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Benefits of a maize–bean–weeds mixed cropping system in Urubamba Valley, Peruvian Andes

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Abstract

In the Urubamba Valley, Peruvian Andes, we evaluated the abundance of insect pests and natural enemies in experimental plots where maize was grown either as monoculture, intercropped with beans, or intercropped with beans plus associated weeds. We also assessed the consequences of the cropping system for maize yield. The main insect pests recorded were *Diabrotica* spp. (Coleoptera: Chrysomelidae), *Carpophilus* sp. (Coleoptera: Nitidulidae) and *Pagiocerus frontalis* (Coleoptera: Scolytidae), and their overall abundance did not differ among crop diversity treatments. However, there was a significant adverse effect of crop diversity on the maximum abundance of both *Carpophilus* and *Pagiocerus*. The main beneficial arthropods were *Paratriphleps* sp. (Hemiptera: Anthocoridae), ladybirds and spiders, and their density did not differ among treatments. Maize yield did not decrease with increasing plant diversity. The reported benefits of intercropping, together with the associated efficiency in land use, make this traditional agricultural practice a valuable alternative to the use of pesticides, particularly for resource-poor Andean farmers.

Keywords: *Pest management, intercropping, maize, beans, weeds, Andes*

1. Introduction

The Peruvian Andes harbour an enormous biodiversity of crops and their wild relatives (Hernández-Bermejo and León 1994). Most of the Andean farmers that maintain the outstanding agricultural biodiversity are below the poverty line, and a critical problem they face is attacks by insects on their crops (Morse and Buhler 1997). The application of costly and toxic insecticides has been promoted as the almost exclusive control measure of insect pests during recent decades. Consequently, pest insects have developed insecticide resistance, and native beneficial insect populations have been adversely affected (Morse and Buhler 1997). Thus, the negative effects of pest damage (and pest control measures) on human wealth and health in Peruvian Andes show an increasing trend. There is a need for adoption (or re-adoption) of pest management strategies that are more cheap, sustainable and environmentally sound. The use of mixed cropping systems is a traditional agricultural practice (Morlon et al. 1982) that may help to alleviate the situation above described.

There is considerable evidence of reduced populations of insect pests in polycultures (Andow 1991; Altieri 1994; Altieri and Letourneau 1999). A decrease in the abundance of insect pests in diversified crop fields may be the result of: (i) increased parasitoid and predator populations due to higher availability of alternative prey, (ii) physical interference with pest colonization and movement, and/or (iii) chemical repellence or masking from non-host plants (Root 1973; Risch et al. 1983; Matteson et al. 1984; Andow 1991; Altieri 1994; Khan et al. 1997), which may be either other crops or weeds. Weeds may function as repellent plants in the field and constitute a reservoir of natural enemies of insect pests (Altieri and Whitcomb 1979; Altieri and Letourneau 1982; Nentwig et al. 1998). However, from the viewpoint of sustainable agriculture, the potential benefits of including other plant species within a cropping system must be balanced against the costs in terms of reduced productivity of the focal crop due to plant competition for resources. Although there are numerous cases of reduced pest density associated with polycultures, studies addressing the causes underlying such patterns are not equally common (Risch 1981; Andow 1991). Likewise, pest-oriented studies on intercropping seldom include evaluations of its effect on crop yield (Letourneau 1987; Power 1987; Abate 1991;

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Lal 1991; Rämert and Ekbom 1996; Girma et al. 2000; but see Karel 1993 and Ogengalatigo et al. 1992).

Maize (*Zea mays*) and beans (*Phaseolus vulgaris*) are native to the New World and have been cultivated together in polyculture for thousands of years. In the Peruvian Andes, maize–bean bicrops and maize–bean–kiwicha (*Amaranthus*) tricrops are traditionally common among small-scale farmers (Early 1990). These agricultural practices are principally a means of enhancing land utilization but are believed to hamper the development of populations of insect pests of maize, which may cause significant yield losses (Holl et al. 2000). Some studies conducted elsewhere have shown that insect pest densities are decreased when maize is grown in diversified cropping systems (Altieri and Whitcomb 1980; Altieri 1994; Altieri and Letourneau 1999). In this study, carried out in Urubamba Valley, Peruvian Andes, we evaluated the abundance of insect pests and their natural enemies in experimental plots where maize was grown either as monoculture, intercropped with beans, or intercropped with beans plus associated, naturally occurring weeds. We also assessed the consequences of the cropping system for maize yield.

