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Weed community responses in a corn-soybean intercrop

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Abstract. Weed community responses were examined in a corn-soybean intercrop in southwestern Michigan, USA, with and without nitrogen fertilization. Weed suppression was observed when intercropping was additive, but the depression in above-ground weed biomass was not due to a synergistic effect of crop diversity, but rather to the effects of crop density and identity. Intercropping did not have a greater suppressive effect than monocrops on weed biomass in a replacement intercrop when crop densities were similar to those in monocultures. Similarly, intercropping *per se* did not alter the diversity, species richness or composition of the weed community. The presence and density of corn was more important in affecting the weed community than was the density of soybeans or than intercropping itself. Fertilization and the interaction between fertilization and crop type had few effects on the weed community.

Keywords: Community diversity; Corn; Intercropping; Non-metric Multidimensional Scaling; Soybean; Weed ecology.

Nomenclature: Gleason & Cronquist (1991).

Introduction

Weeds in agricultural crops have always been considered detrimental because they interfere with the development of the crop species, accounting for a large loss in production (e.g. Caroll et al. 1990; Liebman 1988). However, Cox & Atkins (1979) suggested various potential benefits from weeds, such as protecting the soil surface from erosion, sequestering nutrients that otherwise would be leached, adding organic matter to the soil, inhibiting noxious species through allelopathy, and providing shelter and food for beneficial insects. Weeds add both species and architectural diversity to cropping systems. Despite this ecological importance, relatively little attention has been paid to understanding the biological and ecological bases of interactions within crop communities (Gliessman 1987). Understanding the ecological responses of species in human-dominated systems (such as agricultural fields) is both of scientific interest and of increasing importance as fewer untouched natural systems remain and more species carry out their existences in human-affected systems. However, for many years agricultural weed research has been directed toward eliminating the detrimental effects of interactions between crops, weeds, insect herbivores, and diseases, (and primarily by chemical means) while ecological research has been primarily concerned with pristine natural systems.

Competition from weeds can potentially be lessened by growing two or more crop species together, a practice known as intercropping (Altiere & Liebman 1986; Steiner 1984; Moss & Hartwig 1980). According to Liebman & Dyck (1993), intercrops may be more effective than sole crops in capturing resources from weeds, resulting in reduced weed growth and greater crop yields (Ali 1988; Abraham & Singh 1984; Shetty & Rao 1981), or they could suppress weed growth through allelopathy. Liebman & Dyck (1993) also pointed out that if the intercrops used resources not available to weeds or were more efficient than sole crops, this practice could provide yield advantages without suppressing weed growth. However, although several studies have tested the effects of intercropping on the total biomass or cover of weeds (e.g. Liebman & Dyck 1993; Mohler & Liebman 1987; Moody 1977; Moody & Shetty 1981), few have examined weed species interactions and community responses in intercrops (but see Palmer & Maurer 1997).

The purpose of this experiment was to use a soybean-corn intercrop as a model system for examining how weed community structure changes with fertilization and with the identity of the crop species. The composition of the weed flora in intercrops was compared with the weed flora of the respective sole crops. The research thus considered plant interactions and community ecology in the context of an agricultural crop system. A field experiment was carried out to investigate the effects of crop type and fertilization on the weed community in a soybean-corn system (the performance of the intercrop and the effects of intercropping on plant architecture are reported by Gomez 1996). Specifically, this experiment had three objectives: (1) to determine if weed suppression was greater in mixed cultures than in monocultures; (2) to investigate the community structure of the weeds in the different cropping systems and to compare this with the community structure in an uncropped community; and (3) to determine if fertilization affected the outcome of the interactions between weeds and crops.

