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Weeds and natural enemy regulation of insect pests in upland rice; a case study from West Africa

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Abstract

Effects of five weed management regimes on abundance of weeds, insect pests, generalist predators and on pest damage and rice yield were investigated in upland rice in Côte d'Ivoire over two years. In both years there was a highly significant negative correlation between weed biomass and grain yield across all treatments. Only two pest insect groups, *Nephotettix* spp. (Cicadellidae) and seed sucking Heteroptera, were consistently more abundant in unweeded plots and had a consistent significant positive correlation between abundance and weed biomass across all seven treatments. These polyphagous groups may have been more dependent on resources provided by weeds than the other pests studied. However, pest damage was not affected by presence or absence of weeds, suggesting that populations were below a damage threshold. Ants were the most abundant predators in the rice canopy and were most abundant in unweeded treatments. Abundance of both ants and spiders was significantly positively correlated with weed biomass across treatments. Abundance of reduviid bugs was positively correlated with weed biomass only in 1995. Any benefits due to presence of weeds in the crop were completely outweighed by loss of crop yield due to weed competition. However, if crop losses due to weeds were sufficiently reduced, it is possible that significant losses due to insect pests might emerge.

Introduction

The importance of natural enemies in the control of insect pests of irrigated rice in South East Asia is now widely recognized (Heong *et al.*, 1991; Way & Heong, 1994; Schoenly *et al.*, 1996; Settle *et al.*, 1996). Very much less is known of the role of natural enemies, particularly generalist predators, in insect pest regulation in rainfed rice in West Africa. Although many of the major groups of predatory arthropods are common to rice ecosystems of Asia and Africa, their species composition and abundance differ widely (Lor, 1978; Afun, 1997).

Manipulation of the rice ecosystem to conserve and enhance natural enemies provides a means of reducing pest insect damage while avoiding the costs, both financial and environmental, of excessive use of insecticides which can themselves cause pest outbreaks by suppression of their natural enemies (Settle *et al.*, 1996.). One approach to enhancing natural enemy populations in rainfed crops is by manipulation of weed communities within the crop itself (Altieri, 1995). While weeds compete with rice and reduce yields when present in the crop above a critical threshold density, they also provide protection and other resources for generalist predators and complete clean weeding of crops may result in increased pest damage (Altieri & Whitcomb, 1980; Altieri & Gliessman, 1983; Ezueh & Amusan, 1988). A strategy for integrated management of upland rice pests could therefore be to optimize weed densities such that competition is reduced below a critical damage threshold while at the same time avoiding insect pest damage resulting from creation of unfavourable conditions for natural enemies.

In the present study, we tested the following hypotheses: (i) partial weeding enhances populations and impact of

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natural enemies on rice insect pests; and (ii) increased natural enemy populations result in decreased pest populations and, therefore, greater grain yield. We investigated the effect of five different weed management regimes, defined by different weed-free periods during the crop cycle, on abundance of weeds, insect pests and generalist predators in upland rice in Côte d'Ivoire. Additionally, a recommended herbicide regime was included in the treatments for comparative purposes. We also studied the effect of the different weed management regimes on insect damage to rice and on rice yield. The experiments were designed to imitate, as far as possible, the agronomic conditions prevailing in smallholder farmers' fields in the region.

Materials and methods

Experimental sites

The site was a free draining Alfisol, 300 m amsl at Mbé, 20 km N of Bouaké, Côte d'Ivoire (5° 06′ W, 7° 52′ N). The experiment was conducted over two consecutive seasons in 1994 and 1995. The land used for the experiment in 1994, had been fallow for eight years, having last been planted with cassava by a local peasant farmer. In the first year, the initial weed growth during the experiment was sparse up till the late tillering stage of the rice. To reproduce the type of weed density experienced in farmers' fields, the same site was used for the 1995 experiment, when the weed biomass almost doubled that of the previous year in the unweeded plots. The experimental fields were slashed and burned in the traditional way, without any conventional tillage. Nitrogen (as urea), was applied at 50 kg ha^{-1}, in a split application at seedling and at booting stages of the rice. An improved rice variety, IDSA 6, developed for upland systems with medium tillering and maturity between 125 and 130 days was grown. The rice was sown in the last week of June in both years, with 0.25 m between rows and hills at 5–8 seeds per hill.

Treatments and field design

The experiment was laid out in a two factor factorial arrangement. There were seven weeding regimes, as the main plots, arranged in a randomized complete block design and replicated four times. Each main plot had two sub-plots of equal size, with the systemic insecticide, carbofuran (Furadan®) applied to one and the other without. The seven weeding regimes were:

1. No weed control.
2. Keeping the crop weed-free from planting to 21 days after rice emergence.
3. Weed-free from 14 to 35 days after emergence.
4. Weed-free from 28 to 49 days after emergence.
5. Weed-free from 42 to 63 days after emergence.
6. Complete weed control, i.e. weeding fortnightly until 100 days after emergence.
7. Herbicide application, i.e. application of the pre-emergence herbicide, Ronstar (oxadiazon), 1 kg a.i. ha^{-1}, one day after sowing, followed by a post-emergent herbicide, Garil (triclopyr + propanil), 0.3 + 1.44 kg a.i. ha^{-1}, at 25 days after emergence.

The granular form of the systemic insecticide, carbofuran (Furadan®) was applied to one of the subplots of each treatment at 1 kg a.i. ha^{-1}. The carbofuran, was drilled into shallow furrows about 5 cm from each rice hill at 1 kg a.i. ha^{-1}, to reduce populations of plant feeding insects. It was applied at seedling emergence and repeated every two weeks until flowering stage. The Furadan did not appear to affect abundance of plant feeding insects significantly and results for both sub-plots were pooled in this study. The sub-plots measured 10 × 8 m with 0.5 m alleys between plots and between blocks. Weed control in the partially weeded plots was carried out through traditional hoeing.

Data collection

Activity of ground-living predators

Activity of ground-living predators was estimated with pitfall traps consisting of two nested plastic cups of 83 mm internal diameter. The outer cup was left permanently buried in the ground with the top flush with the soil surface, reducing disturbance when traps were emptied. Mercuric chloride solution (10 ppm) was used as a killing agent and preservative and a few drops of liquid detergent were added to reduce surface tension. Perforated holes were made in the sides of the cups to prevent flooding during rain storms. Two traps were placed in each plot, in opposite corners and equidistant (about 2.5 m) from adjacent edges of the plot. The traps were operated for three consecutive days at 22, 44, 66, 88 and 110 days after emergence and the samples stored in 70% ethanol for sorting and identification.

Abundance of pests and predators in the crop canopy

Foliage insect pests and predators were sampled with sweep nets. Twenty sweeps were made diagonally across each plot and the samples were placed in separate plastic sachets and stored in a deep freezer at −4°C until sorted. Samples were taken at 25, 50, 75 and 100 days after emergence.

