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Analysis and Comment

BIODIVERSITY IN HUMID TROPICAL BANANA PLANTATIONS WHERE THERE HAS BEEN LONG-TERM USE OF CROP PROTECTION PRODUCTS

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Palabras clave: Banano, productos para la protección de los cultivos, pájaros, actividad microbiana del suelo, insectos, áreas reforestadas, áreas de conservación.
Keywords: Bananas, crop protection products, birds, soil microbial activity, insects, reforested areas and conservation areas.

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RESUMEN

La biodiversidad en plantaciones de banano del trópico húmedo, donde han sido usados compuestos fitosanitarios por períodos prolongados. El cultivo del banano, es afectado por plagas y enfermedades que requieren para su control de compuestos fitosanitarios. Entre los compuestos fitosanitarios se cita: fungicidas, nematicidas, insecticidas y herbicidas. En Costa Rica, el público y la comunidad ambientalista comúnmente asumen que el impacto de estos compuestos es severo. Por esto, las industrias bananera y de compuestos fitosanitarios han sido fuertemente criticadas, asumiendo que se generan impactos negativos en la fauna que habita dentro o cerca de las plantaciones comerciales. El presente trabajo resume los resultados publicados en relación con el impacto biológico causado por la utilización de diferentes compuestos fitosanitarios usados dentro de las áreas cultivadas, así como el efecto del establecimiento de áreas de protección y reforestación alrededor de las plantaciones bananeras. Se señala la necesidad de implementar Buenas Prácticas Agrícolas, incluyendo el Manejo Integrado de Plagas como mecanismo de uso sostenible de los compuestos fitosanitarios, en aras de reducir al máximo los posibles efectos colaterales, junto con las prácticas de conservación y reforestación de vías de agua y linderos de finca. También se establece una categorización de los compuestos usados,

ABSTRACT

Bananas, like any agricultural crop, are affected by pests and diseases that require chemical control to prevent crop losses, to maintain quality standards for the consumer market, and to meet phytosanitary requirements of importing countries. Among the crop protection products applied are: specific and broad spectrum fungicides, nematicides, insecticides and herbicides (contact and systemic). In Costa Rica, with more than 130 years of banana cultivation, both the public and the environmental community commonly assume that the impact of these products is severe. Banana and crop protection product industries have been heavily criticized, assuming that faunal communities are negatively affected. However, research results do not support this criticism. The present paper summarizes recent published literature stressing the relative biological impact of the different types of crop protection products used within cultivated areas, and the effects of protected and reforested areas surrounding banana cultivated areas. It stresses the necessity to consider Good Agricultural Practices (GAP) involving Integrated Pest Management (IPM) for sustainable use of crop protection products without harmful side-effects, along with conservation or reforestation practices to protect waterways and farm limits. It also establishes an impact categorization for crop protection products based on the

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con base en los indicadores biológicos analizados, de menor a mayor riesgo de impacto: herbicidas< fungicidas< insecticidas < nematicidas.

biological indicators analyzed, from less harmful to potentially more impacting compounds, as follows: herbicides< fungicides< insecticides < nematicides.

INTRODUCTION

The principal environmental issues that have been highlighted in association with banana production are: use of crop protection products; biodiversity; deforestation; and waste generation (Corbana and Latin American Crop Protection Association 1999).

Banana cultivation in Costa Rica, and in the rest of the humid tropical regions, is based on the monoculture of Cavendish varieties of *Musa* AAA. Average plantation size ranges between 150-250 ha, and planting material comes from suckers obtained from the same plantation or from tissue culture of vegetative growing tips, which stands as the most commonly applied technology for planting new areas, or replanting large areas that have shown signs of poor spatial distribution of plants and severe pest and disease infestations.

Humid tropical lowlands are characterized by high rainfall and high temperature regimes. Both conditions, plus monoculture, are conducive to severe attacks by disease and pests. Among them, the most important commercially occurring disease is the black Sigatoka leaf-spot disease (*Mycosphaerell*a *fijienses* Morelet); which requires weekly applications of fungicide mixtures consisting of triazoles, morpholins, thiabendazoles, dithiocarbamates and strobilirubins (Romero 1995). Another important pest occurring is the burrowing nematode (*Radopholus similis* Cobb) for which 2-4 cycles of carbamate or organophosphate nematicides/ insecticides are applied (Araya *et al*. 1995). Fruit bunches are also subject to attack by a myriad of insects, which requires chemical protection to warrant fruit quality (Cubillo *et al*. 2001). Chlorpyrifos impregnated bags are normally used from bunch emergence to harvesting (*i.e*. approximately 12 weeks). Bunch bagging takes place 3 times a week, since plantations are managed as a perennial crop in which different development plant stages are intermingled to optimized constant supply of fruit. Recently, new alternatives for bunch protection *(i.e*. bags impregnated with pyrethroids and plant extracts showing novel insecticide properties and physical barriers to insect attack) have been evaluated (Corbana 2002).

In spite of the management efforts to have an even distribution of plants at field level, sunlight reaches the understory stimulating weed germination and growth. Weeds are competitors for the nutrients applied through conventional inorganic fertilizers. Above a density threshold, weeds affect other agricultural practices and favor black Sigatoka disease incidence (Marín and Romero 1992). However, weeds could also be viewed in bananas as an important element for protection against soil erosion, habitat, and food sources for the natural enemies of banana pests.

Weed management in bananas is normally done based on weed incidence and ground coverage by alternating mechanical and chemical weeding. Chemical management is achieved with the use of contact systemic and non-systemic herbicides. Systemic herbicides have shown, in some cases and areas, some degree of broad leaf weed selection. Along with traditional methods, non-systemic contact herbicides can help indirectly erosion control and improve microbial activity because remaining root systems bind soil and support a microbially rich and active rhizosphere, as well as not harming new daughter

shoots of banana. These situations imply the use of integrated weed control practices in which hand control and contact herbicides are used. Traditionally, contact herbicides have played a key role in controlling weeds due to their wide action spectrum and relative lower price (Fernández 2004).

The impacts of intensive use of crop protection products on biodiversity have been difficult to demonstrate. Critics of the industry are very concern on the effects of these agrochemicals on the biota within banana plantations and in surrounding habitats (Matlock and De La Cruz 2003). As a result banana farms have been regarded as "green deserts" (Corbana and Latin American Crop Protection Association 1999). However, little formal study has been devoted to the effects of crop protection products (Matlock and De la Cruz 2002).