2. Materials and methods

Field evaluations were conducted in experimental plots in Charcahuaylla, Urubamba (13°18′S; 72°7′W), located in the Sacred Valley of the Incas at Cusco, Perú, at an altitude of 2860 m. The Urubamba valley is the main region of maize cultivation in Peruvian Andes. From September 2003 to March 2004, maize (*Zea mays*, variety Blanco Gigante del Cusco) was grown either as monoculture (M), intercropped with beans (*Phaseolus vulgaris*, variety INIA San Jacinto; M–B), and intercropped with beans plus associated weeds (M–B–W). The three experimental treatments were arranged in a randomized block design with three replicates, for a total of three blocks and nine plots. Each plot measured 12 × 12 m and was surrounded by a 2-m border of bare ground. In all plots maize rows were spaced 1.20 m apart, with 0.6 m between plants within a row. In the M–B and M–B–W plots beans were planted in rows between the maize rows, hence maize plant density was the same across treatments. Hand weeding was carried out once a month in the M and M–B treatments, whereas in the M–B–W plots no cultural practice to eradicate weeds was done.

We carried out weekly evaluations of the abundance of insect pests and natural enemies in maize plants by direct count, from plant emergence to cob ripening. Twenty maize plants per plot were randomly chosen each week and every insect observed on the shoot was recorded. All counts were taken between 08:00 and 11:00 h. At the end of the season, cobs were harvested, sun-dried, and grains were shed and weighed in order to obtain a measure of crop yield per experimental treatment.

Data on insect abundance were analyzed using a repeated measures ANOVA to test for treatment effects over the season. In the case of insect pests, given the agronomical relevance of damage thresholds, we also compared the maximum levels of pest density in each treatment (the highest three counts were averaged in each plot). Data on maximum pest density and on crop yield were analyzed with a one-way ANOVA. We used Tukey tests to compare means between treatments. Statistical analyses were performed with Statistica 6.0.

3. Results

The main insect pests recorded in maize plants were *Diabrotica* spp. adults (*D. sicuanica* and *D. speciosa*; Coleoptera: Chrysomelidae), *Carpophilus* sp. (Coleoptera: Nitidulidae), and *Pagiocerus frontalis* (Coleoptera: Scolytidae); insect pests occurring less frequently and in minor abundance, such as *Rhopalosiphum maidis* (Homoptera: Aphididae), *Epitrix* sp. (Coleoptera: Chrysomelidae), and *Copitarsia* sp. (Lepidoptera: Noctuidae) were not included in the analysis. *Diabrotica*, a rather generalist rootworm (Moeser and Vidal 2004), was present over the whole season with a decline at the end of it. *Carpophilus*, which attacks the immature cobs (Rodríguez del Bosque et al. 1998), appeared about mid-season and peaked short after. *Pagiocerus*, a pest that consumes mature grains (Okello et al. 1996), was detected only at the end of the sampling period but the population rise was important. On one hand, the overall abundance of these three pests did not differ among crop diversity treatments (Figure 1, Table I). On the other hand, the maximum density of *Diabrotica* was not affected by treatments ($F_{2,6} = 0.03$, $P = 0.97$; one-way ANOVA), but there was a significant adverse effect of crop diversity on the maximum abundance of both *Carpophilus* ($F_{2,6} = 5.97$, $P = 0.037$; one-way ANOVA) and *Pagiocerus* ($F_{2,6} = 10.48$, $P = 0.011$; one-way ANOVA) (Table II).

