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Weed Population Dynamics and Weed Control in the Peruvian Amazon

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ABSTRACT

In traditional slash-and-burn agriculture, forest fallow is a primary agent in weed control. Stable continuous-cropping systems could be expected to require a comprehensive program of weed management, probably including the use of herbicides. Weed control measures in a sequence of rice (*Oryza sativa* L.)-corn (*Zea mays* L.)-soybean (*Glycine max* L.)-rice-corn-soybean were studied for 2 yr in Yurimaguas, Peru, with the following objectives to: (i) identify weed species resistant to the herbicide program in a continuous cropping system, and (ii) develop effective weed management practices for intensively managed cropping systems in the humid tropics. First-crop weeds were 60% grass, 25% sedges, and 15% broadleaf weeds. The grass was composed of two species: large crabgrass [*Digitaria sanguinalis* (L.) Scop.] and goosegrass (*Eleusine indica* (L.) Gaertn]. Sixth-crop weed population was 80% grass, 13% broadleafs and 7% spreading dayflower (*Commelina diffusa* Burm. f.); and itchgrass (*Rottboelia exaltata* L.f.) comprised 85% of the grasses. Metolachlor [2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methylethyl)acetamide] controlled crabgrass, goosegrass, and most broadleafs in corn and soybean; but it did not control itchgrass. Metolachlor alone resulted in a weed population that was 97% itchgrass in the sixth crop. Sethoxydim [2-[(1-ethoxyimino)butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one]-plus bentazon [3-(1-methylethyl)-(1*H*)-2,1,3-benzothiadiazin-4(3*H*)-one 2,2-dioxide] on soybean controlled grasses including itchgrass, but broadleaf weeds and dayflower increased. Propanil [*N*-(3,4-dichlorophenyl)propanamide]-plus-oxadiazon [3-[2,4-dichloro-5-(1-methylethoxy)phenyl]-5-(1,1-dimethyl)-1,3,4-oxadiazol-2-(3*H*)-one] on rice resulted in a mixed grass population. Rice was more vulnerable to weed pressure than either corn or soybean and appears inappropriate for this high-input rotation because of the high cost of weed control.

TRADITIONAL AGRICULTURE in the Amazon Basin of Peru is based on shifting cultivation. Infertile soils become temporarily productive when a flush of nutrients is released after cutting and burning the forest. A long fallow period allows the trees to regrow, after which the land can be used again for crop production. The fallow also serves another important function: trees shade out invading grasses, and weed problems are minimal when the area is recropped.

Population pressure in Peru, along with the country's desire to increase its agricultural base, requires alternatives to shifting cultivation. Successful continuous cropping systems, which eliminate the fallow period, will depend on soil fertility management and effective weed control. Research has shown that Ultisols in the Amazon Basin can be intensively cropped if appropriate amounts of lime and fertilizer are added (12, 15), but there has been little work on problems of weed control in continuous cropping systems in this environment.

Physical and socio-economic conditions in the humid tropics affect weed management; practices and knowledge developed in temperate regions are not wholly transferable. In much of the amazon Basin, for example, neither H_2O nor temperature is limiting to plant growth at any time during the year. Consequently, weeds grow continuously, greatly intensifying weed control problems. The humid environment also severely restricts tillage, a primary means of controlling weeds. Although crops can be grown throughout the year, the "window of opportunity" for tillage operations is small and often unpredictable. Labor for hand weeding in the Peruvian Amazon Basin is a major impediment to increasing agricultural production; it is largely unavailable at any price. The use of herbicides, on the other hand, presents special problems: (i) their availability is limited; (ii) the cost is often prohibitive; and (iii) their safe and effective use requires a high level of farmer education.

Despite these limitations, herbicides will likely be a major tool for controlling weeds in high-input cropping systems where soil constraints are eliminated by additions of lime and fertilizer. Researchers in temperate regions have found that continued use of one herbicide can result in a shift in the spectrum of weed species present in the field; weeds resistant to the chemical flourish when competing species are removed (2,9,14,18). Successful weed management involves rotation of herbicides or alternative contol practices.

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We hypothesized that a similar shift in the weed population would occur in a tropical environment and that the problem would be more severe because farmers lack access to a wide array of herbicides. Weeds resistant to the spectrum of herbicides likely to be used in continuous cropping systems need to be identified early in order to devise alternative management practices.

This experiment had the following objectives to: (i) identify weed species resistant to the herbicide program in a continuous-cropping system, and (ii) develop effective weed management practices for intensively managed cropping systems in the humid tropics.

MATERIALS AND METHODS

The study was initiated in September 1983 at the Yurimaguas Res Stn. in Eastern Peru (5°45′ S, 75°5′ W, 184 m above sea level) on a fine-loamy, siliceous, isohyperthermic Typic Paleudult. Mean annual temperature at Yurimaguas is 26 °C with little monthly or daily variation. Average annual precipitation is 2250 mm. There is a distinct dry season from June through August when average monthly precipitation drops to about 100 mm (Table 1).

The Yurimaguas environment permits three harvests per year (three biological cycles) if short-cycle food crops are used. We used a three-crop per year sequence of rice-corn-soybean and this cropping system was continued through six biological cycles (rice-corn-soybean-rice-corn-soybean). The six consecutive crops will be identified in this paper as: Rice 1, Corn 1, Soybean 1, Rice 2, Corn 2, and Soybean 2. Total elapsed time was 2.5 yr.

The experimental design was a split plot. Four weed control treatments applied to rice represented the main plot treatments. Split-plot treatments were five weed control treatments on corn and soybean. In order to reduce the size of the experiment, treatments in corn and soybean were linked; for example, plots which received no weed control in corn also received no weed control in the subsequent soybean crop. With this arrangement, the main-plot effects thus became a measure of the residual effects of weed control practices applied to rice in succeeding crops of corn and soybean. In addition we were able to measure a residual effect of weed control practices applied to corn and soybean on the succeeding crop of rice. We could not, however, measure the effects of weed control practices applied to corn on the succeeding soybean crop.

The experimental site had been cropped to sugarcane for at least 6 yr and was heavily infested with a broad spectrum of weed species. The initial experimental plan included a tillage variable (normal vs. no tillage), but soil tests showed that both lime and P were needed. Since neither of these amendments can be incorporated under no-till conditions, the tillage variable was delayed until a fertile soil condition was achieved. It took three crop cycles to bring the field to an adequate fertility.

Fertilization and Tillage Practices

After destroying the sugarcane, one-half of the estimated lime and P requirement was applied (broadcast) and incorporated to 0.2 m with a moldboard plow (the total lime and P requirement was estimated as 1800 and 75 kg ha^{-1}, respectively). The remaining half of each material, along with K, Zn, Cu, and B (100, 2.0, 2.0 and 1.0 kg ha^{-1}, respectively), was then broadcast and incorporated to about 0.1 m by several passes with a tandem disk. Seedbed preparation, and additional mixing, was accomplished by constructing raised beds on 0.75 m centers which were partially leveled by rototilling just prior to seeding rice. Rice 1 was fertilized with 75 kg N ha^{-1} (as urea) with one-third applied at planting and the remainder about 40 d after emergence (pre-boot stage).

Table 1. Monthly precipitation, in Yurimaguas Peru.

	1983	1984	1985	1986
		mm		
January		234.1	143.7	184.8*
February		331.7	109.7	
March		246.5	396.1	
April		351.0	114.2	
May		376.0	274.8	
June		157.8	63.7	
July		71.1	–	
August		63.9	–	
September*	–	141.6	–	
October	–	164.0	178.5	
November	–	237.1	226.7	
December	–	165.0	98.8	

* The experiment began in September 1983, and ended January 1986. Precipitation data are missing for 4 months in 1983 and 3 months in 1985.