Recent research work done by several organizations interested in the banana industry and the environment has provided important information to produce an inventory of biodiversity in banana plantations considering important insect and microbial indicators. Also, the value of forest fragments conservation and tree plantings efforts adjacent to plantations has been assessed through inventories of the bird fauna and its age structure. The current outputs are inventories of ants and parasitoids populations in bananas (Matlock and De La Cruz 2003, 2002)**;** soil microbial respiration measurements (Blume *et al*. 1998, Vargas y Flores 1996); bird diversity and age structure in forest fragments, reforested plots and plantations (Matlock *et al*. 2002) and the influence of forest structure on bird population structure (Matlock and Edwards, in press).

This paper main objective is to critically review and summarize recent research results on biological impacts of plant protection products continuous use within banana plantations considering insect and soil microbial activities as biological indicators; and current conservation and reforestation practices of plantation surrounding areas on bird communities' structure.

Evaluation sites

Reported data came from studies conducted in typical commercial banana farms in the humid tropical Caribbean lowlands of Costa Rica. In some of the studies conducted 2 relatively low input farms and 4 other tropical monocultures were used for comparative purposes: Macadamia (*Macadamia integrifolia*); Heart of Palm "palmito" (*Bactris gasipaes*); Citrus (*Citrus* spp); and Gmelina (*Gmelina arborea*) (Table 1).

In conventionally managed banana the principal crop protection products were fungicides (25-35 applications $year^{-1}$) to control mainly black Sigatoka; herbicides (2-4 applications $year^{-1}$); nematicides (3-4 applications $year^{-1}$); insecticides (impregnated bunch bags, 3 times $week^{-1}$), and fertilizers (6-13 applications $year^{-1}$). The full details of pesticide applications are presented in Matlock and De La Cruz (2002). All conventionally managed banana plantations had received more than 5 years continuous paraquat use prior to starting the studies.

In the studies by Blume *et al*. (1998) and Vargas and Flores (1996), inventory soil samples were collected from 3 different microhabitats within banana plantations: 1. "nematicide ring" which was considered as the area adjacent to the highest crop protection product inputs (nematicide, fertilizers, herbicides and fungicide); 2. "bare areas" which refers to areas with inputs of herbicides and fungicides and low inputs of organic matter; and 3. "litter piles", which refers to areas subject to fungicides, with high inputs of organic matter, where all harvested plant residues are gathered, away from the nematicide ring. Inventory comparisons among the above 3 microhabitats took into account of differences in sampling efficiency.

Insects as indicators of biodiversity

Research work done in banana plantations of different ages and, subject to different levels of crop protection product inputs, have provided

Table 1. Study sites evaluated, crops present and farm characteristics (farm type, age and planted area), avian census points and number of sites for biodiversity determination (avian species richness according to tree especies richness, density, canopy height and cover, understory density and tree diameter at breast height.ss).

Site and operating institution	Alias used in text	Latitude/Crop Longitude	(Variety)	Farm type	Age Area (yr)	Census (ha)	Sites[a] points	Avian richness[b]	Tree species richness[b]	Tree species (ha^{-1}) [c]	Canopy density (m)[a]	Canopy height (%)[c]	Understory cover (%)[c]	DHB density	(cm)[d]
Freeman II Bandeco (Del Monte)	C1	10° 12.3' N 83° 19.2' W	Banana (Gran Nane)	Conventional	5	316.5	BLK[f]	4	55	50	63.8 (6.1)	27.5 (1.8)	86.5 (2.3)	94.6 (2.5)	40.3 (2.8)
							FOP	2	52	3	11.3 (2.8)	17.0 (1.0)	99.5 (0.5)	10.0 (0.0)	60.5 (8.6)
							FR	10	90	56	24.8 (3.7)	13.0 (1.9)	47.5 (4.9)	87.5 (2.3)	42.8 (2.3)
							FYP	12	53	1	9.7[e]	4.9 (0.2)	90.4 (3.5)	37.9 (5.7)	22.4 (1.1)
							SW	2	62	12	17.2 (7.6)	16.5 (1.5)	95.0 (0.0)	98.5 (0.5)	-
							TRI	4	43	60	99.1 (7.0)	13.1 (0.8)	73.4 (3.8)	91.1 (1.2)	27.0 (2.4)
El Carmen Bandeco (Del Monte)	C2	10° 12.8' N 83° 29.8' W	Banana (Valery)	Conventional	25	1160.2	COP	6	90	12	38.6 (7.0)	13.3 (0.4)	88.4 (2.6)	45.2 (12.6)	44.4 (4.4)
							CYP	12	61	1	28.7[e]	6.1 (0.3)	86.2 (4.3)	33.9 (9.1)	22.5 (0.7)
Project 1. EARTH	C3	10° 13.5' N 83° 36.7' W	Banana (Valery)	Conventional	38	104.1									
Project 2. EARTH	C4	10° 13.4' N 83° 35.0' W	Banana (Valery)	Conventional	33	92.8	ER	14	125	47	25.6 (3.1)	11.5 (0.9)	68.6 (4.3)	42.0 (5.5)	48.7 (3.6)
Project 4. EARTH	C5	10° 11.5' N 83° 35.8' W	Banana (Valery)	Conventional	16	37.8									
Río Frío, Finca 9 Standard Fruit of Costa Rica (Dole)	C6	10° 17.0' N 83° 53.0' W	Banana (Valery)	Conventional	28	1483.8	RFR	6	99	47	35.1 (3.7)	8.6 (2.0)	52.7 (8.9)	64.9 (9.9)	27.4 (2.1)
Project 4. EARTH	L1	10° 14.6' N 83° 34.7' W	Banana (Valery)	Low-input	4	30.4									
La Carolina Independent	L2	10° 25.8' N 83° 43.5' W	Banana (Valery)	Low-input	30	411-150[g]									
Finca 2. Ticofruit	Citrus	10° 17.0' N 84° 27.6' W	Citrus	Other crop	8	325									

Table 1. (*Continued*). Study sites evaluated, crops present and farm characteristics (farm type, age and planted area), avian census points and number of sites for biodiversity determination (avian species richness according to tree especies richness, density, canopy height and cover, understory density and tree diameter at breast height.ss) ac.