Densities of ground-active pests and predators

In 1994, an open-top, metal quadrat measuring 0.5 × 0.5 × 0.3 m was used to sample ground-active invertebrates. After dropping the quadrat firmly on the ground, the delimited area was searched for 15 min and the arthropods sucked up with a hand-held pooter. In 1995, a McClough Super Airstream IV Leaf Blower, modified as a vacuum aspirator, was used together with the metal quadrat. This method was similar to that used by Topping & Sunderland (1994), to study spider population dynamics in winter wheat. The suction tube was made of hard plastic and measured 135 mm internal diameter. A collecting net of 0.1 mm mesh was tied to and pushed into the suction head to intercept the arthropods caught. The suction head was moved up and down the vegetation in the quadrat for 1.5 min, following which the samples were transferred to plastic sachets and the arthropods quickly killed with a pyrethroid-based aerosol spray. Litter and loose soil in the quadrat were then thoroughly searched to recover any remaining arthropods. Two samples were taken per plot at 23, 46, 69, 92 and 115 days after emergence. Samples from the same plot were pooled and stored in glass vials containing 70% ethanol until sorted.

Densities of spider webs in the crop canopy

The density of web-building spiders was estimated by counting webs in a 5 × 1 m rectangle, delimited diagonally across the plots with the cord just above the rice foliage. A fine mist of water was sprayed from a knapsack sprayer into the crop in the marked areas to expose the webs for counting. In 1994, counting was done only at the grain stage of the rice at 110 days after emergence, but in 1995 five counts were made at 21, 42, 63, 84 and 105 days after emergence. Counts were made in all plots on the same day to avoid differential effects of rainfall on web numbers and counts were always carried out prior to weeding plots to avoid the effects of human disturbance on web building.

Stem borer damage and species composition

Deadhearts. At 29 and 58 days after emergence, eight hills were uprooted randomly from any of the outer eight rows of the plots and used to determine percent deadhearts, i.e. the proportion of tillers killed by stem borers in both years. The eight rows were counted from either side of the plot excluding the edge rows. All the uprooted tillers were dissected to determine the stem borer species.

Whiteheads. Percent whiteheads were determined at 112 days after emergence by counting the total number of rice panicles and the number which were dead (whiteheads) in the six middle rows of each plot in both years.

Determination of weed biomass and proportions

After quadrat sampling for arthropods, the rice and weeds in the quadrat were then cut at ground level, separated into grasses and broadleaves, and weighed on all sampling occasions. The samples were air dried for two or three days before drying in an oven at 80°C for 72 h, or until constant weight was obtained.

Determination of grain yield (kg ha^{-1})

Ten middle rows of rice in each plot were not subjected to any destructive sampling and used for grain yield determination. Four 1 m^2 areas were cut at maturity and the rice threshed and air dried until the average grain moisture content was 12%.

Data analysis

Some data were transformed before analysis to reduce variance and improve normality. Insect counts were transformed into square root (SQRT (x + 0.5)) values, percentage data into arcsine values (sin^{-1}(SQRT x + 0.5)), where x is the fractional conversion of the percent value, and weed dry weights into logarithm (log (x + 1)) values before analysis. Differences in treatment means were tested for significance with Analysis of Variance (ANOVA) with randomized complete block design (0.05 level), and Duncan's multiple range test (0.05 level) was used to separate means when significant ANOVA was observed. Pair-wise correlations of arthropod abundance and weed biomass were run using the mean values for each subplot treatment for a particular sampling date for the total number of sampling days (e.g. n = 42; 7 treatments × 2 subplots × 3 sampling days).

Results

Weed biomass

Weed biomass on the unweeded plots averaged about 0.5 kg m^{-2}, 88% of which were grasses, principally *Digitaria horizontalis* and *Imperata cylindrica*. In both years, weeding during the first three weeks after seedling emergence significantly reduced mean weed biomass to a level lower than that of no weeding, but it was higher than the other forms of partial weeding regimes that began two weeks after emergence (fig. 1). The weed biomass on herbicide treated plots was similar to those on the partially weeded plots because the herbicide was effective for only about eight weeks after the germination of the rice.

Grain yield

In 1994, complete weeding produced the highest yield and this differed significantly from the other treatments except weeding between 28 and 49 days after emergence. All treatments weeded between 28 and 63 days after emergence gave grain yields similar to that in the standard herbicide treatment (fig. 1). Grain yield from the unweeded plots was only 340 kg ha^{-1}. Furadan application increased grain yields but not significantly (2164 and 2418 kg ha^{-1}, SE = ± 93). Few interactions occurred between Furadan application and weeding regimes and they follwed the same trend as the main plot (weeding regime) treatment. Yields were generally lower in 1995 but similar in general trend to those in 1994 with the highest yield among partially weeded treatments from plots weeded between 28 and 49 days after emergence. In 1995, the unweeded plots were completely smothered with weeds and produced no grain. There were no differences in yields from carbofuran treated and untreated plots (1087 and 1102 kg ha^{-1}, SE = ± 75 kg). In both 1994 and 1995 there was a highly significant negative correlation between weed biomass and grain yield across all treatments (1994; r = −0.981, P< 0.001: 1995; r = −0.876, P< 0.05).

Abundance of insect pests in the rice canopy

Two genera of leafhoppers (Hemiptera: Cicadellidae), *Nephotettix* spp. and *Cofana* spp., were present in the rice canopy. *Nephotettix* spp. were among the commonest pests, with an average abundance across all treatmentsof 3 and 8 individuals per 20 sweeps in 1994 and 1995, respectively. In 1994, there were no significant differences between weeding treatments in abundance of *Nephotettix* spp., but in 1995 they were significantly more abundant in unweeded plots and less abundant in clean-weeded plots (0–100 days) than in any other treatments (fig. 2A & B). In both 1994 and 1995 there was a significant positive correlation of abundance with weed biomass (1994: r = 0.65, P<0.001, n = 42; 1995 r = 0.65, P<0.001, n = 42).