Analysis of soil samples taken after harvesting Rice 1 showed that the pH of the top 0.2 m was still less than 5.0; dolomitic lime (908 kg ha^{-1}) was incorporated before planting the next crop. At planting of Corn 1, 40 kg P ha^{-1} was applied; and split applications of K and N (100 and 175 kg ha^{-1} total, respectively) were made during the season. The N source was urea. Shortly after emergence, Corn 1 showed signs of micronutrient deficiencies. A foliar spray of Cu, Zn, and Mn in a 1.5% (each) solution applied 18 DAP severely burned the plants.

Before planting Soybean 1, Zn, Cu, and P (8, 6, and 50 kg ha^{-1}, respectively) were applied, and 50 kg K ha^{-1} was broadcast during the growing season. Uniform applications of K (50 kg ha^{-1}) were made to Rice 2, Corn 2, and Soybean 2. Nitrogen as urea was applied to Rice 2 and Corn 2 at rates of 70 and 150 kg ha^{-1}, respectively.

After each harvest, standing crop residues were cut with a bushog. Tillage operations in all crops were similar to those described for Rice 1, but no tillage implements were used in the no-till treatments in Rice 2, Corn 2, and Soybean 2.

Weed Treatments

Weed control treatments for all crops are listed in Table 2. Although the no-till treatment was not initiated until Rice 2, a set of plots for this treatment was available in each crop prior to Rice 2.

Rice. In Rice 1, banded application (between the rows) of propanil [*N*-(3,4-dichlorophenyl)propanamide] was included as a treatment in addition to broadcast propanil because of past problems of phytotoxicity with this herbicide in rice at the Yurimaguas Station. We later learned that the in-stock supply of propanil was contaminated with paraquat (1,1′-dimethyl 1-4, 4′-bipyridinium ion). A new shipment of herbicide eliminated the problem. Banded propanil in Rice 1 was applied to plots which were later (Rice 2) used for the no-till treatment.

Corn. A banded metolachlor (2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methylethyl) acetamide) treatment in Corn 1 was to be applied in tandem with mechanical cultivation, but continuously wet soil early in the growing season prevented cultivation. Consequently this treatment was abandoned after Corn 1 and in Corn 2 the treatment was changed to metolachlor-plus-2,4-D [(2,4-dichlorophenoxy) acetic acid)] on an as-needed basis. As broadleaf weeds were not a problem in Corn 2, no 2,4-D was applied, resulting in duplicate plots of the metolachlor-only treatment in that crop.

Soybean. At the onset of Soybean 1, just two herbicide treatments were planned: (i) metolachlor and (ii) sethoxydim

[2-[1-(ethoxyimino)butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one] -plus-bentazon [3-1(-methylethyl)-(1H)-2,1,3-benzothiadiazin-4 (3H)-one 2,2-dioxide]. The no-till plots in this crop were intended to be duplicates of the metolachlor treatment. When itchgrass, a grassy weed resistant to metolachlor, invaded the site in Soybean 1, the duplicate metolachlor treatment was modified to metolachlor-plus-sethoxydim in an attempt to control this species.

Paraquat was applied pre-emergence to all no-till treatments beginning in Rice 2. (See Table 2 for rates and times of application of all herbicides throughout the experiment). Herbicides were applied with a CO_2 backpack sprayer through a four-nozzle boom with T-Jet 6503 nozzles (Spraying Systems Co., Wheaton, IL) in 0.38-m spacing. Spray volume was 400 L ha^{-1} at 21 kPa.

Rice was hand planted in 0.5-m rows at a population of 60 000 hills ha^{-1}. Corn was planted with a two-row planter in Corn 1 and by hand in Corn 2. Row spacing for corn was 0.75 m with a target population of 50 000 plants ha^{-1}. Soybean were machine planted in Soybean 1 and hand planted in Soybean 2 in 0.5-m rows. Soybean was seeded at a population of 120 000 plants ha^{-1} in Soybean 1 and 200 000 plants ha^{-1} in Soybean 2.

Weeds were sampled 2 wk prior to crop maturity in all crops except Corn 1 when they were sampled 6 wk before harvest. Two weeds samples were taken from each plot: one from the tractor wheel track and another from an untrafficked portion of the plot. Weed weights for each plot are a mean of the two samples from that plot. Weeds were cut at ground level, separated by species, and weighed after drying for 1 wk at 70 °C. In Rice 1 and Corn 1 the samples were taken from 0.5 m^2. In all other crops the samples were taken from 1.0 m^2.

Plot size was 6 by 6 m. Crops were harvested from 9 m^2 in the center of each plot for all crops except for Soybean 1 when 25 m^2 was harvested. All treatments were replicated at least four times. No-till plots were grouped in each block in order to facilitate tillage operations and were replicated six times. Analysis of variance was performed crop by crop; blocks are considered to be random effects, while treatments are fixed. Means were separated using orthogonal contrasts.

RESULTS AND DISCUSSION

Of more than 45 different weeds species identified through the course of the experiment, fewer than 10 species appeared consistently and in significant quantities in all crops. For statistical analysis, weeds were divided into four broad groups: grasses, broadleaf weeds, and two nongrass monocots, sedges and spreading dayflower (*Commolina diffusion* Burm. f.). Since grasses were by far the most important weed group, several subgroups of the most prevalent grass species were analyzed separately.

In the following discussion, "no-control" refers to plots which recieved no weed control measure of any kind; "within-crop effects" refer to those treatments applied to the crop under discussion, e.g., within-crop effects for Rice 1 are treatments applied to plots in Rice 1; "previous-crop effects" are carryover effects of treatments applied in a previous crop on weed populations and crop yields in a subsequent cycle; and "interaction" refers to the combined effect of previous-crop and within-crop treatments.

Because of the experimental design (rice treatments are main-plots and treatments in corn and soybeans are sub-plots), within-crop and previous-crop effects refer to both main-plot and sub-plot treatments, depending on the crop. In rice, within-crop treatments are main-plot effects but in corn and soybeans they are sub-plot effects. Previous-crop effects are the sub-plot treatments in rice while they represent main-plot treatments in corn and soybeans.

Table 2. Treatments applied to six consecutively planted crops, Yurimaguas Experiment Station 1983 to 1986.

Crop sequence (cultivar)	Harvest date	Treatment†		Herbicide rate	Chronology
		Tillage†	Weed control		
				kg ha^{-1}	DAP
Rice 1	December 1983	+	Hand weed	–	34, 45
(Africano desconocido)		+	Propanil broadcast	2.9	20
		+	Propanil band	2.9	19
		+	No control	–	–
Corn 1	May 1984	+	Hand weed	–	38
(Mezcla Amarilla Planta Baja)		+	Metolachlor broadcast	2.3	4
		+	Metolachlor broadcast	2.3	4
		+	Metolachlor band	2.3	4
		+	No control	–	–
Soybean 1	September 1984	+	Hand weed	–	29
(IAC-8)		+	Metolachlor	2.3	1
		+	Metolachlor fb Sethoxydim	2.3, 0.3	1, 47
		+	Bentazon fb Sethoxydim	1.0, 0.3	18, 28
		+	No control	–	–
Rice 2	January 1985	+	Hand weed	–	20, 46
(Africano desconocido)		+	Oxadiazon fb Propanil	1.0, 4.0	1, 45
		0	Oxadiazon + Paraquat fb Propanil	1.0, 0.5, 5.0	1, 1, 45
		+	No control	–	0
Corn 2	June 1985	+	Hand weed	–	38
(Tropical 28)		+	Metolachlor	2.3	1
		0	Metolachlor + Paraquat	2.3, 1.0	1, 1
		+	Metolachlor	2.3	1
		+	No control	–	–
Soybean 2	January 1986	+	Hand weed	–	25
		+	Metolachlor	2.3	1
		0	Metolachlor + Paraquat	2.3, 0.8	1, 1
		+	Sethoxydim + Bentazon	0.3, 1.0	20, 20
		+	No control	–	–

† + = Conventional tillage; 0 = no-till; fb = followed by; DAP = days after planting.