Site and operating institution	Alias used in text	Latitude/Crop Longitude	(Variety)	Farm type	Age Area (yr)	Census (ha)	Sites[a] points	Avian richness[b]	Tree species richness[b]	Tree species (ha^{-1}) [c]	Canopy density (m)[a]	Canopy height (%)[c]	Understory cover (%)[c]	DHB density	(cm)[d]
Agropalmito Demasa, Demasa	Palmito	10º 13.0' N 83º 53.0' W	Palmito (Heart of palm)	Other crop	12-15	550									
Finca Kailúa Macadamia de Costa Rica, S.A.	Macadamia	10º 8.5' N 83º 47.0' W	Macadamia	Other crop	18-20	260									
Manila, Celulosa Turrialba	Gmelina	10º 9.7' N 83º 25.3' W	*Gmelina arborea*	Other crop	20	719									

Data rearranged from Matlock and De La Cruz, 2003 and Matlock *et al.* 2002. a Number of sites in census area. b Census area totals. c Mean (SEM) taken over sites in census area. Data not collected for one site at COP. d DBH: Mean (SEM) tree diameter at breast height, averaged over sites in census area. Data not collected at SW and at one site at COP. e SEM is omitted for CYP and FYP because they were even aged monocultural stands of homogeneous canopy height. f BLK: Terrestrial lowland forest; FOP: 15-yr old reforestation planting; FR: Lowland riparian forest; FYP: 5-yr old reforestation planting; SW: Permanently inundated Rafia swamp forest; TRI: Terrestrial lowland forest; COP: 15-yr old reforestation planting; CYP: 5-yr old reforestation planting; RFR:Riparian gallery forest. g Area in cultivation at L2 declined from 411 ha at initiation of sampling to 150 ha at the close of the study.

valuable information for biological indicators for impact assessment. Matlock and De La Cruz (2002, 2003), in an attempt to elucidate crop protection product impacts on community structures within banana plantations and its surrounding areas, carried out an inventory of ants and parasitic Hymenoptera as biological indicators. They compared ant and parasitoid occurrence in banana plantations that ranged from low-input to conventional banana farms. Other monocultures such as Heart of Palm, Citrus and Macadamia were also evaluated for comparative purposes (Table 1).

Results showed that intensively cultivated tropical monocultures harbor ant faunas dominated by a small number of species. Banana plantations were dominated by ants belonging to 6 subfamilies and 46 genera, for a total of 107 species; some not yet described (Matlock and De La Cruz 2003).

Dominant species found were the same as those reported by Perfecto (1990), Roth *et al.* (1994), and Perfecto and Snelling (1995): *Solenopsis germinata* and *Pheidole radoszkowskii* for coffee monocultures, with *Pheidole punctatissima* also a common inhabitant; *Ectatomma ruidum* and *Pheidole radoszkowskii* dominating in maize crops subject to carbofuran and chlorpyrifos treatments. All species described were dominant in banana or the other monocultures evaluated.

Species richness and composition in ant communities from low-input and conventional banana plantations were similar with no significant differences among them for any of the 4 sampling methods tested (Matlock and De La Cruz 2003) (Table 2).

Also, there was no consistent evidence that the plantations and microhabitats receiving greatest crop protection product inputs (*i.e.* conventional and nematicide ring) harbored fewer ant species, lower ant diversity, or ant communities with unique ecological attributes.

When comparing banana with other monocultures, ants were most diverse in the other monocultures, with Macadamia and Citrus showing the highest and lowest species richness values, respectively (Figure 1).

Monocultures differed more from one another than from conventional bananas when faunal similarity analysis was done. The fact that the other crops plotted in orthogonal directions at the extremes of the graph, all nearer to banana than to one another, can be explained by the superabundance of *Solenopsis picea* captured *(i.e.* Macadamia and Gmelina*).* Variation in ant assemblages among crops seems to be more related to habitat differences than to crop protection product use.

Parasitic Hymenoptera can be regarded as potentially good indicator species, because they exert regulatory control over insect herbivore populations that are central to community structure and function (Hawkins and Sheedan 1994). Parasitic Hymenoptera may also be good indicators of crop protection product impacts, because they are more sensitive to these products than most other insects, including their host species (Plapp and Vison 1977, Croft 1990).

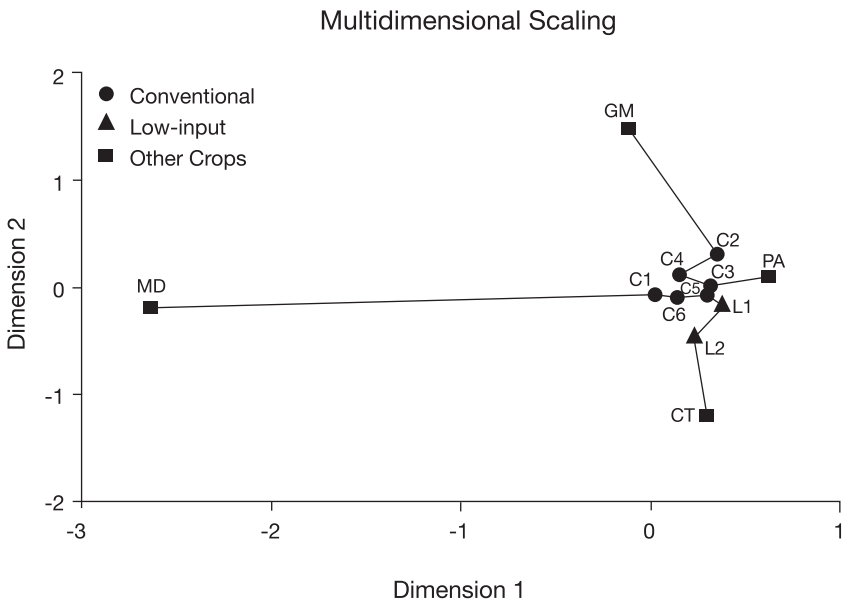
The impact of crop protection product applications on parasitoid communities in banana was assessed by 3 methods. First, an analysis of faunal similarity was conducted to determine whether plantations under different pest management programs harbor different parasitoid communities. Second, quantitative comparisons of parasitoid species richness and abundance were made among the 3 farm types (conventional banana, low input banana, other crops) with species accumulation curves, multivariate analysis of variance and rarefaction analysis (Colwell and Coddington 1994, Brewer and Williamson 1994). Third, parasitoid host affinities were compared across sites to determine whether variation in parasitoid communities among farm types reflected underlying differences in the host species attacked.

