyphosate) destroyed both standing vegetation and surface seeds. Without soil disturbance to bring buried weed seeds to the surface, weed infestation in the first rice crop was minimal. Shifting cultivators take advantage of this phenomenon because it allows them to produce their first crop, virtually weed free, following cutting and burning of the forest.

When the field is cropped continuously, however, lack of tillage through several cropping cycles brings increased weed problems. Soil disturbance has a positive effect in a continuous cropping system because existing vegetation can be completely eliminated between crops, providing a substantial contribution to weed control. While weeds in no-till plots were burned back between crops with a preplant application of paraquat, they quickly regrew. After five consecutive no-till cropping cycles, untilled plots had larger weed infestations than rototilled treatments.

The effect of residue management (mulch *vs* incorporation) on weed infestation and crop yields in this experiment was difficult to interpret. When Crops 2 through 5 were analysed as a single experiment, there was no effect of residue management on weed growth; but crop yields were always higher when residues were incorporated.

These observations suggest that residues are more

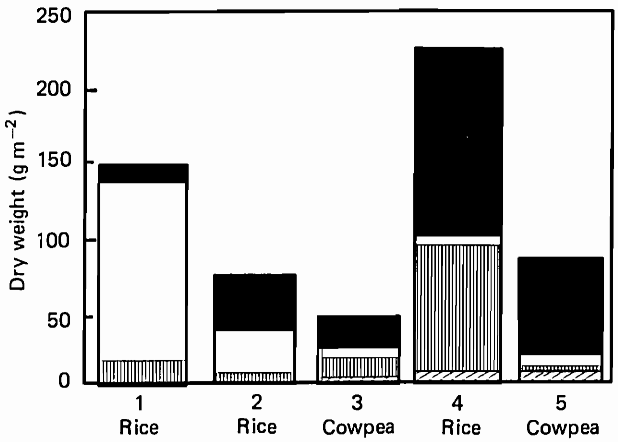


Figure 7 Changes in the level of weed infestation and weed population composition over five consecutively-planted crops (crops 1–5), Yurimaguas, 1983–1985. See Figure 2 for symbols

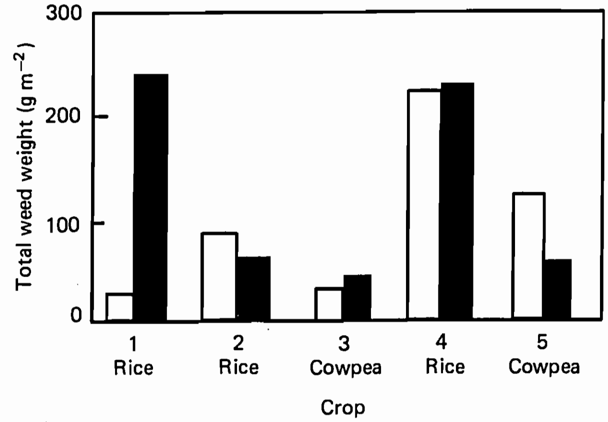


Figure 8 Effect of tillage on the level of weed infestation in five consecutively-planted crops (crops 1–5), Yurimaguas, 1983–1985. □, no till; ■, rototill

closely related to nutrient supply than to weed suppression. We theorize that rapid decomposition of residues following incorporation releases nutrients more quickly for immediate recycling, whereas surface mulches decompose more slowly and provide no quick flush of nutrients. Rice was apparently more sensitive to this nutrient release than cowpea. Cowpea yields increased with residue incorporation only in Crop 5 (data not presented) when soil P may have reached limiting levels. Furthermore, mulching was generally ineffective as a weed control measure. It decreased weed growth only in Crop 3 cowpea; it had virtually no weed-controlling effect on rice (Crops 2 and 4); and weed infestation in Crop 5 cowpea was actually greater with mulching (data not presented). Rice residues from Crop 4, which were used for mulching Crop 5 cowpea, were heavily infested with weeds. This heavy infestation may account for the higher weed infestation in the mulched treatment in Crop 5. Many weed seeds were buried too deep to germinate in the incorporated treatment, whereas they were simply spread on the surface where they could germinate immediately in the mulched plots.