Although weed suppression has often been speculated to be a mechanism for yield advantage in intercropping, Liebman & Dyck (1993) emphasized the lack of information on the influence of intercropping on weed community structure (but see Mohler & Liebman 1987). We are aware of only one study that has examined weed responses in a fertilized maize-soybean intercrop system (Weil & McFadden 1991). In that study, only total weed biomass was measured, and no determination was made of diversity, richness, evenness or community composition. Weil & McFadden (1991) found that mono-cropped soybean allowed greatest weed production, and weed response to fertility was reduced by increasing maize density. Either weed or fertility stress improved the land-use efficiency of the intercrop relative to sole crop, but both stress conditions combined did not. Palmer & Maurer (1997) compared five monocrops (including corn and soy) with a five-species intercrop, and found that weed species richness was higher in the multi-intercrop than in the sole crops. They also found that weed biomass was not suppressed by the intercrop.

Methods

Experimental design and study site

The experiment was conducted at Kellogg Biological Station (KBS) in southwestern Michigan as part of a larger experiment on intercropping (Gomez 1996). These plots were part of a larger conventional annual tillage program followed by the KBS Long Term Ecological Research site. A complete randomized block design was used. There were four blocks, each containing 10 plots, 2 m × 1.8 m in size. Plots and blocks were separated from each other by 1 m and 2 m walkways, respectively. The factors were fully crossed, and consisted of two levels of fertilization (fertilized or unfertilized) and five crop types (soybean monoculture, corn monoculture, intercrop-replacement, intercrop-additive, and unplanted). The ANOVA factors and their respective degrees of freedom (for weed total above-ground biomass, Shannon diversity and species richness) were: block (3 df), fertilization (2 df), crop type (4 df), fertilization × crop type (4 df), and residual error (27 df); all factors were tested against the residual error.

Ammonium nitrate fertilizer (34-0-0, NPK) was used, based on the soil test recommendations by the KBS Long Term Ecological Research Center, and hand scattered a month after sowing when corn plants had reached a height of 25 - 30 cm, at a rate of 124 kg/ha of actual N or 363 hg/ha of fertilizer. Two plots per block were left unplanted to determine weed community characteristics in the absence of crops. Each planted plot had seven rows, 30 cm apart. Within each row, seeds were sown 20 cm apart from each other. In the replacement intercrop, alternate rows of corn and soybean were sown (four rows of corn and three of soybean). In the additive intercrop, corn density was the same as in the corn monoculture (seven rows spaced 30 cm apart), and soybeans were planted between the rows of corn. Total density was therefore seven rows of corn plus six rows of soybeans in these plots. Seeds were sown on 3 June 1993. DeKalb corn (*Zea mays*) hybrid variety DK524 obtained from DeKalb Plant Genetics Co. in DeKalb, Illinois, USA and Pioneer soybean (*Glycine max*) hybrid variety 9272 obtained from Pioneer Hi-Bred International, Inc. in Johnston, Iowa, USA were used in the experiment.

Harvest and data collection

Weeds were sampled on 22-23 August, 1993, the peak of biomass production (about 12 weeks after the crops were sown). A 20-cm strip was harvested from each plot, across the rows in crop-planted plots and in the center of the unplanted plots, giving a sample area of 1.8 m × 20 cm, or 0.36 m^2. All weeds rooted within this strip were clipped at ground level, sorted to species and dried to constant weight. Total biomass, species richness, and species diversity were calculated based upon above-ground dry weight. Richness (S) was determined as the number of species present in a 0.36 m^2 sample. Shannon's index of diversity H' was calculated as

$$H' = -p_i \log_{10} p_i \qquad (1)$$

where p_i is the proportion of each species in the sample. Individual crop plants within the sample area were also clipped above ground at the same time as weeds were harvested, and dried and weighed (see Gomez 1996). Data on soil nitrogen availability in this experiment and further information on crop yields are reported by Gomez (1996).

Data analysis

Analyses of variance were carried out to determine the effects of the treatment factors on weed biomass, species richness and diversity (Shannon H') after testing for the assumptions of analysis of variance. Means were compared using Fisher's Protected LSD test or, where appropriate, using *a priori* contrasts. The effects of the experimental treatments on the overall weed community composition were tested using two approaches. First, the weed community data (dry shoot biomass of each species in a plot) were subjected to ordination using Non-metric Multidimensional Scaling ('global' NMS, using the program PC-ORD; McCune & Mefford 1995). NMS has been found to be a robust and effective technique for the ordination of community data; it is based on ranked distances and is suitable for expressing non-linear relationships (Minchin 1987; James & McCulloch 1990).