A total of 7838 individual parasitoids and 816 morphospecies were collected in the 12 study plantations, representing 27 families and 150 subsidiary taxa (subfamilies, tribes and genera). A full description of recorded species abundance is given in Matlock and De La Cruz (2002).

Table 2. ANOVA for species richness and composition in ant communities from low-input and conventional banana plantations.

Source of variation	df	F	P
Farm type	2.42	7.11	0.005
Collection method	3.42	23.00	0.0001
Contrasts			
Low input vs. other crops	1.42	5.56	0.05
Conv. vs. other crops	1.42	13.58	0.001
Conv. vs. low input	1.42	0.17	>0.05

Source: Matlock and De La Cruz (2003).



Source: Matlock and De La Cruz (2003).

Fig. 1. Multidimensional scaling plot of Morisita-Horn faunal similarity indices. Dimensions 1 and 2 are coordinates fit to similarity values by multidimensional scaling, each point representing a single farm. CT, citrus; GM, *Gmelina arborea;* MD macadamia; PA, palmito. See Table 1 for site description of C1-C6 and L1-L2.

The greatest species richness and abundance of parasitoids among banana plantations was observed at the 2 low-input farms, L1 (199 species, 701 individuals) and L2 (208 species, 1666 individuals), followed by C6 (145 species, 648 individuals) and the remaining conventional farms (64-145 species, 440-648 individuals). Overall, taxa with low host specificity, including the Evaniidae, Chalcididae, and 3 families of egg parasitoids, the Mymaridae, Trichogrammatidae, and Scelionidae were most diverse, abundant and evenly distribuited across farms. Other

common groups included Diapriidae, Eulopidae, Braconidae, and Ichnuemonidae. Only Diapriids were more abundant in conventional banana than in the low-input farms.

Total species richness and abundance were comparable to conventional banana in Macadamia and Gmelina and higher than conventional banana in Citrus and Hearth of Palm. Quirós (1994) reported similar results in species richness for 1 of the study plantations conducted several years earlier, suggesting that the parasitoid fauna was consistent through time.

Calculated faunal similarity indexes and multidimensional scaling of resulting values (Magurran 1988) are shown in figure 2.

Dimensions 1 and 2, the fitted coordinates produced by multidimensional scaling, were plotted for each site and connected by a minimum spanning tree. Distances between sites are inversely proportional to the similarity of their parasitoid faunas. All banana farms plotted to the right side had at least one banana farm as nearest neighbor, suggesting that the parasitoid fauna in banana was distinct from that found in the other crops.

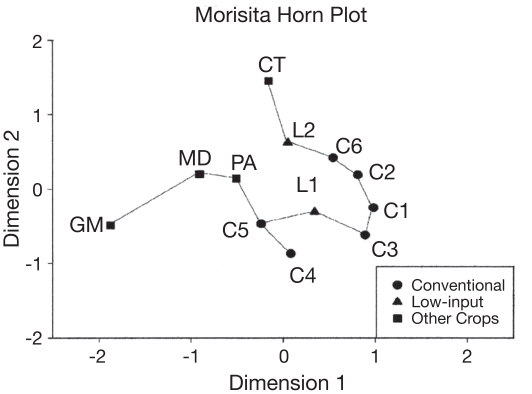
It is interesting to note that farms L1 and L2 plotted closer to their nearest neighbors than to one another, suggesting that there was no special parasitoid fauna associated with low-input farms.

Cumulative species richness curves for the low-input farms exceeded that for conventional plantations over the entire sample range (Figure 3).

Slopes for the other crops appear steeper than for the conventional banana plantations. However, samples in banana and other crops were taken at 2 and 6 monthly intervals, respectively. Thus, it is possible that any seasonal effects may overestimate of species richness slope for the other crops.

Coleman rarefaction curves showed that parasitoids abundance was highest in the low-input, other monocultures (Gmelina, Heart of Palm, Citrus), followed by the commercial banana farms and Macadamia (Figure 4).

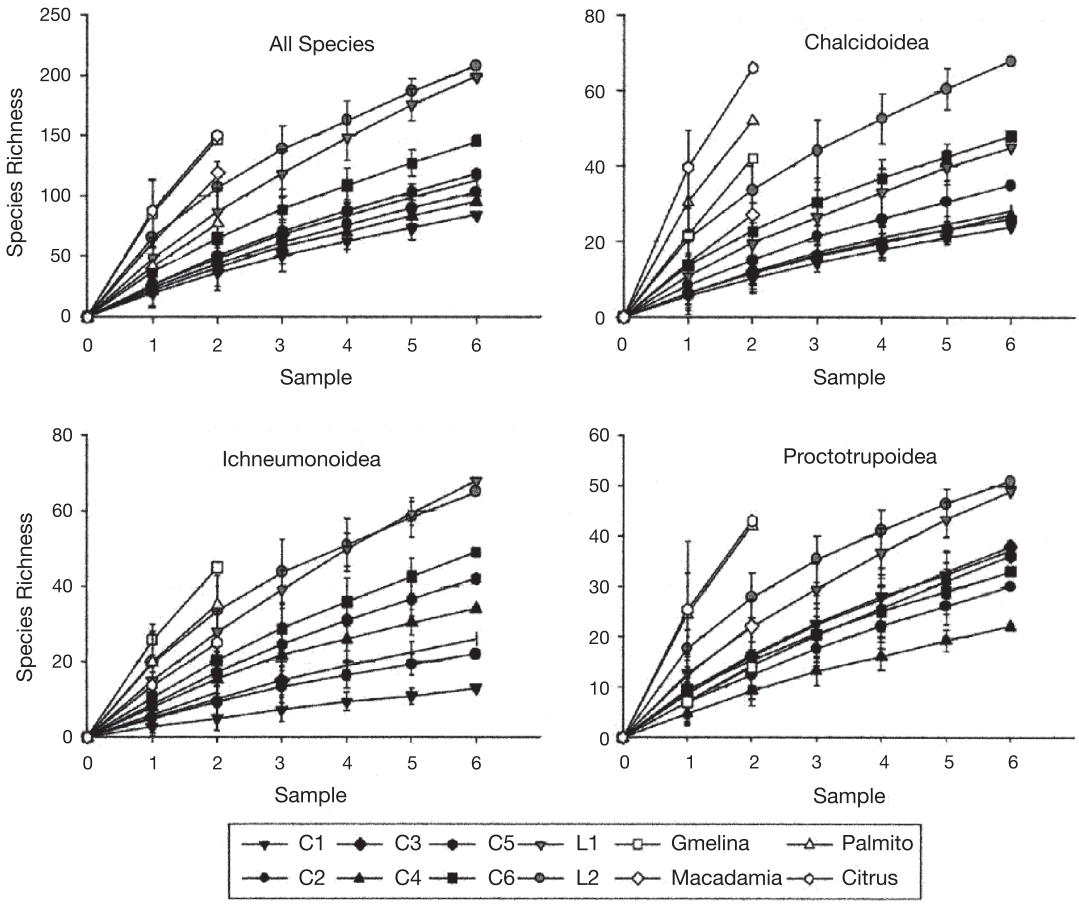
These results showed that differences in abundance and richness could reflect the differences in crop protection product inputs. In conventional banana, carbamate (carbofuran, oxamyl) and organophosphate (cadusafos, ethroprophos, terbufos) nematicides were commonly applied in the same farm in rotating cycles, both being highly toxic to parasitoids (Plapp and Vinson 1997). The organophosphate chlorpyrifos, used in fruit bags, is also toxic to parasitic Hymenoptera (Plapp and Vinson 1997, Bayoun *et al*. 1995).