Rice 1

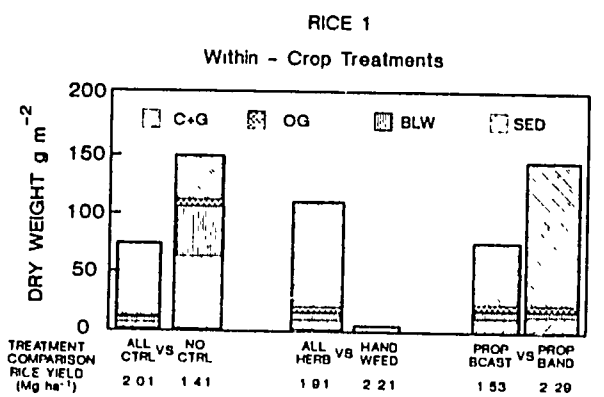
Within-Crop Effects

Relative to the no-control treatment, rice yields were greater and weed weight was less when any weed control measure was used (Fig. 1). Although hand-weeded plots had significantly fewer weeds than plots with chemical control, rice yields were not affected. Band application of propanil resulted in higher rice yields than broadcast application, but total weed weights in the two treatments were not different. Paraquat contamination of the propanil caused much greater damage to the rice in the broadcast treatment; and lower yields following broadcast propanil were a result of crop phytotoxicity rather than weed competition.

Sedges dominated the no-control treatment, representing 45% of the weed population. Two grass species, large crabgrass (*Digitaria sanguinalis* (L.) Scop.) and goosegrass (*Eleusine indica* (L.) Gaertn) were the main weeds in all other plots.

Corn 1

Corn yields were low (1.28 Mg ha^{-1}) (Fig. 2), a combined result of micronutrient deficiencies and of post-emergence efforts to alleviate them (see Methods). Corn growth was variable throughout the experimental area and appeared unrelated to treatment. Statistically significant differences in mean corn yields are not consistent with weed data nor with any other measured or observed biological factors. Despite the poor corn growth, overall weed control was excellent; total weed weight averaged 38 g m^{-2} (Fig. 2).



STATISTICAL SUMMARY

	Mean	CV (%)	p for each treatment comparison		
TW	91	95	0 07	0 01	0 15
GW	54	161	0 53	0 03	0 14
C+G	52	169	0 47	0 03	0 13
OG	2	408	0 01	0 40	0 58
SED	23	65	<0 01	0 44	0 92
BLW	14	167	<0 01	0 18	0 97
RICE	1 86	25	0 01	0 19	0 01

Fig. 1. Orthogonal comparisons of weed control measures on weed infestations (dry weight) and product yield in Rice 1, first crop of a 6-crop experiment, Yurimaguas Experiment Station 1983. Mean values are given in g m^{-2} for weeds and Mg ha^{-1} for rice. ALL CTRL = all treatments with weed control; NO CTRL = no weed control; ALL HERB = all treatments with herbicide; PROP = propanil; TW = total weeds; GW = all grasses; C + G = large crabgrass-plus-goosegrass; OG = all other grasses; SED = all sedges; BLW = all broadleaf weeds.

Within-Crop Effects

Plots with weed control measure had fewer total weeds, fewer grasses, and fewer broadleaf weeds than no-control plots (Fig. 2). Hand weeding resulted in lower weed weights than chemical control, but total weeds in both groups were negligible (4 vs. 25 g m^{-2}). Band-applied metolachlor was not as effective as broadcast metolachlor; all weed groups except itchgrass showed a threefold increase in weight with the banded treatment.

Previous-Crop Effects

Plots which were hand weeded during the previous rice crop had fewer total weeds and fewer grasses than plots to which propanil was applied (Fig. 2). Sedges all but disappeared in Corn 1, regardless of treatment. These species of sedge are probably uncompetitive because they are annuals rather than nutlet-farming perennials. Sixty-five percent of the weeds were grasses, with large crabgrass and goosegrass the dominant species (Fig. 2).

Soybean 1

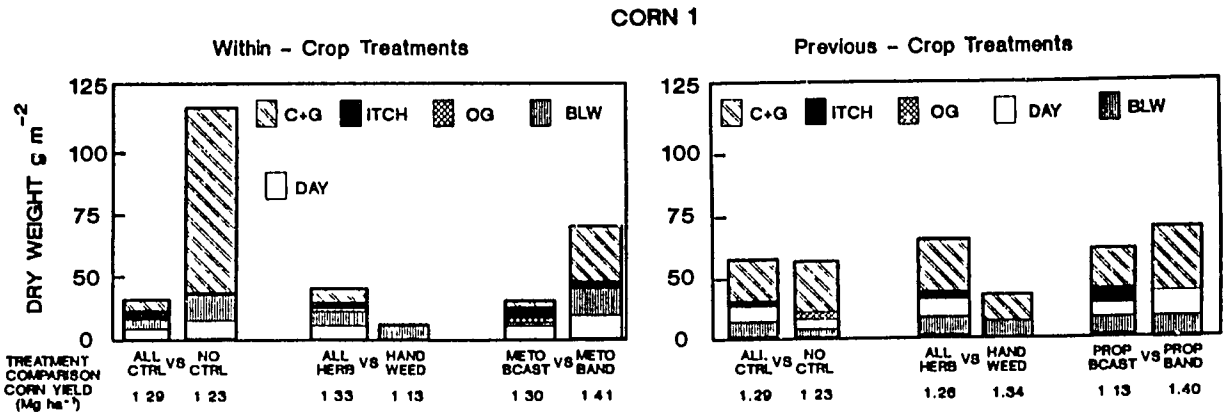
By planting time of this crop, soil fertility problems had been corrected. Soybean yields, while not high (1.58 mg ha^{-1}), were clearly affected by treatment.

Within-Crop Effects

No-control plots yielded less than half the grain of plots with weed control, and the yield reduction was related to weed pressure (Fig. 3). Total weeds in no-control plots were three times greater than in plots with weed control. Composition of the weed population was also markedly different in the two groups of treatments. Two grasses (large crabgrass and goosegrass) dominated the no-control plots; they comprised more than 80% of the weed population. Grasses were also the major weed component (56%) in plots with weed control: but one species, itchgrass (*Rottboelia exaltata* L.f.), accounted for most of the grass population. In addition, broadleaf weeds represented 40% of the weed population in plots with weed control; they accounted for only 11% in the no-control treatment.

Within the group of treatments with weed control, hand weeding and herbicides were equally effective in controlling weeds and maintaining soybean yields (Fig. 3); but the composition of the weed population in these two groups was distinctly different. Although grasses comprised 50 to 55% of the weed population in each group, the grass population in the hand-weeded plots was composed exclusively of large crabgrass-plus-goosegrass. On the other hand, itchgrass dominated plots treated with herbicide.