NMS was run both with a random initial configuration and also using the outcome of a Bray-Curtis ordination as the starting point (as recommended by McCune & Mefford 1995), with distances calculated using Sørensen's index. The association between the axes derived from the ordination analysis and the experimental factors was examined, as was the correlation (Pearson's *r*) between the ordination and the abundances of the weed species.

The second approach we took was to statistically test for the effects of the treatments on the overall similarity in weed community composition using Multiple Response Permutation Procedures (MRPP, using PC-ORD; McCune & Mefford 1995). MRPP uses a randomization technique to test whether the members of a group (here, an experimental treatment) resemble one another more than individuals assigned at random to groups (Biondini et al. 1985; Zimmerman et al. 1985). MRPP compares the actual distances within groups to those obtained by randomly reassigning individuals to groups many times (Gurevitch & Collins 1994). As MRPP is based on distance measures, it can easily be applied to multivariate data such as species abundances. It also offers some of the other advantages of randomization tests, such as relaxed assumptions in comparison with ANOVA or other parametric tests, and greater power than most conventional non-parametric tests (Manly 1991). We used Euclidean distance as the measure of vegetation dissimilarity because its properties appear to be superior to other distance measures for this purpose (McCune & Mefford 1995).

Results

Precipitation in 1993 (807 mm) was just below (92 %) the 10-yr mean, while growing season precipitation was somewhat above the median. Mean and maximum temperatures in 1993 were slightly below average (S. Halstead, pers. comm., based upon the Kellogg Biological Station Long Term Ecological Research site data archives). Regional corn and soy yields were somewhat below average in 1993, both at ca. 85 % of mean yields (S. Halstead, pers. comm., based upon data from the Michigan Dept. Agriculture Agricultural Statistics Service).

Weed biomass was greatest in the unplanted treatment, and then decreased in the following order: soybean monoculture, replacement intercrop, corn monoculture and additive intercrop (Fig. 1; differences were statistically significantly among crop types, with $F = 36.00$, $P < 0.0001$; for all ANOVA results here, error df = 27; see Methods). Each treatment was significantly different in biomass from the others when compared using the Fisher's Protected LSD, except that weeds in corn monoculture did not differ from those in the additive intercrop (at $P < 0.05$, Fig. 1). Biomass data, and all other data (below) met the normality assumptions of ANOVA, except for species richness data which were log-transformed. Neither the addition of fertilizer nor its interaction with crop type affected weed biomass (fertilizer, $F = 2.93$, $P = 0.10$; crop × fertilizer interaction, $F = 0.46$, $P = 0.77$). There was a significant block effect on weed biomass ($F = 8.69$, $P = 0.0003$).

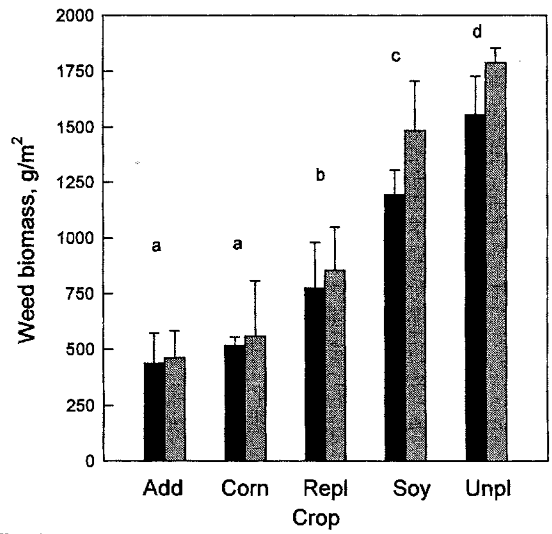


Fig. 1. Means and standard errors of means for oven-dried shoot biomass of weeds in g/m^2 ($N = 4$ plots/treatment). Crop types were: additive intercrop (Add), corn monoculture (Corn), replacement intercrop (Repl), soybean monoculture (Soy) and unplanted (Unpl). Black bars indicate unfertilized plots, gray shading indicates fertilized plots. Letters above bars indicate means that differ from one another as tested by Fisher's LSD test at $P < 0.05$.