The more abundant natural enemies of insect pests recorded in maize plants were *Paratriphleps* sp. (Hemiptera: Anthocoridae), ladybirds (*Hippodamia convergens*, *Eriopis peruviana*, *Coccinellina* sp.; Coleoptera: Coccinellidae), and spiders (Araneae: Araneidae, Tetragnathidae, Clubionidae and Thomisidae); less abundant species, not included in the analysis, were *Hemerobius* sp. (Neuroptera: Hemerobidae), *Aphidius* sp. (Hymenoptera: Braconidae) and syrphid larvae (Diptera: Syrphidae). The density of the main beneficial arthropods did not differ consistently during the season among crop diversity treatments (Table I, Figure 2).

A slight tendency for a decrease in maize yield with increasing plant diversity was observed (Figure 3) but differences among treatments were not significant ($F_{2,6} = 0.33$, $P = 0.73$; one-way ANOVA). In total, 13 species of weeds were at least preliminarily identified, being the more prevalent *Brassica campestris*

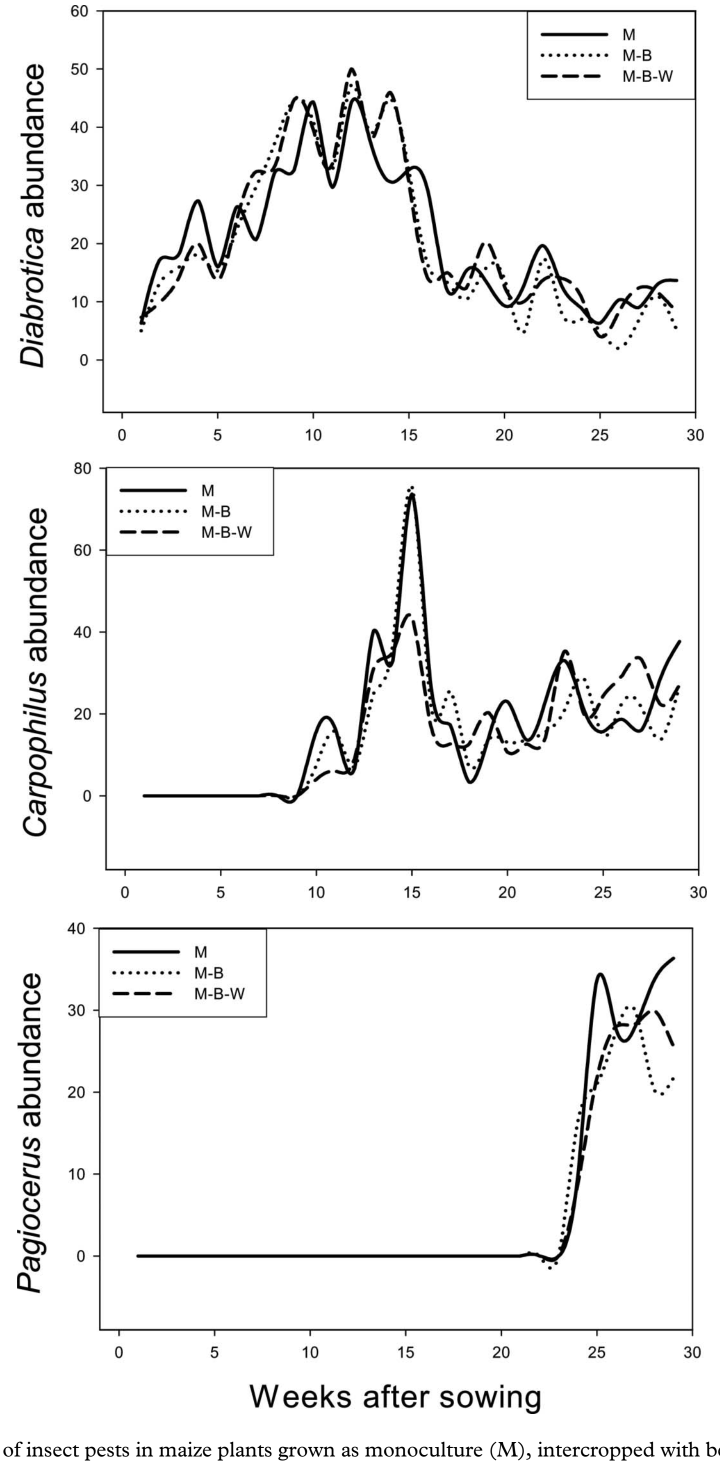

Figure 1. Seasonal abundance of insect pests in maize plants grown as monoculture (M), intercropped with beans (M – B), and intercropped with beans plus associated weeds (M – B – W). Curves show the weekly abundance (number of insects per plot; mean of three plots per treatment) recorded over 29 weeks. *Diabrotica, Diabrotica* spp. (*D. sicuanica* and *D. speciosa*; Coleoptera: Chrysomelidae); *Carpophilus, Carpophilus* sp. (Coleoptera: Nitidulidae); *Pagiocerus, Pagiocerus frontalis* (Coleoptera: Scolytidae).

(Brassicaceae), *Amaranthus hybridus* (Amaranthaceae), *Ipomoea* sp. (Convolvulaceae), *Trifolium repens* and *Melilotus indica* (Fabaceae).

4. Discussion

We found contrasting results with regard to the effect of intercropping on insect pests. On one hand, the overall abundance of the main insect pests recorded did not differ among crop diversity treatments. This would imply a lack of benefits of a mixed cropping system in this Andean locality. On the other hand, two of the three main insect pests recorded in maize plants (*Carpophilus* sp. and *Pagiocerus frontalis*) showed a decrease in maximum abundance with crop diversity. The maximum density of pests may be a critical issue for pest management because the decision of applying pesticides is often dictated by