Source: Matlock and De La Cruz (2002).

Fig. 2. Multidimensional scaling plot of Morisita-Horn faunal similarity indices. Dimensions 1 and 2 are coordinates fit to similarity values by multidimensional scaling, each point representing a single farm. CT, citrus; GM, *G. arborea*; MD, macadamia; PA, palmito. See Table 1 for site description.

Little information has been published on the effects of herbicides on parasitic Hymenoptera, but Laub and Luna (1992) found that paraquat had no effect on parasitism rates by 12 parasitoids of the armyworm (*Pseudaletia unipuncta*). Data from other taxonomic groups suggest that the principal herbicides applied in banana, paraquat, glyphosate and diuron, are non- or at most slightly toxic to honeybees (Kidd and James 1991, Walker and Keith 1992) and other terrestrial insects (Holck and Meek 1987, Ahmad 1995). Parasitoid exposure will also be limited as the sprayed plant dies quickly and becomes a non-attractive food source.

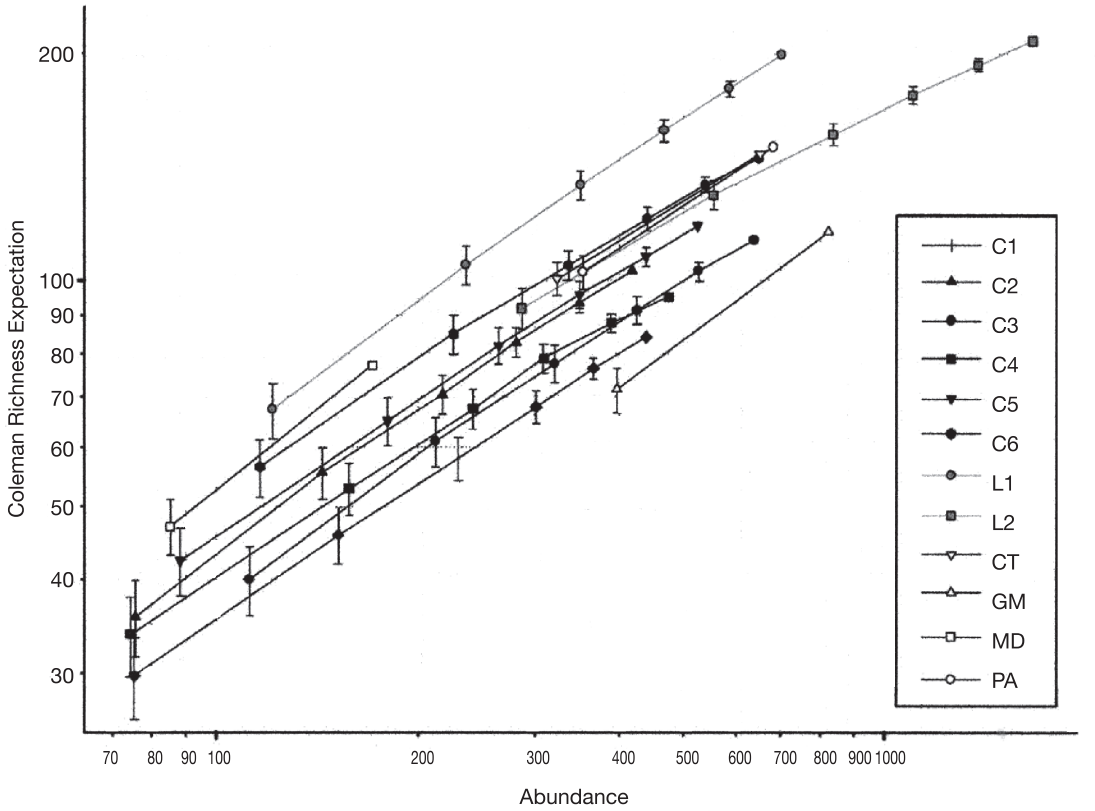


Source: Matlock and De La Cruz (2002).

Fig. 3. Smoothed species accumulation curves for the 12 study sites, calculated by resampling data for each location 100 times. Each curve represents the average increase in cumulative species richness per sample, error bars are 1 S.E.M. calculated from variation in the 100 random reorderings of sample data. CT, citrus; GM, *G. arborea*; MD, macadamia; PA, palmito. See Table 1 for site description.

In addition to direct toxic effects, herbicides could affect species richness and abundance indirectly via suppression of food plants for parasitoid host species. It is assumed that because of lower herbicide use, percentage vegetation cover was higher in low-input vs. conventional banana plantations, suggesting that food plants were more abundant there also.

The analysis of host guilds (Figure 5) provided no evidence for shifts in host affinities across farm types. In addition, there was no evidence in the analysis of faunal similarity that low-input farms had a parasitoid community distinct from that found in conventional farms. Hence, there was no evidence that the differences in species richness among sites derived from differences in vegetation cover. The 2 farms with the highest herbicide treatment rates and lowest vegetation cover among the other crops, Heart of Palm and Citrus, also had the highest species



Source: Matlock and De La Cruz (2002).

Fig. 4. Log-log plots of Coleman rarefaction curves ± 1 S.E.M. for the 12 study sites, each curve representing the expected cumulative species richness vs. cumulative number of individual sampled. See Table 1 for site description.