In addition to testing for differences among crop types as above, another way of examining the potential effects of intercropping *per se* is to test the effects of relative corn density (0 in the unplanted and soybean monocultures, 1 in the replacement intercrop, and 2 in the additive intercrop and in corn monoculture), relative soybean density (determined in the same fashion), and the interaction between soybean and corn, as well as block and fertilizer effects using ANOVA (Table 1). For these analyses, the factors and their associated degrees of freedom were: block (3 df), fertilization (1 df), corn density (1 df), soybean density (1 df), corn × soybean interaction (1 df) and residual error (32 df); all factors were tested against the residual error term. If intercropping has a synergistic effect on weeds, this would be reflected in a significant corn × soybean interaction term. (Note that alpha levels are compromised by analyzing the same data in two ways; however, as we are actually more interested in nonsignificant outcomes in this case, this is a conservative test and there is not much to be gained from applying a Bonferonni correction.) Corn density had a large effect ($F = 131.43$, $P < 0.0001$) and soybean density had a more modest effect ($F = 5.61$, $P = 0.024$) on weed biomass, but

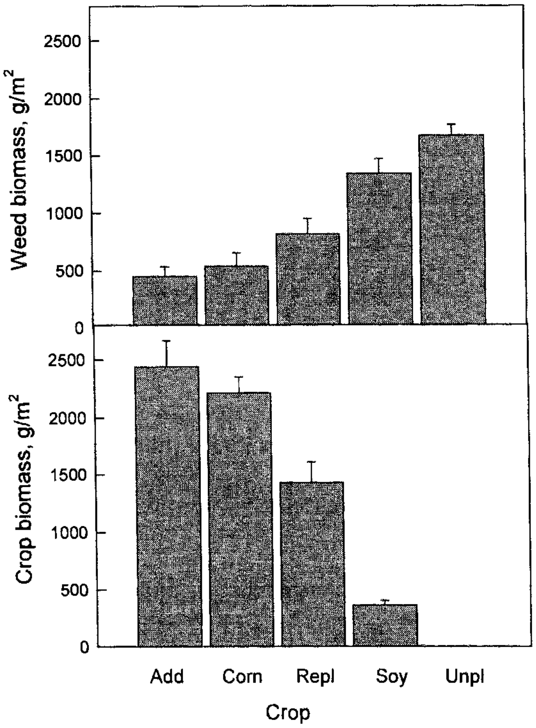


Fig. 2. Means and standard errors of means for oven-dried shoot biomass of weeds (top) and crop plants (bottom) in g/m^2 in intercrops and monocultures (averaged over the fertilization treatments; $N = 8$ plots/treatment). Crop types are as in Fig. 1.

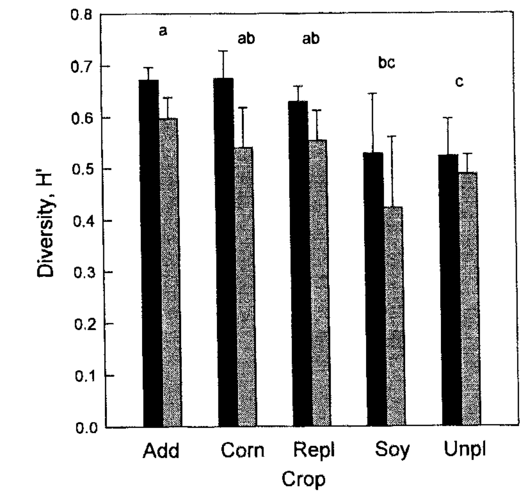


Fig. 3. Means and standard errors of means for species diversity (Shannon H') in 0.36 m^2 plot samples ($N = 4$ plots/ treatment). Abbreviations, shading and symbols are as in Fig. 1.

the interaction between corn and soybean did not affect weed biomass ($F = 1.92$, $P = 0.18$). Mean weed biomass had a negative relationship with mean crop biomass across crop treatments (Fig. 2). Total plant biomass (i.e. crop + weed) was greatest in the additive intercrop, and decreased in the order corn monoculture > replacement intercrop > soybean monoculture (Fig. 2; Fisher's protected LSD at $P < 0.05$).