Cofana spp. were on average much less abundant than *Nephotettix* spp., with a maximum abundance of 2.8 individuals per 20 sweeps. As with *Nephotettix* spp., there were no significant differences between weeding treatments in abundance in 1994. In 1995, this genus was significantly more abundant in plots weeded between 28 and 49 days than in other treatments although otherwise there were no differences between treatments (fig. 2C & D). In 1994, abundance of this pest showed a highly significant positive correlation with rice biomass across treatments (r = 0.80,

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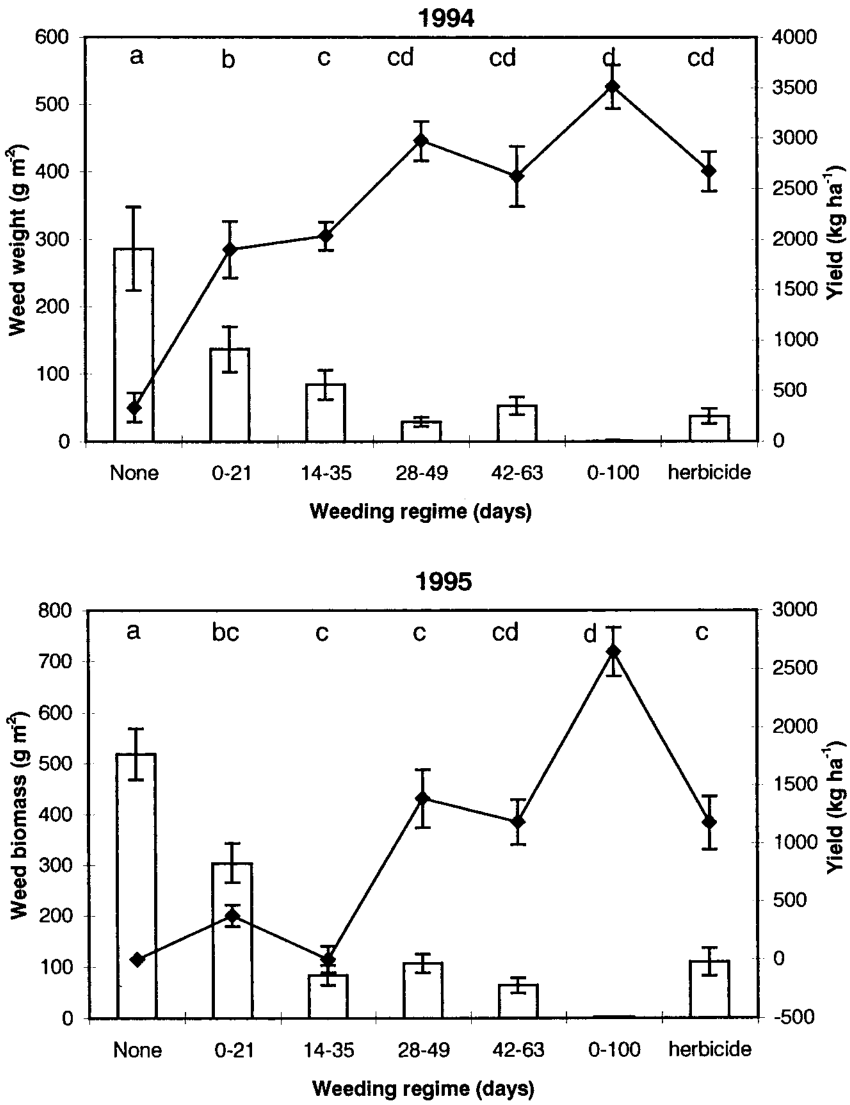

Fig. 1. Effects of weeding regimes and herbicide treatment on weed biomass (columns) and grain yield (graph line) in upland rice, Côte d'Ivoire, 1994 and 1995. Columns with the same letter do not differ significantly ($P > 0.05$).

P<0.001, n = 42) but none with weed biomass. In 1995, there was no significant correlation between the abundance of *Cofana* spp. and either rice or weed biomass.

Planthoppers (Hemiptera: Delphacidae) were also abundant in the sweep net samples with average abundance across all treatments of 4.3 in 1994 and 14.3 in 1995. However, in neither year were there any significant differences in abundance of planthoppers between the different weeding treatments.

Two species of *Diopsis* (Diptera: Diopsidae) were swept from the rice canopy, *Diopsis longicornis* Macquart and *D. apicalis* Dalmas, but the species were not separated in the data. Adult diopsids were relatively infrequent, with an average abundance of only 0.7 individuals per 20 sweeps in both years. In both 1994 and 1995, adult diopsids were significantly less abundant in unweeded plots than in any other treatment. In 1994 they were significantly more abundant in clean-weeded plots than in any other treatment while in 1995 they were significantly more abundant in plots weeded between 14 and 35 days than in other treatments (fig. 2E & F). In 1994, diopsid abundance correlated positively with rice biomass (r = 0.59 P<0.001, n = 42) but there was no significant correlation with weed biomass. In 1995, diopsid abundance correlated significantly neither with rice nor with weed biomass.

Flea beetles *Chaetocnema* spp. (Coleoptera: Chrysomelidae) were present in the canopy in both years but were relatively infrequent. In 1994, they were significantly more abundant in plots weeded between 42 and 100 days than in other treatments and least in unweeded plots. In 1995, there was no difference in abundance of these pests between any of the weeding treatments (fig. 3A & B). In neither year was there a significant correlation between abundance and weed biomass in the different treatments.

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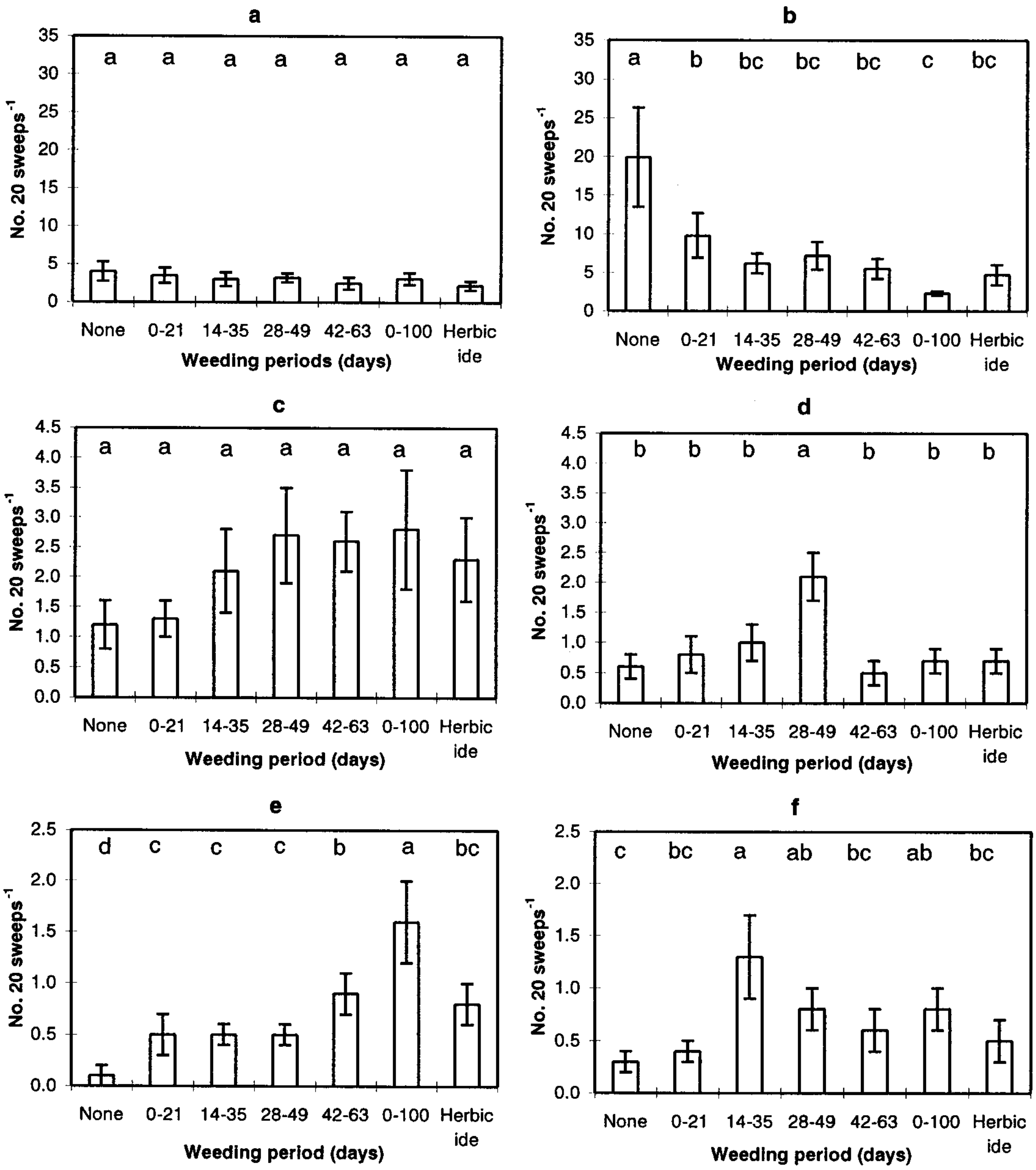