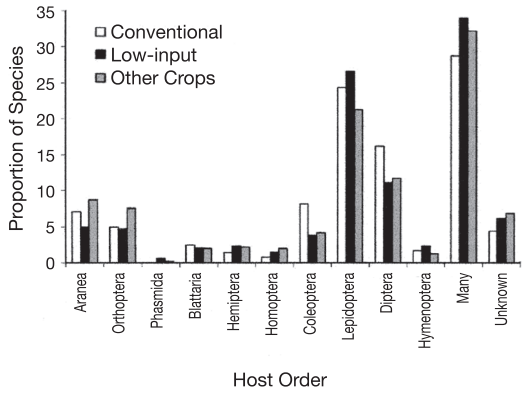
richness of parasitoids. Thus, herbicides commonly used in bananas (*i.e.* paraquat and glyphosate) do not appear to affect Hymenoptera parasitoids and their community structure and function.

Fungicides used in banana have low toxicity to parasitic Hymenoptera (Sewall 1987, Idris 1993a,b, Jalali 1993), honeybees (Harding 1979, Kidd and James 1991), and other terrestrial insects (Lamb and Lilly 1980). Plapp and Vinson (1997), Kidd and James (1991), Walker and Keith (1992) and Bayoun *et al.* (1995) suggested that both herbicides and fungicides applied to banana were less toxic to insects than nematicides in soil and chlorpyrifos-treated bunch bags.

Thus, of the crop protection products applied in banana, volatile insecticides such as the nematicides and chlorpyrifos treated bags were most likely to have significant direct toxic effects on hymenopteran communities.

Application rates of compounds toxic to parasitoids in the present study ranked roughly as: L1, L2 and other crops < C6 < C1-C5 (see Matlock and De La Cruz, 2003, for site description), and rarefaction estimates of richness per individual sampled ranked in the reverse order (Figure 4).

Matlock and De La Cruz (2002), suggest that the higher abundance and richness at C6 vs.



Source: Matlock and De La Cruz (2002).

Fig. 5. Proportion of parasitoid species in each of the 12 host guilds per farm type.

C1-C5 could reflect the differences in the use of chlorpyrifos-treated banana bunch bags at these sites. During the study, C6 received only a 10% of treated fruit bags compared to 100% treated with chlorpyrifos at C1-C5.

Dyer *et al.* (in press) in a recent study to evaluate the most effective natural enemies of Lepidoptera feeding on banana leaves, and the impact of crop protection products regimes, at conventional and moderate-input plantations, provided further evidence for the interpretation given by Matlock and De la Cruz (2002). Following the Dyer-Gentry model (Dyer and Gentry 1999), these authors compared parasitism data derived from natural systems in primary and secondary wet tropical forests, with that from banana plantations subject to the different crop protection product regimes. Conventional farms received normal inputs of fungicide, nematicide, herbicide and chlorpyrifos-treated fruit bags; while moderate-input farms received similar fungicide treatments as conventional plantations, but reduced inputs of herbicides, nematicides and chlorpyrifos. Data was used to construct a predictive logit model of success/ failure of biological control in banana plantations; based on the caterpillar traits previously found to successfully predict parasitism, such as defensive mechanisms, of *Caligo memnon, Opsiphanes tamarindi* (Nynphhalidae), and *Antichloris viridis* (Arctiidae). Parasitoids evaluated were those obtained after rearing 1121 caterpillar larvae (in third or later instar) collected along haphazardly selected transects in the studied banana plantations. *Caligo memnon* was parasitized by: *Meteorus laphygmae* (Braconidae: Meteorinae), *Brachymeria comotator* (Chalcididae), *Blepharipa sp.* (Tachinidae) and *Lespesia aletiae* (Tachiidae); with tachinids representing the most frequent parasitoids obtained. In the case of *Opsiphanes tamarindi,* parasitoids emerging from larvae were identified as: *M. laphygma, Cotesia sp.* (Braconidae: Microgastrinae) and *L. aletiae*; with tachinids being the most frequent followed by braconids. *Antichloris viridis* was parasitized by: *M. laphygmae, Cotesia sp., B. comitatot, Elachertus sp.* (Eulophidae: Eulophinae) and *L. aletiae*; with tachinids as the most frequent parasitoids followed in order by braconids, eulophids and chalcidis.

When parasitism due to Hymenoptera (Braconidae, Eulophidae, Chalcididae) was compared with that due to Diptera (Tachinidae) an interesting relationship was found. The total proportion of parasitism by Hymenoptera was lower in conventional (32%) vs. moderate-input (68%) plantations, whereas the opposite was found for dipteran parasitoids (74% of dipteran parasitism occurring in conventional and 26% in moderate-input farms).

Hymenopteran caterpillar parasitism was lower in conventional plantations where crop protection products inputs are applied at higher rates than in moderate-input plantations. An opposite effect was obtained for tachinids. Thus, as pointed out by Matlock and De La Cruz (2002), Hymenoptera can be regarded as more sensitive to agrochemicals than tachinids. Dyer *et al.* (in press) provide 2 possible explanations for this behavior: a. the first possible mechanism is potential increased host availability for tachinids, due to lower numbers of hymenopterans; and b. the second possibility, which closely relates to the first, is that tachinids are released from control by

hyperparasitoids. Both possibilities find support in available literature (Wang and Messing 2003, Castillo and Velasco-Hernandez 2003, Hanson and Gauld 1995, Chalapathy *et al*. 1998, White *et al*. 1998). However, the 2 potential mechanisms still deserve more research to explain why tachinids are less susceptible to crop protection products than hymenopterans and, to evaluate the impact of individual crop protection products, particularly volatile insecticides and nematicides, on the levels of parasitism and hyperparasitism by hymenopterans.

A logit model (Dyer and Gentry 1999), using data obtained from primary and secondary wet tropical forest, predicted that tachinids would rank first, and that braconids and eulophids would rank second and third in parasitism for each of the species of banana Lepidoptera studied. This is an important contribution towards predicting the likelihood of biocontrol success for specific pests or in designing effective biological control programs.

Microbial decomposition of crop residues in banana plantation soils

Since a high proportion of crop protection product inputs end up in soil, soil microorganisms play a key role in degrading these compounds if not physically or chemically altered (Pankhurst 1994, Alexander 1977, Turco *et al*. 1994, and Burbano 1989). Microbes are also crucial for the processes of organic matter breakdown and decomposition (Burbano 1989, Goyal *et al*. 1999, Primavesi 1977, Vargas and Flores 1996).