If corn and soybeans do not interact to suppress weed growth when grown together, then weed biomass in the replacement intercrop should be intermediate between weed biomass in corn monoculture and in soybean monoculture, and there should be no difference between the mean weed biomass in the replacement intercrop and the mean weed biomass in the two sole crops. Conversely,

Table 1. Coding for alternative analysis of weed total biomass (above-ground dry mass), Shannon diversity and species richness. Number of rows per plot are indicated.

Treatment	Rows corn	Rows soy	Corn density code	Soy density code
Unplanted	0	0	0	0
Soy monoculture	0	7	0	2
Corn monoculture	7	0	2	0
Replacement intercrop	4	3	1	1
Additive intercrop	7	6	2	2

if intercropping has a synergistic effect on suppressing weeds, the weed biomass in the replacement intercrop should be significantly less than the mean weed biomass of the two monocultures. Contrasts were therefore made between mean weed biomass in the two monocultures and mean weed biomass in each intercrop. There was a significant difference between mean weed biomass in the additive intercrop and the mean in the two sole crops, but the difference between the mean in the replacement intercrop and the mean in the sole crops was not significant (Table 2).

H'-diversity of the weeds was affected by crop type (Fig. 3; $F = 3.75$, $P = 0.015$), and was highest in the two intercrop treatments and in corn monoculture and lowest in the soybean monoculture and unplanted treatment. The addition of fertilizer reduced the diversity of the weed community ($F = 7.18$, $P = 0.012$). No interaction between crop and fertilization on diversity was observed ($F = 0.27$, $P = 0.89$). Diversity, like biomass, differed among blocks ($F = 12.59$, $P = 0.0001$). Tested as above for biomass, corn influenced weed community diversity ($F = 14.99$, $P = 0.0005$), but neither soybean nor the interaction between corn and soybean had an effect on weed diversity (for soybean and the corn-soybean interaction, respectively, $F = 0.00$, $P = 0.97$, and $F = 0.72$, $P = 0.40$). Like diversity, evenness (H'/H_{max}) differed among crop types (not shown; $F = 5.31$, $P = 0.003$) and among blocks ($F = 5.26$, $P = 0.006$) but was not affected by either fertilization ($F = 2.24$, $P = 0.146$) nor its interaction with crop type ($F = 0.95$, $P = 0.453$).

Species richness did not differ significantly among the crop types ($F = 0.78$, $P = 0.547$), nor was there a significant interaction between crop type and fertilization ($F = 1.39$, $P = 0.26$), although the results suggested a

Table 2. Results of the contrasts between mean weed biomass (above-ground dry mass) ± SE (g/m^2) in the intercrops and mean weed biomass ± SE (g/m^2) in the corresponding monocultures; $N = 8$ plots/crop type.

Intercrop	Mean in intercrops	Mean in monocultures	F-value	P-value
Replacement	814.5 ± 132.0	937.6 ± 104	1.308	0.2628
Additive	448.8 ± 83.3	937.6 ± 104	20.614	0.0001

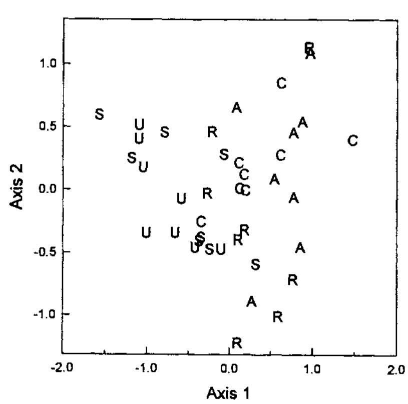
tendency for fertilization to reduce species richness ($F = 3.86$, $P = 0.0598$). The mean number of species per 0.36 m^2 plot sample was 7.15 (s.e. = 0.30); the mean and s.e. per sample was 7.7 (0.36) species in the unfertilized plots and 6.6 (0.45) in the fertilized plots. Blocks differed significantly in species richness ($F = 7.97$, $P = 0.0006$).