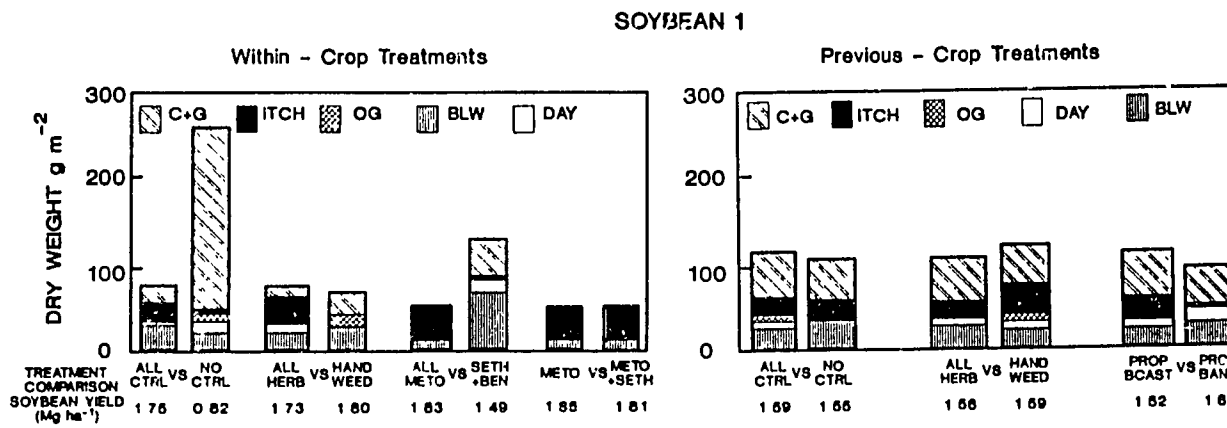
For chemically treated plots, the type of herbicide applied affected grain yield as well as weed weight and population composition. Treatments with metolachlor had fewer total weeds and higher crop yields than the sethoxydim-plus-bentazon treatment (Fig. 3). Grasses comprised 78% of total weeds on metolachlor-treated plots, and 98% of total grass weight was itchgrass. In contrast, plots with sethoxydim-plus-bentazon had only 33% grass; itchgrass was unimportant; and most



STATISTICAL SUMMARY

	Mean	CV (%)	p for each treatment comparison					
TW	38	82	<0.01	0.02	<0 01	0.95	0.01	0.38
GW	25	145	<0.01	0.18	0 06	0.43	0.01	0.38
C+G	22	155	<0.01	0 38	0 02	0.37	0.02	0 09
ITCH	2	847	0.45	0 33	0.69	0.23	0.39	0 02
OG	1	169	0 90	0.02	0.24	0 01	0.73	0.72
DAY	5	329	0.19	0 43	0 16	0.66	0.16	0.72
BLW	6	157	0 01	0 36	<0 01	0 51	0.63	0.29
CORN	1 28	27	0 44	0 03	0 48	0.53	0.43	0 02

Fig. 2. Orthogonal comparisons of weed control measures applied to Corn 1 (within-crop treatments) and weed control measures applied to Rice 1 (previous-crop treatments) on weed infestations (dry weight) and product yield in Corn 1 (second crop of a six-crop experiment), Yurimaguas Experiment Station 1984. Mean values are given in g m^{-2} for weeds and Mg ha^{-1} for corn. ALL CTRL = all treatments with weed control; NO CTRL = no weed control; ALL HERB = all treatments with herbicide; METO = metolachlor; PROP = propanil; TW = total weeds; GW = all grasses; C + G = large crabgrass-plus-goosegrass; ITCH = itchgrass; OG = all other grasses; DAY = dayflower; BLW = all broadleaf weeds.



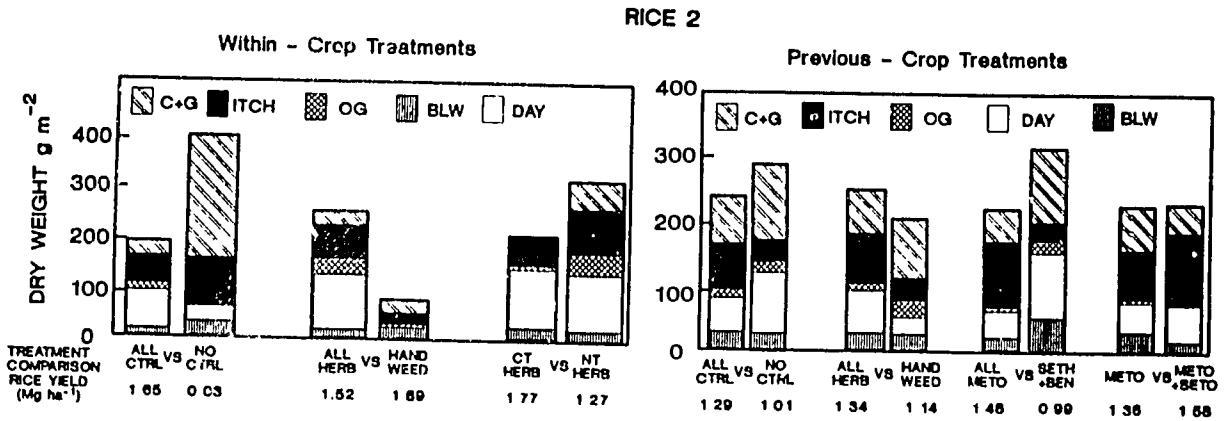
STATISTICAL SUMMARY

	Mean	CV (%)	p for each treatment comparison						
TW	116	62	<0 01	0 45	<0 01	0.42	0.44	0 39	0.49
GW	78	86	<0.01	0 47	0 55	0 36	0.61	0.27	0 13
C+G	51	70	<0 01	0 09	<0.01	0 98	0.46	0.30	0.71
ITCH	23	269	0 18	0 03	0.01	0 32	0.71	0.09	0.02
OG	4	252	0 08	0 01	0 37	0 88	0 25	0.01	0.99
DAY	5	230	0 12	0.12	0 01	0 68	0.19	0.72	0.34
BLW	32	115	0 68	0 83	<0.01	0.78	0.24	0.10	0.29
SOYB	1 58	19	<0 01	0 35	<0 01	0.71	0.63	0.94	0.17

Fig. 3. Orthogonal comparisons of weed control measures applied in Soybean 1 (within-crop treatments) and weed control measures applied in Rice 1 (previous-crop treatments) on weed infestation (dry weight) and product yield in Soybean 1 (third crop of a 6-crop experiment), Yurimaguas Experiment Station 1984. Mean values are given in g m^{-2} for weeds and Mg ha^{-1} for soybean. ALL CTRL = all treatments with weed control; NO CTRL = no weed control; ALL HERB = all treatments with herbicide; ALL METO = all treatments with metolachlor; SETH + BEN = sethoxydim-plus-bentazon; METO = metolachlor; METO + SETH = metolachlor-plus-sethoxydim; PROP = propanil; TW = total weeds; GW = all grasses; C + G = large crabgrass-plus-goosegrass; ITCH = itchgrass; OG = all other grasses; DAY = dayflower; BLW = all broadleaf weeds.

of the grass population consisted of large crabgrass-plus-goosegrass. Broadleaf weeds were the dominant weed group in the sethoxydim-plus-bentazon treatment; this group comprised more than half the total weed weight. On the other hand, broadleaf weeds represented less than 20% of the weed population in metolachlor-treated plots.