Fig. 2. Average abundance of (a) *Nephotettix* spp. 1994, (b) *Nephotettix* spp. 1995, (c) *Cofana* spp. 1994, (d) *Cofana* spp. 1995, (e) *Diopsis* spp. 1994, (f) *Diopsis* spp. 1995 in different weeding treatments in upland rice, Côte d'Ivoire. Columns with the same letter are not significantly different ($P > 0.05$).

Heteropteran bugs that feed on rice grain were frequent in the rice canopy, with average abundance of 2.9 and 5.3 per 20 sweeps in 1994 and 1995, respectively. In both years they were significantly more abundant in unweeded plots than in other treatments and in 1995 they were least abundant in the clean-weeded plots (fig. 3C & D). There was a significant correlation between abundance of pest Heteroptera in weed biomass in both 1994 (r = 0.70, P<0.001, n = 42) and 1995 (r = 0.89, P<0.001, n = 42).

Grasshoppers were present in the rice canopy in relatively low numbers in both years. There was no significant effect of weeding treatments on abundance of acridids in 1994 but in 1995 they were significantly more abundant in plots weeded between 0 and 21 days than in other treatments (fig. 3E & F). There were no significant correlations between acridid abundance and weed biomass in either year.

Stem-borer damage

Deadhearts are caused by a complex of larvae of stem boring Lepidoptera and *Diopsis* spp. during the vegetative phase of rice growth and whiteheads in the reproductive phase. There were no significant effects of weed

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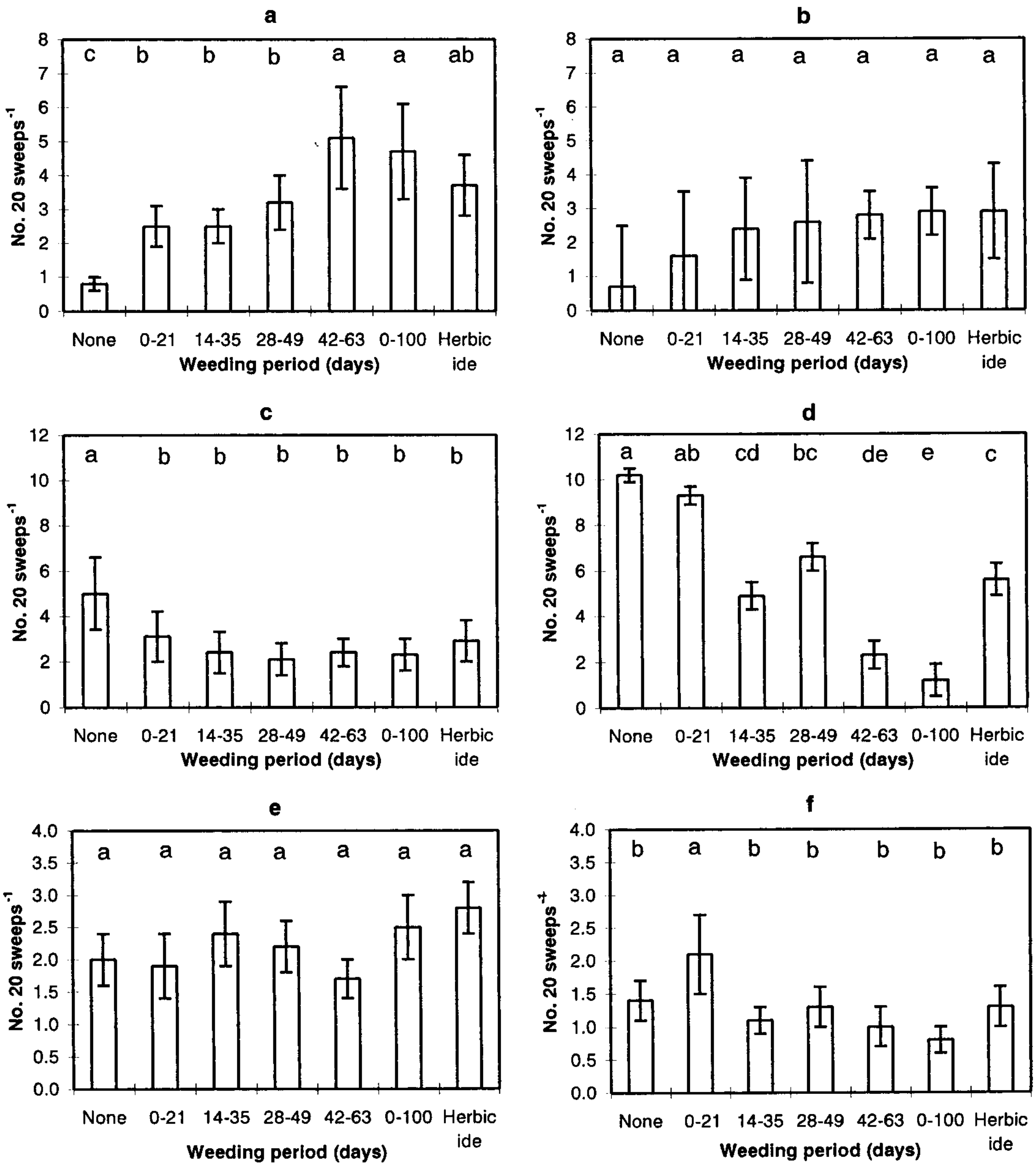