Ordination of the weed species abundances revealed a strong relationship between crop type and the first ordination axis (Fig. 4 a, b). Unplanted and soybean monoculture plots had lower Axis-1 scores, while plots with corn present (corn monoculture, replacement and additive treatments) had intermediate and high scores on that axis. Fertilization was not related in any clear way to the ordination (not shown). The results of the ordination did not differ when Non-metric Multidimensional Scaling was run beginning with a random starting point or with a Bray-Curtis ordination, and were similar in several runs of NMS (results not shown). Final 'stress' was 35.83 after fitting the first dimension (axis), 14.13 after the second, and 9.79 after the third. Further reductions in stress were minimal.

Because the presence of corn, but neither of soybeans nor the combination of the two in intercrops appeared to be largely responsible for driving the pattern of response of the weed species, we examined the correlation between the proportion of each crop and the ordination axes. These proportions were, for corn and soy respectively, 0:0 in the weeds-alone plots, 0:2 in the soy monoculture, 1:1 in the replacement intercrop, 0:2 in the corn monoculture, and 2:2 in the additive intercrop. The proportion of corn was strongly correlated with Axis 1 (Fig. 4a, $r = 0.74$), weakly but also positively correlated with Axis 2 ($r = 0.20$), and weakly negatively correlated with Axis 3 scores (Fig. 4b, $r = -0.39$). There was no clear association between the proportion of soy and any axis (Axis 1, $r = 0.16$; Axis 2, $r = 0.01$; Axis 3, $r = 0.09$). In addition to the effect of crop type on the vegetation composition, plots in the same block tended to resemble one another in weed composition (based on NMS scores; data not shown). Clearly, factors other than the treatments in this experiment had important effects on weed community responses.

The weed species most strongly associated with the first ordination axis was *Abutilon theophrasti* (see Table 3), which was highly negatively correlated with Axis 1 scores ($r = -0.90$), and was present in greatest abundance where corn was absent. *Ambrosia artemisisiifolia* and *Panicum dichotomiflorum* were also negatively correlated with Axis 1, but much more weakly than was *A. theophrasti* ($r = -0.25$ and $r = -0.28$, respectively). An *Agropyron* species had a slight positive correlation with Axis 1 ($r = 0.26$). *A. artemisiifolia* was strongly negatively correlated with Axis 2 scores $r = -0.76$), as were *Polygonum persicaria* ($r = -0.54$) and *Oxalis dilleni* ($r = -0.49$).

We used Multiple Response Permutation Procedures to test whether, as hypothesized, weed species composition was affected by the presence of corn, but not by soybeans or fertilizer. We defined group membership by the proportion of corn (0, 1 or 2: see above), or by the proportion of soybeans (0, 1 or 2) or by the addition of fertilizer (fertilized *vs.* unfertilized). Corn had a strong and significant effect on the weed community ($M = -11.57$, $P = 0.00000018$). Soybeans did not affect weed composition ($M = -0.92$, $P = 0.16$), nor did fertilization ($M = 0.64$, $P = 0.70$).



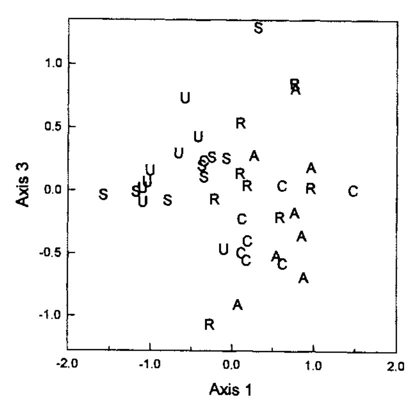


Fig. 4 a. Results of the Non-metric Multidimensional Scaling ordination for the first two axes. Each point is a single plot. Abbreviations indicate crop types as follows: additive intercrop (A), corn monoculture (C), replacement intercrop (R), soybean monoculture (S) and unplanted (U). **b.** Results of the NMS ordination for axes 1 and 3. Each point is a single plot. Abbreviations as above.