Table I. Repeated measures ANOVA of the abundance of main insect pests and beneficial arthropods in maize under three treatments of crop diversity (maize monoculture, maize intercropped with beans, and maize intercropped with beans plus associated weeds) over the season.

	CD	T	CD × T
Insect pests			
Diabrotica (29)	0.826	< 0.001	0.649
Carpophilus (20)	0.232	< 0.001	0.504
Pagiocerus (6)	0.654	0.213	0.892
Natural enemies			
Paratriphleps (24)	0.381	< 0.001	0.201
Coccinellidae (28)	0.708	< 0.001	0.571
Araneae (29)	0.551	< 0.001	0.873

Between brackets: number of weeks spanned by the analysis. Independent variable: crop diversity treatment (CD); dependent variable: insect number; repeated measured factor: time (T). *P* values are shown.

Table II. Maximum abundance (Mean ± SE) of insect pests in maize under three treatments of crop diversity: maize monoculture (M), maize intercropped with beans (M–B), and maize intercropped with beans plus associated weeds (M–B–W).

	Diabrotica	*Carpophilus*	*Pagiocerus*
M	47.33 ± 1.96a	55.90 ± 4.14a	43.22 ± 1.56a
M–F	47.37 ± 2.60a	54.43 ± 2.81ab	33.11 ± 2.28b
M–F–W	48.33 ± 5.17a	42.53 ± 1.39b	33.33 ± 1.39b

Means sharing letters within a column are not significantly different ($P > 0.05$, Tukey test).

damage thresholds evaluated in the field (Metcalf and Luckmann 1982). With the available data it is not easy to determine which of the pest parameters (overall abundance vs. maximum density) is of greater relevance. An experimental approach to the interaction between amount of damage, crop phenology, and yield consequences might allow a proper evaluation of the agroecological importance of maximum pest density.

In contrast with other studies (Verkerk et al. 1998; Sunderland and Samu 2000), we did not detect any consistent relationship between crop diversity and the abundance of the main beneficial arthropods. An early comprehensive review (Risch et al. 1983) concluded that the lower pest abundance in diversified crops is better explained by the differential movement patterns of herbivores than by an enhanced pressure of natural enemies. However, more recent studies on maize intercropping provide evidence of the significant role of both herbivore movement (Power 1987; Litsinger et al. 1991) and predator/parasitoid density (Letourneau 1987; Coll and Bottrell 1995) in explaining lower pest abundance in diversified plots.