Biederbeck *et al*. (1997) noted that microbial respiration was a function of crop residue and not of long-term use of herbicides glyphosate and paraquat in a fallow-wheat rotation. Vargas and Flores (1995) extended this concept to fungicides, nematicides and insecticides used in bananas.

Banana plantation soils can be regarded as rich in soil organic matter with relatively high residual concentration of crop protection products. Mirgain (1993) observed an increase rate at which crop protection products degradate in soil possibly due to microbial adaptation to repeated exposure to the products. Pattison *et al*. (2000) noted the same phenomena in surface banana plantation soils exposed to nematicides. Roeth (1986), Mueller *et al*. (1989) obtained similar results when soils were subject to herbicide applications.

Vargas and Flores (1995) studied the mineralization of nutrients present in organic residues in banana farms of different ages (from 1 to 20 years of monoculture), all subject to commercial applications of the crop protection products previously mentioned. Soil organic matter degradation patterns did not differ significantly among the studied farms, indicating the presence of a "healthy" soil microbial structure capable of degradating organic matter, and indirectly, of residual crop protection products present in the analyzed organic residues (pseudostem, leaves, corms and bunch raquis) in relatively short times. Peak decomposition was observed 24-28 weeks (*i.e*. 168-196 days) after banana plant residues were returned to the soil as piles between rows at harvesting. Thus, it seems that in soils derived from volcanic ashes, where soil organic matter is strongly bound to amorphous clays, oxides and metals (Nanzyo *et al*. 1993), continuous inputs of fresh organic materials maintain adequate microbial activity to sustain nutrient cycling, adequate physical properties and crop protection product breakdown. Vargas and Flores (1995) demonstrated total annual savings in fertilizer use of about US$17 million (as per total cultivated area) by just adjusting national fertilization programs based on the amounts of organically bound elements added to soil through mineralization of fresh crop residues.

Edwards *et al*. (unplublished data) measured decomposition rates of leaves from harvested plants in 6 conventionally managed and 2 low input banana farms (see Table 1 in this review for a full farm description). Five kilograms of fresh-cut leaves were placed in galvanized wire bags (1x2 m, 1 cm mesh) and distributed on top of existing litter decomposition piles

starting in September 1995, and left undisturbed. Leaf weight determinations (wet weight) were done at 2-4 week intervals in a fashion similar to that described by Vargas and Flores (1995). Leaf weight loss was used to estimate the rate of decomposition. Some bags were covered by foliage from additional harvested plants. Bags were removed from underneath composting plant material for weighing and replaced beneath it afterwards. Four replicate wire bags were placed in each of the 8 banana plantations studied.

Calculated DT_{50} and DT_{90} and Decay Rate values area summarized in table 3.

Calculated values showed no apparent differences attributable to farm management. Average dry weight loss of leaves measured by Vargas and Flores (1995), at 3 week intervals, were similar to the values obtained in the present evaluation. Thus, crop protection product inputs did not affect microbial decomposition rates of harvested banana plant residues incorporated into the litter decomposition piles.

In both studies, initial decomposition was mediated by the combination of arthropod and fungal activites. Initial fragmentation was done by several millipedes (Diplopoda). Berlese extraction of litter samples and soil samples indicated presence of microarthropods like Cryptostigmatid mites (Acari) and Collembola. In association with these primary decomposers were predatory Gamasina (Acari), spiders (Aranae), ants (Formicidae) along with other less numerous species. The abundance and diversity of all these species is indicative of an active biological structured community associated with banana crop residue decomposition, which is not seriously affected by crop protection product inputs.

Table 3. Estimated decomposition rate values for banana leaves.

Farm type	DT_{50}	DT_{90}	Decay rate (kg day^{-1})
Conventional	72.4	241	0.011
Low-input	71.2	236	0.012

DT_{50}=Decomposition time at which 50% of the leaf weight remained undecomposed. DT_{90}= Decomposition time at which 90% of the leaf weight was decomposed.

Source: Edwards *et al*. (unpublished data).

The patchy distribution of organic matter input between rows creates different equilibrium contents in soil organic matter and microbial activity over different periods of time (Vargas and Flores 1996). Blume *et al*. (1998) investigated the effect of crop protection product input level, plantation age and soil organic matter content on soil microbial respiration and mineralization rates. Their results showed that age of plantation had no effect on soil organic matter content. Nanzyo *et al*. (1993), Hassink and Whitmore (1997), and Mazzarino *et al*. (1993), considered that this could be possibly due to soil organic matter stability resulting from its characteristic tendency to strongly bind to volcanic derived amorphous clays. The continuous input of fresh organic residues resulting from daily harvest of bananas maintain adequate rates of microbial activity to sustain its decomposition, nutrient cycling, adequate physical properties and ultimately banana productivity (Vargas and Flores, 1995). However, their results also showed that areas not subject to fresh organic residue inputs (*i.e*. nematicide ring and bare areas, respectively), had lower microbial densities (CFU g-$soil^{-1}$) in all sampled farms, independent of plantation age and crop protection product application. Bacterial, fungal and protozoan counts (densities g $soil^{-1}$) measured over 60 weeks in farms located across the Caribbean of Costa Rica support those results (Vargas and Flores 1996).

Acid reaction fertilizers added to soils were assumed to be responsible, since low microbial counts correlated with the low pH values determined at the nematicide ring "NR" (Blume *et al*. 1998). Research done by Cornelissen and Thompson (1997) provide further support to the idea that bacterial and fungal community activities can be affected by litter pH during decomposition. Bending *et al*. (2002) extended the concept indicating that the

types of nutritional substrates available will be different in soils with contrasting soil organic matter quality, with direct effects on the nature of microbial and faunal communities active in the soil. Thus, microbial densities g $soil^{-1}$ obtained can reflect nutrient availability to support large microbial populations capable of degrading the large amounts of fresh organic residues added to banana plantations (estimated at 150-200 t fresh weight ha^{-1} $year^{-1}$) (Godefroy 1974 quoted by Lahav and Turner 1983). Low microbial density values then reflect carbon limitations for rapid crop protection product breakdown in spite of the presence of highly bound soil organic matter.

Blume *et al*. (1998) collected soil samples from the surface soil (0-25 cm) at 5 sampling sites: three 5 years-old plantings at EARTH (Escuela de Agricultura de la Región Tropical Húmeda) and two 20 years-old plantings at EARTH and Carolina farm. Farms were subject to different combinations of herbicide, nematicide and fungicide use (Table 4).