Two treatments received metolachlor: (i) metolach-



STATISTICAL SUMMARY

	Mean	CV (%)	p for each treatment comparison						
TW	253	38	<0.01	<0.01	<0.01	0.16	0.04	0.01	0.25
GW	155	46	<0.01	<0.01	<0.01	0.72	0.58	0.91	0.09
C+G	83	78	<0.01	0.60	0.04	0.04	0.41	<0.01	0.26
ITCH	56	142	0.09	0.07	0.27	0.08	0.04	<0.01	0.01
OG	16	237	0.16	0.03	0.01	0.41	0.06	0.15	0.64
DAY	61	115	0.08	<0.01	0.94	0.05	0.04	0.02	0.60
BLW	36	109	0.01	0.27	0.18	0.58	0.67	0.04	0.30
RICE	1.24	45	<0.01	0.02	0.01	0.13	0.39	0.01	0.44

Fig. 4. Orthogonal comparisons of weed control measures applied in Rice 2 (within-crop treatments) and weed control measures applied in Soybean 1 (previous-crop treatments) on weed infestations (dry matter) and product yield in Rice 2 (fourth crop of a 6-crop experiment), Yurimaguas Experiment Station 1985. Mean values are given in g m^{-2} for weeds and Mg ha^{-1} for rice. ALL CTRL = all treatments with weed control; NO CTRL = no weed control; ALL HERB = all treatments with metolachlor; SETH + BEN = sethoxydim-plus-bentazon; METO = metolachlor; METO + SETH = metolachlor-plus-sethoxydim; TW = total weeds; GW = all grasses; C + G = large crabgrass-plus-goosegrass; ITCH = itchgrass; OG = all other grasses; DAY = dayflower; BLW = all broadleaf weeds.

lor and (ii) metolachlor-plus-sethoxydim; but there were no differences between them, neither in crop yield nor weed weight (Fig. 3). Sethoxydim was applied 30 d later in the metolachlor-plus-sethoxydim treatment than in the bentazon-plus-sethoxydim treatment. Late application of sethoxydim had little effect on itchgrass, the only major weed species not controlled by metolachlor.

There were no previous-crop effects (treatments applied to Rice 1) (Fig. 3).

Rice 2

Within-Crop Effects

Average weed weight in this crop more than doubled that of the previous soybean crop (253 vs. 116 g m^{-2} (Fig. 4.). Rice yields were severely reduced by weeds. Plots with weed control produced 1.65 mg of rice ha^{-1} while no- control plots had almost no harvestable grain. All weed groups except dayflower were present in greater amounts in the no-control plots than in plots with weed control.

Hand-weeded plots had fewer total weeds and higher rice yields than plots where weeds were controlled with herbicides (Fig. 4). Total grasses and dayflower were much greater in herbicide-treated plots. Dayflower was virtually absent in the hand-weeded treatment, but it comprised more than 40% of the weed population in plots with herbicides. On the other hand, broadleaf weeds represented a larger portion of the weed population in hand-weeded plots than in the herbicide-treated group.

Conventionally tilled plots with herbicide had fewer weeds and produced more rice than no-till plots with herbicide (Fig. 4). Dayflower was the predominant weed (58% of total) under conventional tillage, with grasses comprising only 30%. Just the reverse was observed under no-till; the grasses dominated (58%), and dayflower accounted for 34%. Dayflower reproduces vegetatively (rooting-stem segments) and by seed. Tillage seemed to enhance the spread of stems.

Previous-Crop Effects

Rice following no-control soybeans had higher amounts of large crabgrass-plus-goosegrass and dayflower than plots which followed soybeans with weed control (Fig. 4). In contrast, itchgrass, was greater in rice plots following soybeans with weed control than following soybean no-control plots. Total weed weight and rice yields, however, were not different in these two previous-crop treatment groups.

Rice following hand-weeded soybeans had fewer total weeds than rice following herbicide-treated soybeans, but rice yields in the two treatment groups were similar (Fig. 4). Hand weeding of soybeans resulted in higher levels of large crabgrass-plus-goosegrass in the succeeding rice crop. These two species comprised more than 50% of the total weed weight after hand-weeded soybean but only 31% of the total when rice followed herbicide-treated soybean. When soybean was treated with herbicides, itchgrass levels were higher in the succeeding rice crop, representing almost 30% of the total weed weight. If rice followed hand-weeded soybeans, however, this species comprised just 14% of the weed population. Weed control measures applied to the preceeding soybean crop also affected dayflower infestation in the rice. Rice following herbicide-treated soybeans had more dayflower than rice following hand-weeded soybeans. Rice following soy-

beans treated with sethoxydim-plus-bentazon had more total weeds and lower yields than rice following metolachlor-treated plots (Fig. 4). Large crabgrass-plus-goosegrass, dayflower, and broadleaf weeds were all greater in rice when they succeeded soybeans treated with sethoxydim-plus-bentazon; but the infestation of itchgrass in rice was more severe following metolachlor-treated soybeans. When soybeans were treated with sethoxydim-plus-bentazon, dayflower and broadleaf weeds in the succeeding rice crop accounted for almost 50% of the total weeds; they comprised 32% of the total when rice followed metolachlor-treated soybeans.

Corn 2

Total weeds in this crop was 68% of the total infestation in the rice that preceeded it (172 g m^{-2} in corn vs. 259 g m^{-2} in rice) (Fig. 5). Composition of the weed population also changed. Grasses accounted for a much larger percentage of the weeds in Corn 2 (78 vs. 61%), and itchgrass dominated the weed population. This species represented 50% of the total weed weight in Corn 2. Broadleaf weeds and dayflower declined in importance; they accounted for less than 25% of the total weed weight in Corn 2 but almost 40% in the previous rice crop.

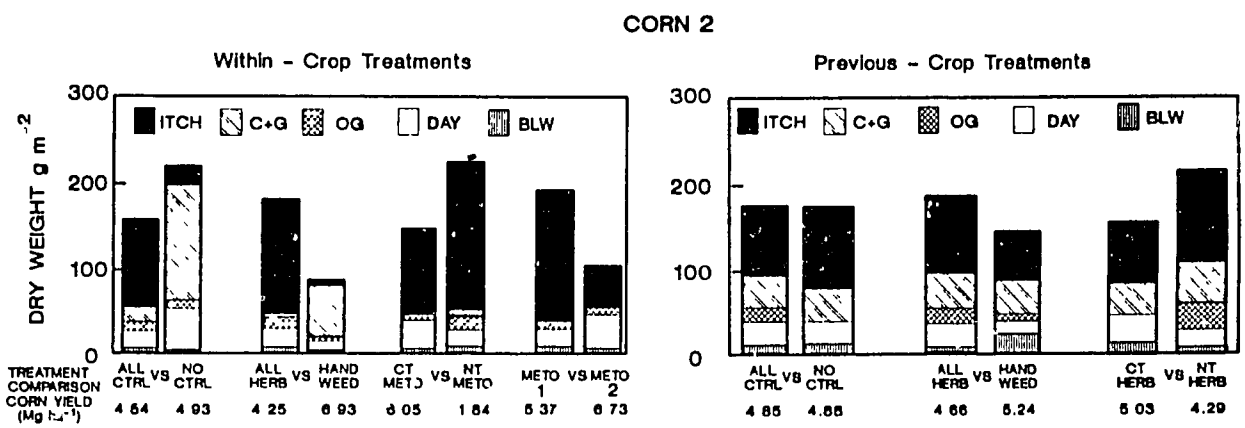
Within-Crop Effects

Total weeds were higher in no-control plots than in treatments with weed control, but corn yields in the two groups did not differ (Fig. 5). Total grass weight in no-control plots was the same as in plots with weed control, but the composition of the grass population was markedly different. Large crabgrass-plus-goosegrass comprised most of the grass population in the no-control treatment while itchgrass was the major species in plots with weed control. Dayflower was a more important component of the weed population in no-control plots than in treatments with weed control.