The host range of the herbivore species may at least partially account for the contrasting evidence discussed above (Andow 1991). Thus, whereas a monophagous herbivore is predicted to have a lower abundance in polycultures regardless of the relative importance of the two explanatory factors, a polyphagous species should show a lower density in polycultures only if the enhancement of natural enemies pressure is the prevailing factor, otherwise it should be equally or more abundant in polycultures than monocultures (Andow 1991). In the present case, both *Carpophilus* and *Pagiocerus* (the pests showing reduced maximum abundance in polycultures) may be considered monophagous herbivores of maize because they were rarely observed on bean plants. In contrast, *Diabrotica*, being able to feed on both maize and bean plants (data not shown), did not have a higher incidence on diversified plots. Therefore, even though we did not assess experimentally the movement behavior of herbivorous insects, the patterns herein recorded might be interpreted as consistent with those predictions of Andow (1991).

Given that the more abundant natural enemies recorded on maize plants (anthocorid bugs, ladybirds, spiders) were all generalist predators, it would have been expected a greater population density of beneficial arthropods in the more diversified plots due to the availability of preys on the other host plants (beans and weed species). However, this was not the case. The results suggest that the assumption that greater availability of alternative food translates into greater pressure by natural enemies should be relaxed. The persistence of populations of natural enemies is undoubtedly promoted by alternative prey, and the population size of these arthropods at the plot level should be greater, but the net density on the focal crop plant is not necessarily increased. This may be explained by the attractive effect of the other plant species on natural enemies (high *sink* function) and/or a limited movement from these species to the focal plants (low *source* function) (Coll and Bottrell 1996; Ferro and McNeil 1998).

Unlike a previous report (Silwana and Lucas 2002), the presence of a competing crop (beans) and the combined effect of this competing crop and weeds did not reduce significantly maize yield, suggesting that the evaluated mixed cropping system is sustainable from the Andean farmer point of view. Work in other systems has shown a yield cost of intercropping practices that successfully reduced pest damage, hence posing a dilemma for the farmer (Altieri 1994). The particular combination of maize and leguminous crops has proven advantageous (e.g. Grisley 1997) because of relatively weak interspecific competition (Li et al. 1999), and the bean-mediated enhancement of N and P uptake by intercropped maize (Zhang and Li 2003). In the present case, the conservation of weeds within the cropping system was not only harmless in terms of maize yield but also useful for human purposes. Thus, weed diversity encompassed native and introduced species used by Andean people