Fig. 3. Average abundance of (a) *Chaetocnema* spp. 1994, (b) *Chaetocnema* spp. 1995, (c) Heteroptera 1994, (d) Heteroptera 1995, (e) Acrididae 1994, (f) Acrididae 1995 in different weeding treatments in upland rice, Côte d'Ivoire. Columns with the same letter are not significantly different ($P > 0.05$).

management treatments on percent deadhearts in 1994. In 1995, deadhearts were significantly (13%) more abundant in the completely weeded plots and significantly less abundant in the unweeded plots than any other treatment. (fig. 4A & B). Whiteheads showed a similar trend in both years, with significantly fewer in unweeded plots and significantly more in heavily weeded plots (fig. 4C & D). When deadhearts and whiteheads were combined, their % abundance was significantly positively correlated with grain yield in both 1994 ($r = 0.9802$, $P<0.001$) and 1995 ($r = 0.9470$, $P< 0.01$).

Table 1 shows correlations between the abundance of different pest groups in the crop canopy and grain yield across the seven treatments. Only one group, pest Heteroptera, showed a significant negative correlation with grain yield. Two other groups, *Chaetocnema* spp. and *Diopsis* spp., showed significant positive correlations of abundance with grain yield in both years while *Nephotettix* spp. and Delphacidae showed such a positive correlation in 1994 only.

Abundance and activity of ground-active predators

Spiders and ants were the two most abundant ground-active predator groups with average numbers across all treatments for both groups of approximately 8 m^{-2} in 1994 and 15 m^{-2} in 1995. Spider abundance was greater in the

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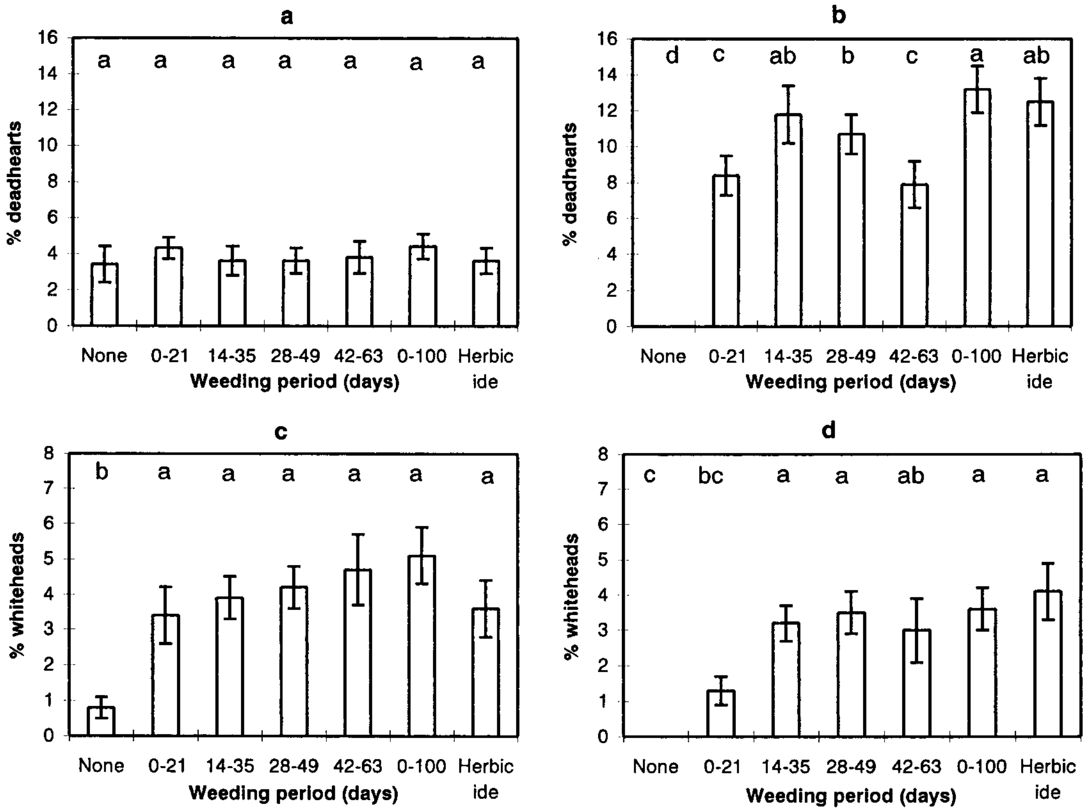

Fig. 4. Effect of weed management treatments on stem-borer damage in upland rice, Côte d'Ivoire. (a) % deadhearts 1994, (b) % deadhearts 1995, (c) % whiteheads 1994, (d) % whiteheads 1995. Columns with the same letter are not significantly different ($P > 0.05$).

Table 1. Correlations between grain yield and abundance of pest groups in canopies of different weed management treatments in 1994 and 1995.

Pest	1994		1995	
	r value	*P*	r value	*P*
Chaetocnema	0.871	<0.02	0.812	<0.05
Heteroptera	−0.902	<0.01	−0.876	<0.02
Acrididae	0.379	NS	−0.730	NS
Diopsis	0.819	<0.05	0.885	<0.01
Cofana	−0.671	NS	0.358	NS
Nephotettix	0.867	<0.05	−0.111	NS
Delphacidae	0.976	<0.01	0.006	NS

unweeded treatment and in treatments weeded after 28 days than in other treatments and were least in the herbicide treatment in 1994 and in treatments weeded after 42 days after emergence in 1995 (fig. 5A & B). Differences between the treatments with highest and lowest densities of spiders were greater in 1995 than in 1994. However, these differences were not reflected in patterns of spider activity and there were no significant differences in activity between treatments in either year. Spider density correlated positively with weed biomass both in 1994 (r = 0.50, P<0.001, n = 42) and in 1995 (r = 0.80, P<0.001, n = 70). There were also no significant differences between treatments in abundance and activity of ants in either 1994 or 1995. Ant activity was, on average, more than six-fold greater in 1995 than in 1994. Ant abundance was not significantly correlated with weed biomass in either year.

Reduviid bugs and carabid beetles occurred in both years but in numbers generally an order of magnitude lower than those for spiders or ants, with maximum densities of only 3.3 m^{-2} in 1995. There was no effect of treatments on the abundance of Carabidae in 1994 or 1995, although there was a positive correlation between carabid density and weed biomass in both 1994 (r = 0.38, P<0.01, n = 42) and 1995 (r = 0.48, P<0.001, n = 42).