Discussion

Weed biomass

Proponents of intercropping have hypothesized that the yield advantage attained in intercropping is a result of a stronger weed suppression by intercrops than by monocultures (Liebman 1988; Shetty & Rao 1981; Tripathi & Singh 1983; Weil & McFadden 1991). In the present experiment, the additive intercrop treatment had a land equivalent ratio (LER, the equivalent amount of land needed to produce the combined intercrop yield for crops grown in monoculture; Mead & Willey 1980) greater than 1.0 while LER in the replacement intercrop treatment was only about 1.0 (Gomez 1996).

No synergistic effect of intercropping on weed biomass was observed in this experiment, as indicated by the absence of a significant difference in weed biomass between the mean in the sole crops and the mean in the replacement intercrop (Table 2), and by the absence of a significant interaction between corn and soybean density on weed biomass. The monocultures and the replacement intercrop had similar crop densities per plot, while the additive intercrop had higher crop densities. The mean weed biomass in the monocultures was significantly greater than the mean weed biomass in the additive intercrop. But this cannot be assumed to be due to a synergistic effect of the mixture on the weeds because the total crop density in the additive intercrop was higher than in the sole crops. The observed reduction in weed biomass could be due merely to a density effect rather than to a synergistic effect by the crops.

Table 3. Common weed species found in the experiment, listed from most abundant to least abundant.

Abutilon theophrasti
Ambrosia artemisiifolia
Chenopodium album
Setaria lutescens/Setaria glauca (could not be distinguished)
Agropyron sp. (most likely *A. repens*)
Amaranthus retroflexus
Rumex acetosella
Panicum dichotomiflorum
Setaria faberri
Polygonum persicaria
Setaria viridis
Oxalis dilleni
Taraxacum officinale
Polygonum aviculare
Erigeron canadensis
Echinochloa crus-galli
Digitaria sanguinalis
Solanum dulcamara
Trifolium repens
Stellaria media

Taken as a whole, the results also suggest that the density of corn present is the critical component affecting the weed community in this corn-soybean system, rather than any synergism between corn and soybeans.

The absence of a synergistic effect was also observed by Mohler & Liebman (1987) in a pea/barley intercrop. The significant difference between the weed biomass in the replacement intercrop and in the additive intercrop confirms the observation that weeds decrease as crop density and biomass increases. Similar results on the relationship between crop density and weed biomass were reported by Lawson & Topham (1985). In a review of the literature on the effects of intercropping and crop rotation on weed productivity, Liebman & Dyck (1993) reported mixed results (unfortunately based on a flawed vote-counting approach; see Gurevitch & Hedges 1993) on the success of intercrops in suppressing weed biomass.

Corn and soybean compete with weeds in ways that are intuitively different. Corn is taller than most other plants in the field and is therefore likely to be a good light competitor (see Gomez 1996). The broad, low canopy of soybeans may also reduce light levels for shorter weeds. In this experiment (pers. obs. P.G.), in soybean monoculture, weed species began to germinate at the same time as the soybeans, just as in the corn monoculture. But unlike corn, by the time the soybeans had developed a dense canopy, the weed species already had grown to a height above that of the soybean canopy.

Diversity and species richness

Diversity was lowest in the soybean monoculture and the unplanted plots and greatest in the crops where corn was present (corn monoculture and the intercrops). Species richness did not differ among crop types. The dominant weed species, particularly *A. theophrasti*, were most suppressed in plots where corn was present. *A. theophrasti* resembled the subordinate weeds in stature and morphology when grown with corn (pers. obs. P.G.), but the individual plants were larger and total above-ground biomass of *A. theophrasti* greater when corn was absent (unpubl. data). In addition, weeds in the corn monoculture and the two intercrops had a higher evenness index than when corn was absent (data not shown). These observations suggest reduced vigor and competitive ability of the dominant weeds in the presence of corn.