Hand-weeded plots yielded more corn and had less total weed growth than plots which were treated with herbicide (metolachlor) (Fig. 5). Herbicide-treated plots contained twice as much grass as the hand weeded treatment, and almost 90% of the grass was itchgrass. Hand-weeded plots were dominated by large crabgrass-plus-goosegrass, but itchgrass was virtually absent.

Tillage had a far greater positive effect on Corn 2 yields than any weed control measure. No-till plots with metolachlor yielded about 30% of the corn grown under conventional tillage with metolachlor (Fig. 5). Although weeds were greater in the no-till treatment (225 vs. 148 g m^{-2}), weed pressure alone could not account for such a large yield reduction. We hypothesize that nutrient utilization may have been different under no-till than in the conventionally tilled treatment. Although the corn showed no N deficiency symptoms, losses of surface-applied urea via volatilization may have been greater under no-till. More grasses were present in plots with no-till, but itchgrass dominated the grass population in each tillage treatment.

In the last within-crop comparison in Fig. 5, two sets of plots received the same application of herbicide (metolachlor), yet both yields and weed weights differed in the two treatment groups. A much larger population of itchgrass in the "metolachlor 1" treatment



STATISTICAL SUMMARY

	Mean	CV (%)	p for each treatment comparison						
TW	172	48	0.01	<0.01	<0.01	<0.01	0.90	0.12	0.08
GW	134	62	0.11	<0.01	<0.01	<0.01	0.90	0.12	0.04
ITCH	86	103	<0.01	<0.01	<0.01	<0.01	0.51	0.27	0.31
C+G	38	76	<0.01	<0.01	0.32	0.86	0.69	0.62	0.14
OG	48	94	0.94	0.50	0.27	0.77	0.09	0.13	<0.01
DAY	27	124	<0.01	0.09	0.08	0.55	0.88	0.21	0.21
BLW	10	125	0.22	0.61	0.09	0.81	0.81	<0.01	0.34
CORN	4.88	25	0.54	<0.01	<0.01	<0.01	0.92	0.05	0.04

Fig. 5. Orthogonal comparisons of weed control measures applied to Corn 2 (within-crop treatments) and weed control measures applied to Rice 2 (previous-crop treatments) on weed infestations (dry matter) and product yield in Corn 2 (fifth crop of a 6-crop experiment), Yurimaguas Experiment Station 1985. Mean values are given in g m^{-2} for weeds and Mg ha^{-1} for corn. ALL CTRL = all treatments with weed control; NO CTRL = no weed control; ALL HERB = all treatments with herbicide; CT METO = conventional tillage with metolachlor; NT METO = no till with metolachlor; CT HERB = conventional tillage with propanil-plus oxadiazon-plus-paraquat; NT HERB = no-till with propanil-plus oxadiazon-plus-paraquat; TW = total weeds; GW = all grasses; ITCH = itchgrass; C + G = large crabgrass-plus-goosegrass; OG = all other grasses; DAY = dayflower; BLW = all braodleaf weeds.

accounts for the increased weed weight and lower corn yields relative to "metolachlor 2". Although "metolachlor 1" and "metolachlor 2" were duplicate treatments in this crop, there was one important difference. "Metolachlor 2" plots had been treated with sethoxydim-plus-bentazon in Soybean 1 whereas "metolachlor 1" plots in Soybean 1 were treated with metolachlor. A large difference in the itchgrass population was observed in these two treatment groups in Soybean 1 (Fig. 3), and a residual effect from the treatments remained in Rice 2 (Fig. 4). It therefore seems obvious that large differences in the itchgrass population during Corn 2 are a continuing effect from the different herbicides applied two crops earlier.

Previous-Crop Effects

Broadleaf weeds were more prevalent in Corn 2 when the previous rice had been hand weeded rather than when treated with herbicides (Fig. 5). Corn yields were lower and weed weights higher following no-till rice than following rice that was conventionally tilled.

Soybean 2

Total weed weight in this cycle increased dramatically to an average of 343 g m^{-2} (Fig. 6). Soybean yields, while related to treatment, were very low. Itchgrass continued to increase in importance; it averaged 68% of the total weed population.

Within-Crop Effects

Soybean yields were lower and weed weights higher in no-control plots than in treatments with weed control (Fig. 6). Most of the weeds in these two treatment groups were grasses, and itchgrass was the dominant species. No-control plots had greater amounts of large crabgrass-plus-goosegrass while plots with weed control had more broadleaf weeds.

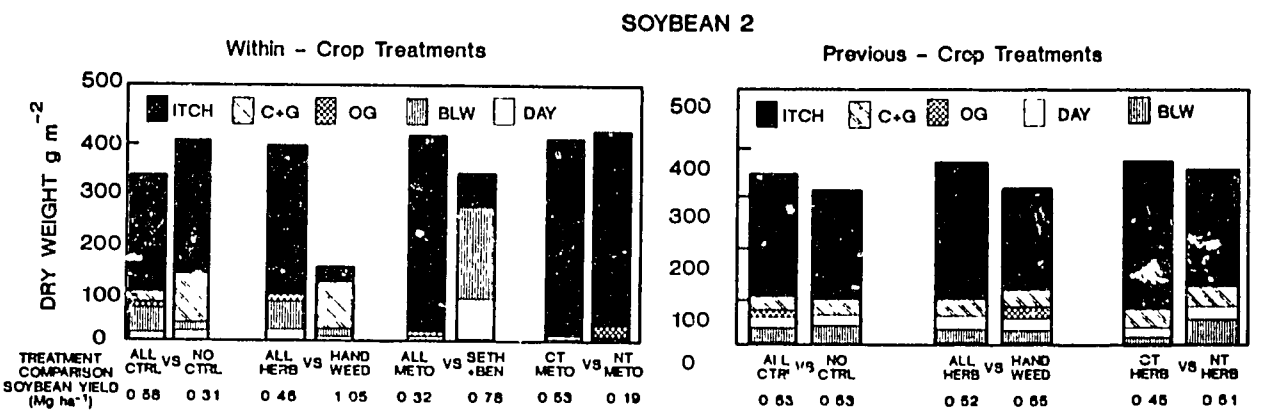
Hand-weeded plots yielded twice as many soybeans but only half as many weeds as plots treated with herbicide (Fig. 6). The composition of the weed population also differed with weed control method. Large crabgrass-plus-goosegrass were the major species in hand weeded plots, while itchgrass was dominant in the herbicide treatments.

The type of herbicide applied affected both crop yields and weed infestation (Fig. 6). Soybean yields were higher and total weed weight was less if sethoxydim-plus-bentazon rather than metolachlor was the chemical. Itchgrass comprised more than 90% of the weed population in metolachlor-treated plots; it was less than 20% of the population in the sethoxydim-plus-bentazon treatment. Broadleaf weeds and dayflower, each of which was a minor component of the weed population in the metolachlor treatments, accounted for 80% of the weeds in the sethoxydim-plus-bentazon plots.

Tillage had a large effect on crop yields, but no effect on the weed population (Fig. 6). Yields were higher with conventional tillage than no-tillage, but the weed in each tillage group was virtually a pure stand of itchgrass.