The weeding regimes did significantly affect the density of predatory bugs, but no distinct pattern of effects was observed in 1994, except that the weedier plots appeared to have greater densities. The unweeded and early weeded plots had significantly greater populations of reduviids in 1995 (fig. 5C & D). Reduviid abundance was positively correlated with weed biomass in 1994 (r = 0.46 P<0.01, n = 42) but not in 1995.

Abundance of rice canopy predators

Ants were the most abundant predators in sweep-net samples, on average twice as abundant as spiders. Abundance of canopy ants was greatest in unweeded plots and least in weed–free plots in both 1994 and 1995 (fig. 6C & D). There was a significant positive correlation between

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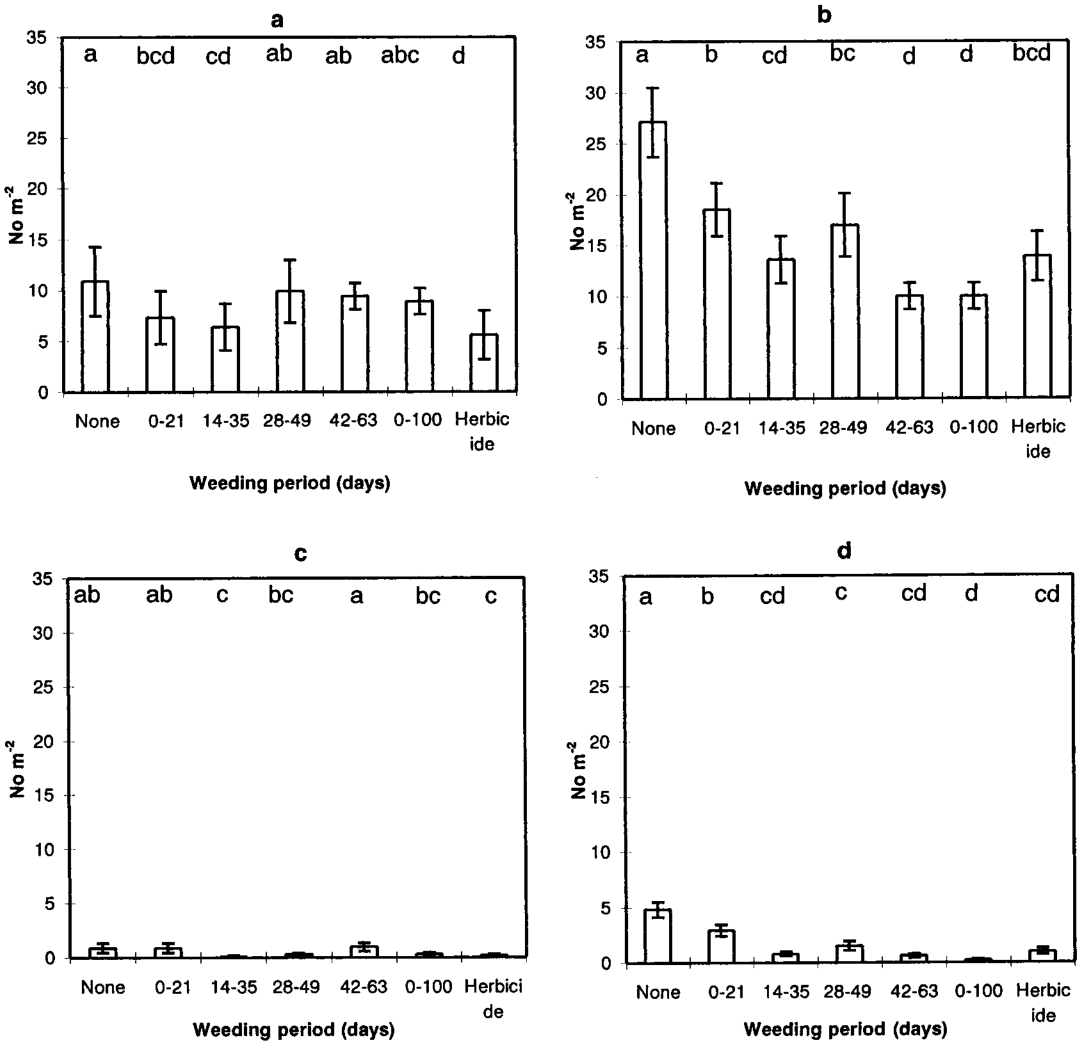

Fig. 5. Average abundance of ground-dwelling predators in different weed management treatments in upland rice, Côte d'Ivoire. (a) Spiders 1994, (b) spiders 1995, (c) Reduviidae 1994, (d) Reduviidae 1995. Columns with the same letter are not significantly different ($P > 0.05$).

weed weight and ant abundance in 1994 (r = 0.68, P<0.001, n = 42) and in 1995 (r = 0.59, P<0.001, n = 56).

In 1994, abundance of spiders was significantly greater in the plots weeded between 28 and 49 days after emergence and significantly lower in herbicide treated plots than in other treatments (fig. 6A & B). Correlations of spider abundance with weed biomass were not strong but highly significant (r = 0.55, P<0.001, n = 42). However, in 1995, spider abundance was not significantly affected by the weeding regimes.

Reduviid bugs were scarce in the rice canopy, abundance was on average one tenth that for ants. The weeding regimes did not significantly affect the abundance of assassin bugs in 1994 but in 1995 unweeded plots had significantly greater abundance than other treatments (fig. 6E & F). In 1994, the bugs showed a higher correlation with rice biomass than they did with weed biomass (r = 0.62, P<0.001 and 0.43, P<0.01 respectively, n = 42), while in 1995 they showed a high positive correlation with weed biomass (r = 0.79, P<0.001, n = 42).

Abundance of spider webs in the rice canopy

All spider webs in the rice canopy belonged to orb-web weavers (families Araneidae and Tetragnathidae). In 1994, the density of spider webs was estimated only at the milk grain stage and the unweeded plots had significantly greater densities than both the herbicide treated plots and those weeded between 28–49 and 42–63 days after emergence. There were fewer webs in the weed-free plots than in the unweeded plots but the differences were not significant (fig. 7). However, there was a positive and significant correlation between weed biomass and web density (r = 0.60, P<0.05, n = 14). In 1995, the webs were counted at seedling, tillering, booting, milk-grain and mature grain stages. Clean-weeded and herbicide treated plots had significantly fewer webs than in the very early weeded and unweeded plots which had the highest density of webs (fig. 7). There was a highly significant correlation between web density and weed biomass (r = 0.88, P<0.001, n = 14). The very much higher density of webs in 1994 was due to the