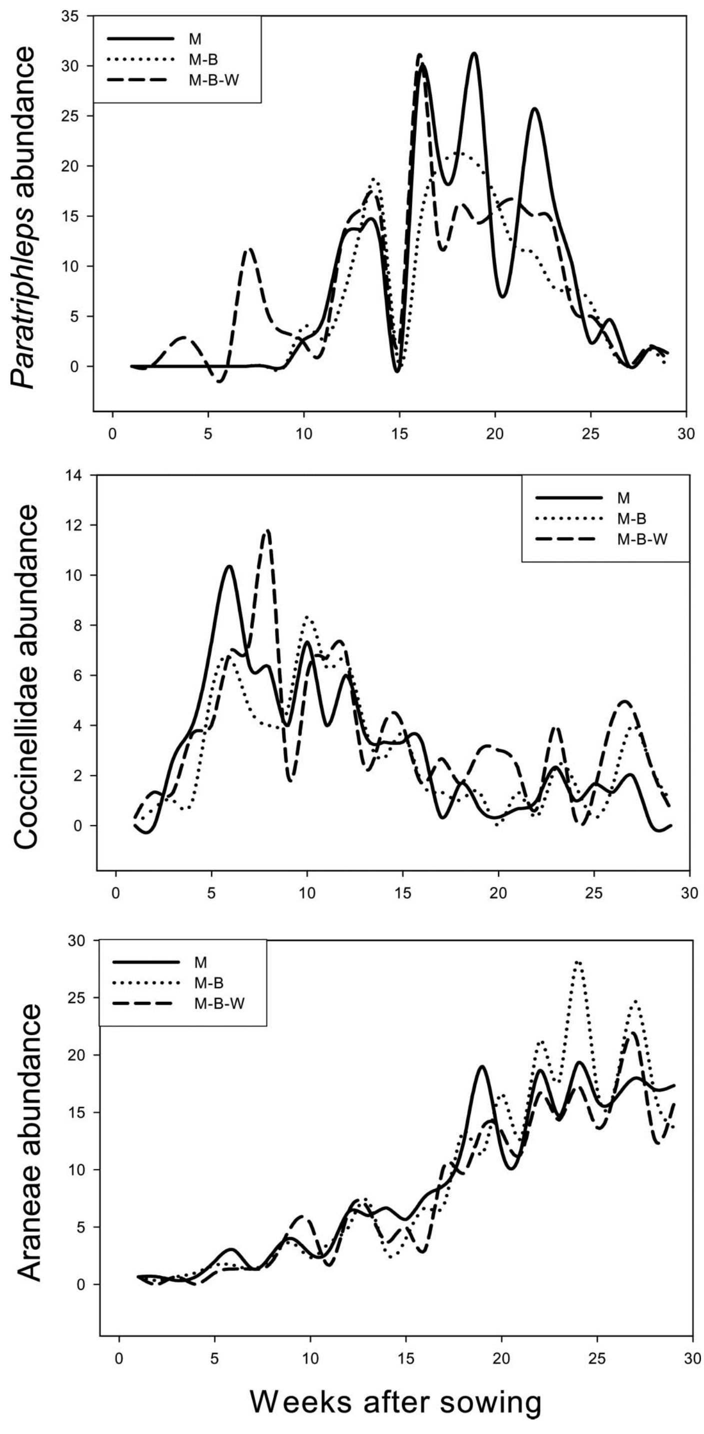

Figure 2. Seasonal abundance of beneficial arthropods in maize plants grown as monoculture (M), intercropped with beans (M–B), and intercropped with beans plus associated weeds (M–B–W). Curves show the weekly abundance (number of specimens per plot; mean of three plots per treatment) recorded over 29 weeks. *Paratriphleps, Paratriphleps* sp. (Hemiptera: Anthocoridae); Coccinellidae, *Hippodamia convergens*, *Eriopis peruviana*, *Coccinellina* sp. (Coleoptera: Coccinellidae); Araneae, Araneidae, Tetragnathidae, Clubionidae and Thomisidae.

as medicinal plants (e.g. *Amaranthus hybridus* and *Melilotus indica*).

Intercropping and weed management in Andean agriculture dates from pre-Inca times and, despite the influence of 'modern' agriculture that promotes monocultures, it has persisted as a distinctive pattern of small-scale agriculture. Our study shows a maize–bean–weeds diversified crop that is associated with reduced maximum abundance of pests, unaffected yield of the focal crop, and a more efficient use of land. Though limited in its temporal scope, this study illustrates the benefits of agricultural practices alternative to the use of pesticides and particularly relevant for resource-poor Andean farmers. Further research should address the relative importance of maximum pest density versus overall seasonal abundance of insect pests as indicators of benefits of mixed cropping systems.

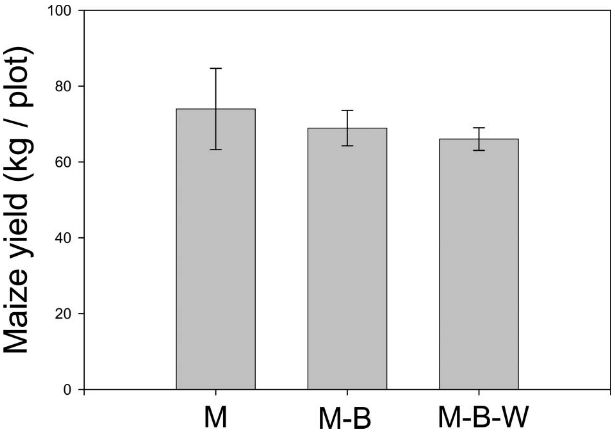

Figure 3. Yield (grain weight/144 m^2 plot; mean of three plots $\pm$ SE) of maize plants grown as monoculture (M), intercropped with beans (M–B), and intercropped with beans plus associated weeds (M–B–W) in Urubamba valley, Cusco, Perú.

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