The similarity in species richness between the unplanted plots and the cropped plots offers evidence that the presence of crops, whether in monoculture or intercropped, did not result in the elimination of the less competitive weed species. Suppression by crops resulted in a decrease in weed growth rather than the elimination of species. Crop type affected weed community composition (as shown by the Non-metric Multidimensional

Scaling ordination and the results of the Multiple Response Permutation Procedures) even though it did not alter species numbers. However, the presence and density of corn was consistently more important in this regard than was the density of soybeans or crop diversity.

In agreement with these results, Mohler & Liebman (1987), showed that shifts in the composition of the weed community in a pea/barley intercrop were dependent on the competitive dominance of the crop or crops planted, not on the diversity of the crop. They also found that increases in crop density were correlated with decreases in weed biomass, and that the abundance of the most common weed species was more suppressed than other species as crop productivity increased (Mohler & Liebman 1987).

In a replacement polyculture, Palmer & Maurer (1997) concluded that 'diversity begets diversity', with higher numbers of weed species in the polyculture than in the monocultures. In agreement with our results, they found the highest weed species richness in corn monoculture and the lowest in soy monoculture, but contrary to our findings they reported that weed biomass was highest in corn and lowest in soy monoculture. Further study is warranted to resolve these differences, but it is tempting to speculate that small differences in the timing of emergence of crop and weed species may play a critical role.

Janiya & Moody (1984) compared the weed community in rice monocultures with that in an *Azolla*-rice intercrop, and found that the dominance of the primary weed species, *Monochoria vaginalis*, was greatly reduced in the intercrop. Shetty & Rao (1981) observed a change in the weed species composition in a groundnut-pearl millet intercrop that depended on the relative proportions of the two crop species. Increasing the proportion of millet increased weed species richness, while increasing the proportion of groundnut increased the dominance of a small number of weed species, and hence decreased species diversity.

Across crop treatments, weed diversity in our experiment was higher in the unfertilized treatments. These results conform with the observations of Huston (1979) and Tilman (1985) as well as with the results of several experimental studies in natural communities (e.g. Gurevitch & Unnasch 1989; Wilson & Tilman 1991). The influence of fertilization on the hypothesized suppressive effect of intercropping on weeds remains open for investigation. Weeds, like most crops, respond positively to increased level of soil nutrients. Liebman & Robichaux (1990) noted that the competitive suppression of weed growth in a pea/barley intercrop was strongest when N-fertilizer was not applied. Their results suggest that the structure of the weed community as well as the outcome of weed-crop interactions can be altered by changing the level of soil nutrients. Tripathi & Singh (1983) found that NPK-fertilization increased crop yield twice as much as it increased weed biomass in a corn-soybean intercrop. In contrast, in this study neither fertilizer nor its interaction with crop type affected weed biomass (Fig. 1). It is important to learn more about how the responses of weeds to added nutrients might be altered in intercrops.

Conclusions

Results from this experiment show that intercropping did not have a greater suppressive effect on weeds at densities similar to its sole crop counterparts. Weed suppression was observed when intercropping was additive, but was more likely a simple density effect rather than being a synergistic effect of intercropping. Similarly, intercropping *per se* did not alter the diversity, species richness or composition of the weed community. These measures were affected by both density and the identity of the crops, but not by crop diversity. Fertilization had surprisingly few effects on the weed community, reducing weed species diversity, but having no substantive effects on biomass, evenness, species number, or overall species composition. The weed community was also not affected by interactions between fertilization and crop type.

Weed community responses should be studied using several pairs of intercrops at the same time and under similar environmental conditions to learn if the results obtained here are unusual, are typical for corn and soybean intercrops, or are a more general pattern for other intercrops as well. Because few similar studies have been conducted, it is difficult to make reliable generalizations regarding the effects of intercrops on weed community structure.

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