Previous-Crop Effects

Total weeds in Soybean 2 were higher following herbicide-treated rice than in soybeans following hand-



STATISTICAL SUMMARY

	Mean	CV (%)	p for each treatment comparison						
TW	343	34	0 03	<0 01	<0 04	<0.46	0.20	0 05	0.72
GW	276	42	<0 01	<0.01	<0.01	0 59	0 19	0.05	0.10
ITCH	234	51	0 19	<0 01	<0 01	0 70	0.57	0.07	0.16
C+G	33	89	<0 01	<0 01	0 95	0 81	0.64	0.93	0 17
OG	8	86	0.46	0 84	0.58	0.20	0 46	0.30	0.87
DAY	23	124	0.31	0.01	<0 01	0.71	0.76	0.95	0.08
BLW	43	127	0 04	0.01	<0 01	0.88	0.88	0.88	0.04
SOYB	0.53	49	<0.01	<0.01	<0 01	<0.01	0.97	0.54	0.10

Fig. 6. Orthogonal comparisons of weed control measures applied to Soybean 2 (within-crop treatments) and weed control measures applied to Rice 2 (previous-crop treatments) on weed infestation (dry matter) and product yield in Soybean 2 (sixth crop of a 6-crop experiment), Yurimaguas Experiment Station 1986. Mean values are given in g m^{-2} for weeds and Mg ha^{-1} for soybean. ALL CTRL = all treatments with weed control; NO CTRL = no weed control; ALL HERB = all treatments with herbicide; ALL METO = all treatments with metolachlor; SETH + BEN = sethoxydim-plus-bentazon; CT METO = conventional tillage with metolachlor; NT METO = no-till with metolachlor; CT HERB = conventional tillage with propanil-plus-oxadiazon; NT HERB = no-till with propanil-plus-oxadiazon-plus-paraquat; TW = total weeds; GW = all grasses; ITCH = itchgrass; C + G = large crabgrass-plus-goosegrass; OG = all other grasses; DAY = dayflower; BLW = all broadleaf weeds.

weeded rice (Fig. 6). Soybeans following no-till rice had more broadleaf weeds than soybeans following conventionally tilled rice.

Interactions

Statistically signifcant within-crop × previous-crop interactions occurred in most crops, but few of them were judged agriculturally critical. Some of the interactions that were agriculturally relevent as well as statistically significant are shown in Table 3. There were no effects on crop yields. In Corn 1, the difference in weed weights (total and grasses) between no-control plots and those with weed control was much greater when the corn followed herbicide-treated rice than when the corn followed hand-weeded rice.

Comparisons of Rice 2 broadleaf weeds between no-control plots and those with weed control also differed, depending on whether the rice followed soybean with metolachlor or sethoxydim-plus-bentazon: there were many more broadleaf weeds in no-control plots when the preceeding crop of soybeans had been treated with sethoxydim-plus-bentazon. Weed weight comparisons (grass and dayflower) in Rice 2 between conventional and no-till plots differed if the previous soybean had been treated with metolachlor or sethoxydim-plus-bentazon. No-till rice had much more grass than conventional treatments when the rice followed soybean treated with sethoxydim-plus-bentazon. Rice 2 dayflower infestation was greater in no-till plots following metolachlor-treated soybeans, but higher in conventionally tilled plots when they followed soybeans with sethoxydim-plus-bentazon. In Corn 2, total grass weight was much higher in no-till corn (compared to conventional rice), when it followed no-till rice than when no-till corn followed conventionally tilled rice. Perennial grasses in this crop showed the same pattern (data not presented).

Table 3. Agronomically important interactions between within-crop and previous-crop weed control treatments and their effects on weed weights. Corn 1, Rice 2 and Corn 2 of a six-crop experiment, Yurimaguas Experiment Station 1984 to 1985.

Crop	Comparisons† Within crop	Previous crop	TW‡	GW	BLW	DAY
			g m⁻²			
Corn 1	AC	HRB	24	11	5	6
	NC	HRB	151	115	12	17
	AC	HW	11	7	4	0
	NC	HW	54	35	13	3
		P	<0.01	<0.01	0.61	0.45
Rice 2	AC	METO	174	88	25	69
	NC	METO	391	328	38	20
	AC	S + B	267	109	33	124
	NC	S + B	473	321	126	24
		P	0.54	0.31	0.01	0.26
	CT	METO	154	79	26	48
	NT	METO	311	156	27	128
	CT	S + B	321	38	29	254
	NT	S + B	368	240	23	105
		P	0.19	0.03	0.79	<0.01
Corn 2	CT	CT	141	98	6	37
	NT	CT	181	141	5	34
	CT	NT	176	138	3	35
	NT	NT	316	300	2	15
		P	0.06	0.03	0.67	0.44

† AC = all treatments with some weed control; NC = no weed control; HRB = all treatments with herbicide; HW = hand weed; METO = all treatments with metolachlor; S + B = sethoxydim-plus-bentazon; CT = conventional tillage; NT = no-till.

‡ TW = total weeds; GW = all grasses; BLW = all broadleaf weeds; DAY = dayflower. The sum of GW + BLW + DAY does not always equal TW because sedges, a minor component of the weed population, are not included.

Relationships with Previous Research

Other researchers have reported that continued use of one herbicide can shift the weed population in favor of tolerant species. For example, applications of trifluralin [2,6-dinitro-*N*, *N*-dipropyl-4-(trifluoromethyl) benzename] or fluometuron [*N*,*N*-dimethyl-*N'*[3-(trifluoromethyl)phenyl] urea-plus-prometryn (*N*,*N'*-bis (1-methylethyl)-6-(methylthio)-1,3,5-triazine-2,4-diamine)] greatly increased *Cyperus esculentus* L. (4,7,19). *Polygonum pensylvanicum* L., *Panicum dichotomiflorum* Michx., *Digitaria* spp., and several serious perennials increased when 2,4-D and atrazine (6-chloro-*N*-ethyl-*N'*-(1-methylethyl)-1,3,5-triazine-2,4-diamine) were applied to corn (3). Doll and Piedrahita (6) had mixed results in Colombia with corn and soybean. There was no shift in the weed population when corn was treated for four seasons with atrazine or atrazine-plus-alachlor [2-chloro-*N*-(2,6-diethylphenyl)-*N*-(methoxymethyl) acetamide]; but continuous use of alachlor alone in corn or soybean caused a rise in the broadleaf weed population

Johnson (11) found that even when herbicides were rotated in turfgrass, some species were not controlled and greatly increased. Two researchers reported that when both herbicides and crops are rotated, composition of the weed population was not greatly altered, and overall weed control was excellent (5,8).

Other workers, in agreement with our findings, have found that weed problems under no-till are more severe and the weed species different than those encountered with conventional tillage. Wrucke and Arnold (19) found nearly twice as many weeds in no-till treatments than in conventionally plowed plots. Most of the increased weeds were grasses. Heron and Slack (10), Triplett and Lytle (17), and Pollard and Cussans (13) all found an increase in perennial weeds under no-till management.

Economic and Management Considerations

Costs of the weed control treatments are listed in Table 4. Upland rice, which is particularly vunerable to weed pressure, appears to be an inappropriate crop

Table 4. Approximate cost of herbicides used in treatments applied to rice, corn and soybean, Yurimaguas Experiment Station 1983 to 1986.

	Treatment	Cost* $ ha⁻¹
Rice	Oxadiazon + propanil	150
	Paraquat + oxadiazon + propanil	175
Corn	Metolachlor	100
	Paraquat + metolachlor	125
Soybean	Metolachlor	100
	Paraquat + metolachlor	125
Soybean	Metolachor	100
	Paraquat + metolachlor	125
	Sethoxydim + bentazon	160
	Metolachlor + sethoxydim	185

* Cost of herbicide in Lima, Peru, 1985.

.9

for this high-input rotation if the difference between weed control costs and crop value is considered. The greater competitive abilities of corn and soybean suggest that lower rates of herbicides in these crops can provide weed control that is both effective and economic.