Increasing crop planting density was an effective weed control measure. There were fewer weeds and higher product yields when crops were planted at the higher density. But yields, particularly rice, increased at the higher density even when weed infestation was not affected. Apparently, closer-spaced rice was more efficient in intercepting sunlight for photosynthetic production, and the higher yields were independent of the effect of planting density on weed suppression.

Comparisons with previous research

Yield losses

Other researchers have reported yield reductions in upland rice ranging 40–100% as a result of weed infestation (Akobundu and Fagade, 1978; DeDatta, 1972; Sahai *et al.*, 1983). In this study, rice yields declined 54–100% when there was no weed control. DeDatta (1974) found relative yield reductions of 0.9 to 1.6% for every 10 g m^{-2} weed weight in upland rice. Although the 3.6% decline (per 10 g m^{-2} weed weight) in relative yields obtained in this study is larger than DeDatta's values, our work confirms the vulnerability of upland rice to weed infestation.

Cowpea yields in this experiment were reduced 20–29% in the absence of weed control. This is in contrast to yield reductions of 46–81% reported by others working with cowpeas in tropical environments (Akobundu, 1982; Moody, 1982; Nangju, *ibid.*). Because cowpea cultivars differ substantially in their competitive ability (Nangju, *ibid.*), the smaller yield losses observed here may be attributed to the use of a competitive cultivar.

Changes in the composition of the weed population and in level of infestation over time

Kang *et al.* (1980) and Moody (1982) found that broadleaf weeds dominated the weed population in the first crop following forest clearing. When the land was cropped a second season, Moody reported a distinct shift to grasses. In our experiment, sedges rather than broadleaf weeds dominated early, but we also observed a marked shift to grasses in subsequent cropping cycles. In agreement with Lambert and Arnason (1986), we found that weed infestation increased, the longer the field was cropped after clearing; but Moody (*ibid.*) did not observe large increases in weed levels in later cropping cycles after the forest was cleared.

Tillage

The effects of tillage on weed infestation and crop yield changed substantially over the course of the experiment. Tillage effects reported in the literature are equally inconsistent. Some researchers (Liebl and Worsham, 1983; Roberts and Potter, 1980; Shilling and Worsham, 1983) found that tilling increased weed infestation, yet others have reported an increase in weed problems under no-till (Shilling *et al.*, 1986; Wrucke and Arnold, 1985). In like manner, reports of tillage effects on crop yields are contradictory (Hayward *et al.*, 1980; Kang *et al.*, *ibid.*; Olofintoye and Mabbayad, 1980; Sankaran and DeDatta, 1985). Initiation of tillage in relation to time after forest-clearing, as well as the time a field is kept in crop production without tillage, may explain some of these inconsistencies.

Table 6 Approximate cost of weed control treatments applied to rice and cowpea. Yurimaguas, 1983–1985

Treatment	Cost+ (US$ ha^{-1})
Rice	
Oxadiazon + propanil	150
Paraquat + oxadiazon + propanil	175
Cowpea	
Metolachlor	100
Paraquat + metolachlor	125
One hand weeding	50

+ Cost of herbicide in Lima, 1985

Table 7 Approximate cost (US$ ha^{-1}) in 1985 for controlling weeds in a rice–rice–cowpea–rice–cowpea cropping sequence under no-till after forest fallow. Yurimaguas, 1983–1985

Crop/species	Weed control methods	
	Hand weed	Herbicide+
1 Rice	0	0
2 Rice	50	175
3 Cowpea	0	0
4 Rice	100	175
5 Cowpea	0	0
Total cost	150	350
Cost/crop	30	70