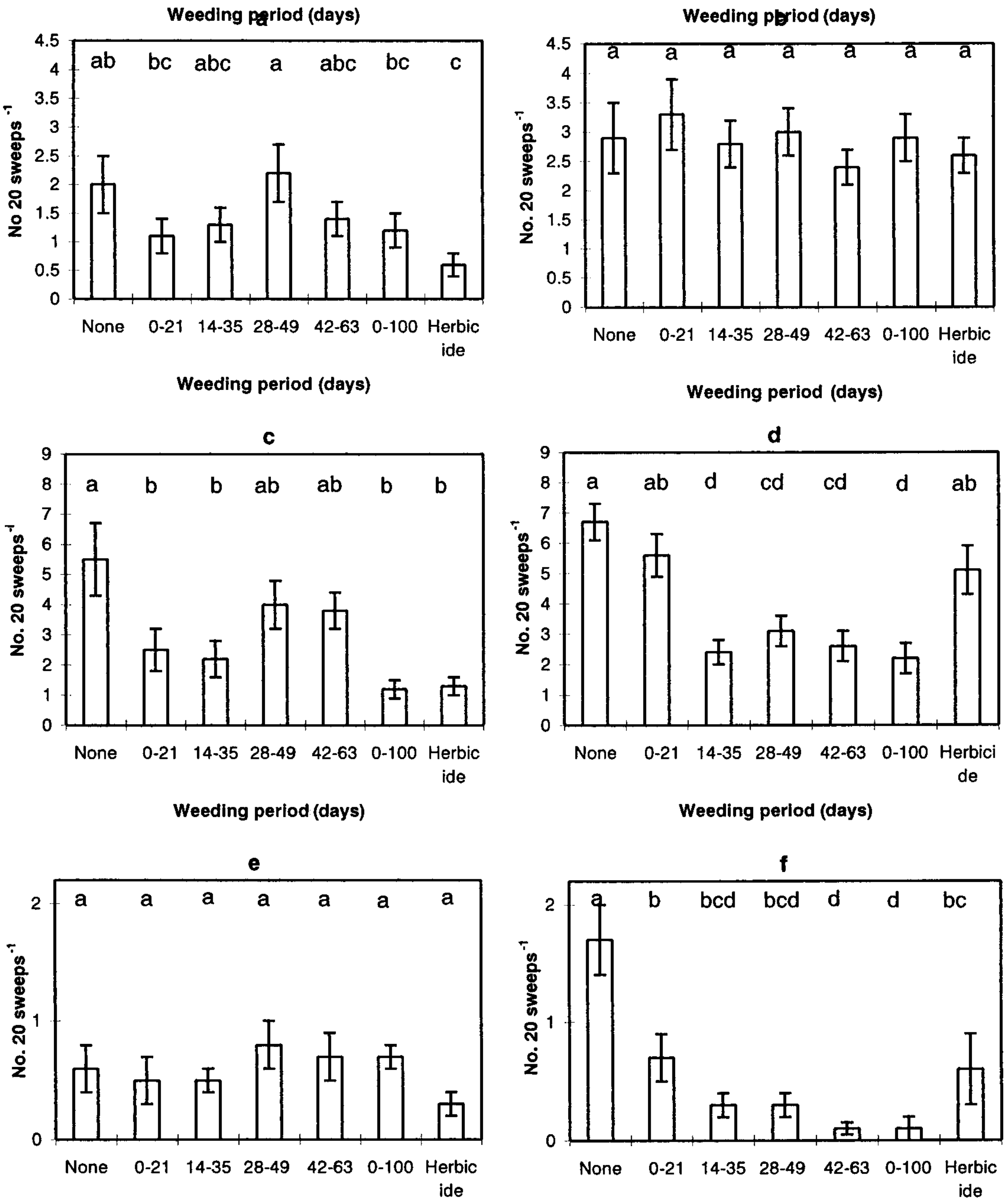

Fig. 6. Average abundance of predator groups in the canopy of upland rice in different weed management treatments in upland rice, Côte d'Ivoire. (a) spiders 1994, (b) spiders 1995, (c) ants 1994, (d) ants 1995, (e) Reduviidae 1994, (f) Reduviidae 1995. Columns with the same letter are not significantly different ($P > 0.05$).

fact that numbers were estimated close to the peak of abundance in this year.

Discussion

Weed management practices applied in these experiments clearly affected crop yield, such that weeding periods that most reduced weed biomass gave the highest crop yields but the relationship between weed management treatments and yield differed in the two years. In the first year weed biomass was only half that in the second year and yields in plots weeded between 28 and 63 days after emergence were only 20% below that in the weedfree plots and well above the average yields obtained by small-holder farmers in the region. In 1995, these treatments gave yields only *c.* 50% of that in the clean-weeded treatment and perhaps only 20%

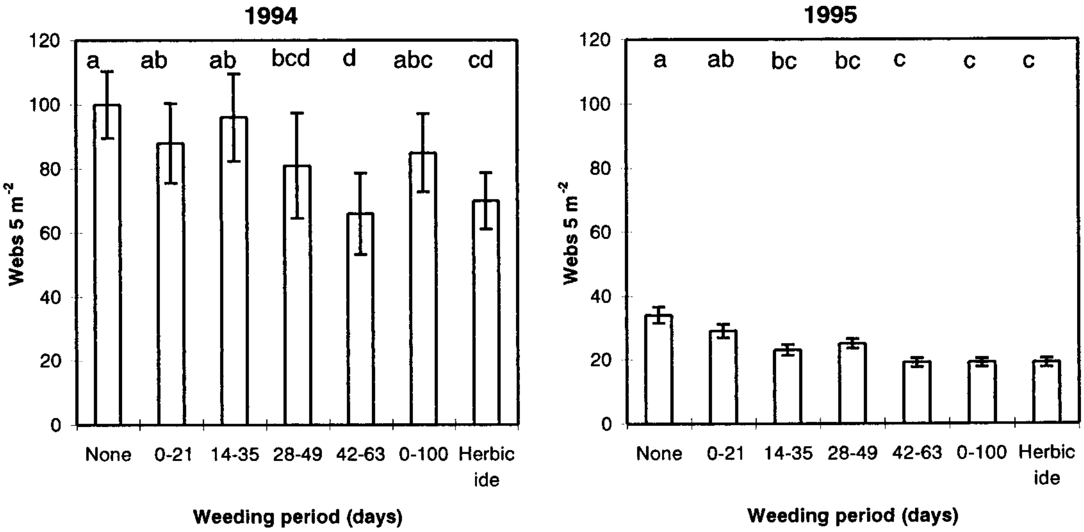

Fig. 7. Density of spiders webs (no. 5 m^{-2}) in different weed management treatments in upland rice, Côte d'Ivoire in 1994 and 1995. Columns with the same letter are not significantly different ($P = 0.05$).

higher than average farmer yields for the region. Clearly, weed competition was a major determinant of rice yield throughout the two experiments and increased in successive crops.