In Yurimaguas, continued use of metolachlor on itchgrass infested land results in almost pure stands of this species. In this experiment itchgrass was effectively controlled in grain legumes with sethoxydim, moderately controlled in upland rice with propanil-plus-oxadiazon and controlled in corn only with hand weeding. Our work suggests that itchgrass may be kept in check within a rotation of rice-corn-soybean if the grass is aggressively controlled in soybean with sethoxydim. Other researchers have reported that pendimethalin [*N*-1-ethylpropyl)-3,4 dimethyl-2,6-dinitro-benzenamine] controls itchgrass in both corn and soybeans (1, 16).

CONCLUSIONS

1. The spectrum of weed species in the field changed dramatically over the course of the experiment (Fig. 7). Large crabgrass-plus-goosegrass was the most important weed problem in the first three crops of the experiment. At the conclusion of the study itchgrass dominated the site.
2. Changes in the weed population were attributable to the weed control treatments employed.

a) Metholachlor controlled broadleaf weeds, dayflower and most annual grasses in corn and soybeans. Itchgrass is resistant to metolachlor, however, and it vigorously invaded plots when competing species were eliminated.

b) In soybean, sethoxydim applied 30 DAP controlled all grasses including itchgrass; but bentazon was ineffective against broadleaf weeds and dayflower.

c) Propanil-plus-oxadiazon was moderately effective against all grasses and broadleaf weeds in rice, but dayflower was resistant. This species flourished when competition from other weeds decreased.

d) All herbicides were effective in controlling sedges but even when no herbicide was applied, sedges disappeared after the first crop.

3. We were able to measure residual effects of weed control treatments on subsequent crops, although these effects generally disappeared after two crops. Large weed populations in one crop often resulted in more weeds and decreased crop yields in the next crop regardless of the weed control treatment used. In particular, failure to control itchgrass in one crop dramatically increased its level of infestation and ability to reduce yields in the next. At the end of the experiment, treatments which had received only metolachlor in both corn and soybean had weed populations with 97% itchgrass.
4. Tillage had large effects on the level of weed infestation, population composition, and crop yields. In most instances, weed infestations were higher and crop yields lower under no-till management. Grasses were predominant under no-till conditions, but dayflower grew more readily when the field was tilled. When no-till followed no-till, perennial grasses increased.
5. The three crop species differed greatly in their ability to compete with weeds. The order of competitiveness was corn > soybean > rice. Rice 2 yields were essentially zero without weed control but Corn 2 no-control plots were reduced by just 30% compared to the hand-weeded treatment.
6. An effective weed control program for intensively managed crops in this region is possible, but it may not be economical. Costs for the different weed control treatments ranged from $50 for one weeding by hand to $185 ha^{-1} for the metolachlor-plus-sethoxydim treatment.

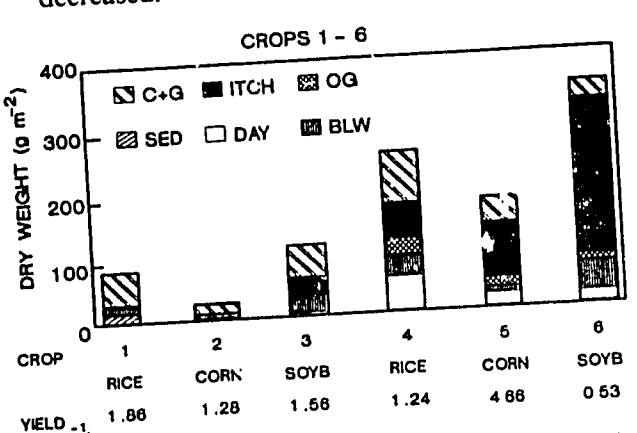


Fig. 7. Changes in the weed population and level of infestation through six consecutively-planted short-cycle crops, Yurimaguas Experiment Station 1983–1986. Weed dry weights and crop yields in each crop are the mean of all treatments in that crop. C + G = large crabgrass-plus-goosegrass; ITCH = itchgrass; OG = all other grasses; SED = sedges; DAY = dayflower; BLW = all broadleaf weeds.

REFERENCES

1. Akobundo, I.O. 1982. Weed control in cowpea in the humid tropics. Weed Sci. 30:331–334.
2. Bachthaler, G. 1969. Development of weed flora in Germany in relation to changes in methods of cultivation. Angew. Bot. 43:59–69.
3. Brimhall, P.B. 1971. Modifications in the weed flora due to weed control techniques. Weed Abstr. 20:828.
4. Buchanan, G.A., C.S. Hoveland, V.L. Brown, and R.H. Wade. 1975. Weed population shifts influenced by crop rotations and weed control programs. Proc. Annu. Meet. South. Weed Sci. Soc. 28:60–71.
5. Burnside, O.G. 1978. Mechanical, cultural, and chemical control of weeds in a sorghum-soybean rotation. Weed Sci. 26:362–369.
6. Doll, J., and W. Piedrahita. 1975. Herbicide and crop rotation effects on the weed complex. Proc. 5th Asian-Pac. Weed Sci. Soc. Conf. 5:339–343.
7. Dowler, C.C., and E.W. Hauser. 1974. The effect of cultivation on weeds controlled by fluometuron in cotton. Proc. Annu. Meet. South. Weed Sci. Soc. 27:112–115.
8. Dowler, C.C., E.W. Hauser, and A.W. Johnson. 1974. Crop-herbicide sequences on a Southeastern Coastal Plain soil. Weed Sci. 22:500–505.
9. Fryer, J.D., and R.J. Chancellor. 1970. Evidence of changing weed populations in arable land. Proc. Br. Weed Control Conf., 10th 10:958–964.
10. Herron, J.W., and C.H. Slack. 1971. Weed problems in no-till corn. Proc. Annu. Meet. South. Weed Sci. Soc. 24:170.
11. Johnson, B.J. 1982. Influence of herbicide rotation treatments on species composition of weeds in turfgrass. Weed Sci. 30:548–552.
12. Nicholaides, J.J., D.E. Bandy, P.A. Sanchez, J.R. Benites, J.H. Villachica, A.J. Coutu, and C.S. Valverde. 1985. Agricultural alternatives for the Amazon Basin. BioSci. 35:279–285.

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13. Pollard, F., and G.W. Cussans. 1981. The influence of tillage on the weed flora in a succession of winter cereal crops on a sandy loam soil. Weed Res. 21:185–190.
14. Rademacher, B., W. Koch, and K. Hurle. 1970. Changes in the weed flora as the result of continuous cropping of cereals and the annual use of the same weed control measures since 1956. Proc. Br. Weed Control Conf., 10th. 10:1–6.
15. Sanchez, P.A., D.E. Bandy, J.H. Villachica, and J.J. Nicholaides. 1982. Amazon Basin soils: Management for continuous crop production. Sci. 216:821–827.
16. Sharma, D., and O. Zelaya. 1986. Competition and control of itchgrass (*Rottboelia exaltata*) in maize. Trop. Pest Manage. 32:101–104.
17. Triplett, G.B., Jr., and G.D. Lytle. 1972. Control and ecology of weeds in continuous corn grown without tillage. Weed Sci. 20:453–457.
18. Weber, J.B., J.A. Best, and W.W. Witt. 1974. Herbicide residues and weed species shifts on modified-soil field plots. Weed Sci. 22:427–433.
19. Wrucke, M.A., and W.E. Arnold. 1985. Weed species distribution as influenced by tillage and herbicides. Weed Sci. 33:853–856.