+ Cost of herbicide in Lima, 1985

Mulching

In contrast to our findings, most researchers report that weed infestation is less and product yields higher when crops are mulched (Kamara, 1981; Lal, 1975, 1978; Liebl and Worsham, *ibid.*; Shilling and Worsham, *ibid.*; Shilling *et al.*, 1986; Wilhelm *et al.*, 1986). Mulches are advantageous to crop growth because they can reduce erosion, maintain soil structure, conserve moisture, reduce soil temperature and suppress weeds through chemical and physical inhibition. Some mulching materials, however, are more effective than others, and this may explain, in part, the lack of response to mulching in this experiment. Cowpea residues decomposed very quickly and had little weed-suppressing effect, but the more stable rice residues were often heavily infested with weed seed.

Crop planting density

Our conclusions concerning the effect of planting density on weed growth and crop yields are in agreement with previous research: fewer weeds and more product yield when rice is planted at higher densities (Ahmed and Hogue, 1981; Akobundu and Ahisson, 1985; Moody, 1978; Tosh *et al.*, 1981). Nangju (*ibid.*) reported the same effect with cowpea.

Management and research implications

If, under the present socio-economic conditions, a viable low-input continuous cropping system is to evolve in the Peruvian Amazon, it will depend on upland rice as the central cash crop. Furthermore, the rice or any associated crop will be planted without tillage. It is now apparent that we cannot control weeds through repeated cycles of a rice–cowpea rotation without large and unprofitable inputs for weed control. For this reason, such a cropping system must be considered transitional. It may form a bridge between shifting cultivation and a permanent agriculture, but it is not a stable, long-term alternative to shifting cultivation.

The poor competitive ability of upland rice and lack of tillage are the primary causes of the weed control problem. Weed infestation in rice increases markedly with time when a field is cropped continuously, even when rice is rotated with cowpea. Because upland rice is such a poor competitor, grasses invade vigorously and crop yields decline sharply with successive rice crops. Each of these problems is compounded when there is no between-crop tillage.

While it is possible to control weeds (either manually or with herbicides) and maintain yields, the cost of controlling them is extremely high under the present price–cost structure in Peru (Table 6). Based on our present knowledge, a realistic 'lifespan' for this low-input system is five or six crops, after which the cropping system must be interrupted by a fallow period or by tillage, either of which will disrupt and displace the weed community. Research should now focus on developing effective and economic weed control strategies for this transitional, low-input period. Our work suggests several avenues that may be productive for a five-crop sequence of rice–rice–cowpea–rice–cowpea, planted without tillage after cutting and burning secondary forest: (1) Since weed control is not needed in the first rice crop or in either cowpea crop, the cost of controlling weeds in the remaining rice crops can be amortized over the entire five-crop sequence (Table 7). Using weed control inputs only when they are required, significantly reduces the cost per crop to US$30 and US$70 ha^{-1} for manual and chemical control, respectively. Further cost reductions may be possible by shifting the number and position of cowpea crops within the five-crop sequence; (2) Increasing the planting density of rice is an effective and inexpensive weed control measure. Work is needed to establish optimum planting densities for rice cultivars in this environment; (3) As demonstrated with cowpea, an aggressive, fast-growing crop is another form of inexpensive weed control. Rice cultivars used in the low-input system should be selected for their competitive abilities. Early canopy formation, to shade out weed seedlings, is probably a critical characteristic for rice cultivars in this management system.

We have shown that herbicides can provide excellent weed control in upland rice. Furthermore, we suggest that this control method may be economically feasible if herbicide use can be integrated with other control practices so that the number of applications as well as the rate of herbicide per application can be reduced. As has been shown in other environments (Balyan *et al.*, 1983; DeDatta, 1980; Moody, 1978; Sankaran and DeDatta, 1985), a practical and effective weed-management programme for continuously cropped systems must combine cultural practices with chemical and manual methods of control. Our observations suggest that a similar integration of control measures is needed during this transitional period that bridges the time-span between forested land and the cultivatable fields of a permanent agriculture.

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