The results for abundance of insect pests in the rice canopy must be treated with some caution as it is known that the efficiency of capture of sweep net samples is affected by a range of factors including type of vegetation, stage of growth, time of day, variations in weather, variations in flight ability of the pests and variations between individual operators (Southwood, 1966). We controlled for time of day and variation between operators in this study which allows valid comparisons between treatments on individual sampling occasions. However, the efficiency of sampling will have varied between different stages of development of the rice crop, with a relatively smaller proportion of the rice canopy being sampled as the crop developed.

Different pest groups showed contrasting patterns of abundance in relation to the weeding treatments. Two groups, the plant-sucking planthoppers *Nephotettix* spp. and seed sucking Heteroptera, showed a consistent pattern of highest abundance in unweeded plots and lowest in clean-weeded plots. These were also the only groups that showed a consistent significant positive correlation between abundance and weed biomass across all seven treatments, suggesting that these polyphagous groups may be more dependent on resources provided by weeds than the other pests studied. The apparent lack of damage to the crop from these pests may have been because populations were below the damage threshold. Schoenly *et al.* (1996) argue that *Nephotettix* spp. only cause damage to rice in Asia if they transmit rice tungro virus disease. On the contrary, however, it is possible that the decreased crop yields in the weedier plots could have been due, in part, to greater damage caused by leafhoppers and plant sucking bugs.

The planthopper *Cofana*, stem-boring *Diopsis* spp. and leaf-feeding *Chaetocnema* beetles showed a tendency to have highest abundance in weed-free or late-weeded plots and lowest in unweeded plots although the differences were not always significant, nor consistent between the two years. Diopsids showed a positive correlation of abundance with rice biomass across all seven treatments, suggesting they may have been more directly dependent on rice than other pest groups in the study. *Diopsis longicornis* has not been reported to feed on plants other than rice, although eggs and larvae have been found on *Cyperus difformis* (Cyperaceae), a common weed of wetland rice (Alghali, 1979). It is much more common in wetland than in upland rice which may explain the low abundance in this study. It is not clear why *Cofana* and *Chaetocnema* spp. were more abundant in clean-weeded rice but rice could be a preferred host or they aggregated where they suffered the least impact from their natural enemies. Abundance of the polyphagous leafhoppers (Delphacidae) and grasshoppers (Acrididae) did not seem to be affected by weeding treatments.

Despite the various patterns of pest distribution among the weeding treatments, there was little evidence that their abundance correlated negatively with grain yields in this study. The abundance of only one group, grain-sucking Heteroptera, showed a significant negative correlation with grain yield across all treatments. Abundance of all other groups was either positively correlated or entirely uncorrelated with grain yield. There was also a significant positive relationship between % stem-borer damage and grain yield across the seven weed management treatments. Although stem borer damage was generally highest in clean-weeded and herbicide treatments, yields were also highest in these treatments. Overall, the evidence from this study suggests that insect pest populations were generally too low to have an impact on rice yields. However, although economic damage thresholds have been developed for all the major Asian rice insect pests, many of which are taxonomically closely related to West African species, equivalent information is not yet available for the pests in this study. Because economic damage thresholds are highly site specific, it is not possible to say with certainty whether the pest populations observed would have been likely to cause significant damage.

Among the ground-active predators, density of ants and carabid beetles was unaffected by weed management

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treatments. Spiders and reduviid bugs were, by contrast, most abundant in the unweeded and least abundant in the weed-free treatments, the effects being more significant in 1995, when density of weeds was greater, than in 1994. In these two groups there was a significant positive correlation between abundance and weed biomass across all treatments. Ants were also the most abundant predatory group in the rice canopy but here they were most abundant in the unweeded and least abundant in the weed-free treatments, abundance being positively correlated with weed biomass across treatments. Although the same pattern of abundance in the different treatments was not clearly evident for spiders, abundance of this group was also significantly positively correlated with weed biomass across treatments. Abundance of reduviid bugs in the canopy was unaffected by weeding treatments in 1994 but the pattern of abundance in 1995 was similar to that for ants with abundance positively correlated with weed biomass. Thus, in general, weeding treatments apprently affected more groups amongst canopy predators than ground-active predators and abundance was generally higher in the weedier treatments.

There is an extensive literature on the impact of weed management on insect populations in agro-ecosystems, much of the earlier work being reviewed by Andow (1988). Although many studies have demonstrated increased abundance of generalist predators and/or decreased abundance of insect pests in weedy as opposed to weed-free crops, relatively few have also investigated the impact this has on crop yields. Exceptions include work by Altieri and colleagues in beans, maize and various vegetable crops in central America and California which showed either non-significantly increased yields or (in one study) significantly reduced yields in weedy plots (Altieri *et al*., 1977; Alteri & Whitcomb, 1980; Alteiri & Gliessman, 1983; Altieri *et al*., 1985). Mack *et al*. (1987) demonstrated that groundnut kept weed free for six weeks gave yields that were as high as those weeded over 14 weeks and had significantly higher populations of predators and lower corn earworm populations than the clean-weeded plots. However, very weedy plots had significantly lower groundnut yields than all other treatments. Ofuya (1989a) found reduced populations of leafhoppers and flea beetles in weedy cowpea plots in Nigeria but also significantly reduced yields as compared with weed-free plots. However, in a subsequent study with either no weeding or one to four weedings, he found that crops weeded twice gave as high yields as those weeded four times and that pest populations in this treatment were not significantly higher than those in plots weeded four times (Ofuya, 1989b). Many studies have concluded that predator abundance is increased, insect pest abundance and damage are reduced and yields are at least maintained in weedy crops so long as weeds are controlled during critical periods for competition with the crop. Unfortunately, not all studies report on weed density or biomass and it is often not possible to judge whether or how much competition has occurred between crops and weeds.

The present study suggests firstly that the effect of weeds in a crop is likely to vary from one group or species of insect pest or predators to another. In part, this will depend on whether pest species are specialist herbivores on the crop, in which case the presence of non-host plants (weeds) will reduce the pest populations (Andow, 1988). In the case of generalist herbivores, the presence of weeds may actually increase populations by providing food or other resources they require. It will also depend on the requirements of different groups of predators which may obtain resources (e.g. prey, nectar, pollen or shelter) from weeds in the crop, or may, on the contrary, require a weed-free crop in order to, for example, hunt efficiently. A second point that emerges is that weed competition changes with the development of the weed flora over time as indicated elsewhere in Côte d'Ivoire by de Rouw (1991). This will inevitably alter the balance of any advantages weed presence may have relative to disadvantages due to direct competition with the crop.

Although it can be concluded that any benefits accruing from the presence of weeds in the crop in this study are completely outweighed by loss of crop yield due to weed competition, it should not be assumed that this will always be the case. In the (currently unlikely) event of smallholder farmers being able to control weeds sufficiently to largely eliminate crop losses due to weed competition, it is possible that losses due to insect pests could become much more significant. Whether or not the presence of a residual weed population in the crop would then reduce or increase crop losses due to insects would depend on the biology of individual weed, pest and predator species involved.

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