All sampling sites had received crop protection products since their establishment but documentation was only available after 1992. The plantations were selected because their long-term use (5-20 years) or zero use of the herbicide paraquat.

Triplicate soil samples were collected in each of the 3 following microhabitats: the nematicide ring (NR: an area around the plant where nematicide, herbicide and fertilizers are applied); the litter pile (LP: an area outside the NR where harvested banana crop residues decompose); and the bare area (BA: an area outside the NR but without decomposing banana residues where weeds are managed with herbicides). Analyzed variables included soil properties (Henríquez *et al*. 1995), and microbial respiration (NaOH trapping of evolved CO_2) in unamended soil and soil amended with glucose and ground banana leaves. Kinetic assessments of mineralization rates were used to compare the different treatments; Zero-order and first order

Table 4. Treatments, plantation, and number (mean and range) of crop protection products cycles applied to each study site during the interval 1992-1996.

Site[a]	Plantation	Class	Crop Protection Products Applied
F (5 yr)	EARTH	F	benomyl, bitertanol, dithiocarbamate, hexaconazole, mancozeb, propiconazole, iconazole, tebuconazole, tridemorph.
HF (5 yr)	EARTH	H	glyphosate, paraquat;
		F	benomyl, bitertanol, dithiocarbamate, hexaconazole, mancozeb, propiconazole, tebuconazole, tridemorph.
HNF (5 yr)	EARTH	H	glyphosate, paraquat;
		N	cadusafos, carbofuran, terbufos;
		F	benomyl, bitertanol, dithiocarbamate, hexaconazole, mancozeb, propiconazole, tebuconazole, tridemorph.
F (20 yr)	Carolina Farm	F	benomyl, bordeaux spray, chlorothalonil, mancozeb, propiconazole, tridemorph.
HNF (20 yr)	EARTH	H	diuron, glyphosate, paraquat;
		N	cadusafos, carbofuran, ethoprophos, terbufos;
		F	benomyl, bitertanol, dithiocarbamate, hexaconazole, mancozeb, propiconazole, tebuconazole, tridemorph.

[a] F, fungicide; H, herbicide; N, nematicide. Values in parentheses indicate age of the plantation.
Source: Blume *et al*. (1998).

(Paul and Clark 1989) and first-order plus linear term (Brunner and Focht 1984).

Table 5 shows the organic matter content and microbial respiration for 3 microhabitats and 5 sites with different carbon amendments.

The soil organic matter contents varied, as expected, among microhabitats, higher beneath the LP where banana residues were composting than for the BA and NR. These results are similar to those reported by Vargas and Flores (1995) and Haron *et al*. (1998) for banana and oil palm farms, respectively.

Farms with high crop protection product input (HNF), where weeds were managed with herbicides, had less soil organic matter than low (F) or medium (HF) crop protection product use. It is possible that weed control with herbicides reduced the input of soil organic matter from decaying plants.

Age of plantation had no effect on soil organic matter content. Similar results had been reported elsewhere (Vargas and Flores 1995, Nanzyo *et al*. 1993, Hassink and Whitmore 1997, Mazzarino *et al*. 1993).

Table 5. Organic matter content and microbial respiration for 3 microhabitats and 5 sites subject to different pesticide use history, with different carbon source amendments.

Location	Organic matter %	Microbial respiration			
		No addition[b]	Glucose	Banana leaf	Total
		mg CO_2 g soil^{-1}			
Microhabitats					
Bare area (BA)	7.7	0.56	2.85	3.66	7.07
Litter Pile (LP)	9.8	0.66	3.01	3.87	7.54
Nematicide Ring (NR)	7.2	0.56	3.34	3.51	7.40
Site (pesticide use (time)[a])					
F (5 yr)	10.4	0.77	3.09	3.86	7.72
HF (5 yr)	8.6	0.51	3.03	3.56	7.10
HNF (5 yr)	7.0	0.68	3.09	3.85	7.62
F (20 yr)	8.5	0.47	3.06	3.36	6.89
HNF (20 yr)	7.6	0.53	3.04	3.78	7.35
Selected contrasts		Level of probability			
BA vs. LP	**	NS[c]	NS	*	**
BA vs. NR	NS	NS	**	NS	*
LP vs NR	**	NS	**	**	NS
5 vs. 20 yr	NS	**	NS	*	**
Low vs. high input	**	NS	NS	*	NS
Low vs. medium input	NS	NS	NS	NS	NS
Medium vs. high input	*	NS	NS	**	*

[a] F, fungicide (= Low input); HF, herbicide and fungicide (= Medium input); HNF, herbicide, nematicide and fungicide (= High input). [b] No addition= control. [c] NS=not significant; * P<0.05; ** P<0.01.
Source: Blume *et al*. (1998).

The addition of carbon substrates (glucose and ground banana leaves) increased the microbial respiration for all sites and microhabitats (Table 5 and Figure 6).

A readily degradable substrate, such as glucose, increased microbial respiration. No differences were observed for farm age or crop protection product level use. NR area had the greatest measured respiration rate. Proximity to the rhizosphere and its microbial structure might explain the recorded values since microbes are adapted to root exudates. Skipper *et al*. (1996), Buchanan and King (1991), and Tate (1979) provide support for the observed results. The presence of labile carbon as compared to more complex substrates available from crop residues or crop protection products, can increase microbial activity.

Soil amendment with ground leaf residues resulted in greatest microbial respiration in samples from young farms (5 years), high crop protection product input (HNF), and for LP. These sites also had the greatest soil organic matter content among the microhabitats. These results indicate that microbial respiration was not decreased by crop protection product application on banana farm soils in the humid tropics.

The response of microbial communities to substrates and chemicals and the degradation rates of those compounds can be described using reaction kinetics. Blume *et al*. (1998) calculated decay constants (k_0 and k_1) without correction for microbial biosynthesis to reflect net degradation rates (Table 6).

Calculated values for unamended soil samples followed zero-order kinetics. For all sites and microhabitats k_0 values averaged 22 μg CO_2 g $soil^{-1}$ day^{-1}. Glucose and ground leaves amended soil samples followed first-order kinetics. The degradation rate, k_1 was about 18 times greater for glucose than for ground leaves. Van Veen *et al*. (1984) and Paul and Clark (1989) reported similar results for easily decomposable and for more complex organic substances.

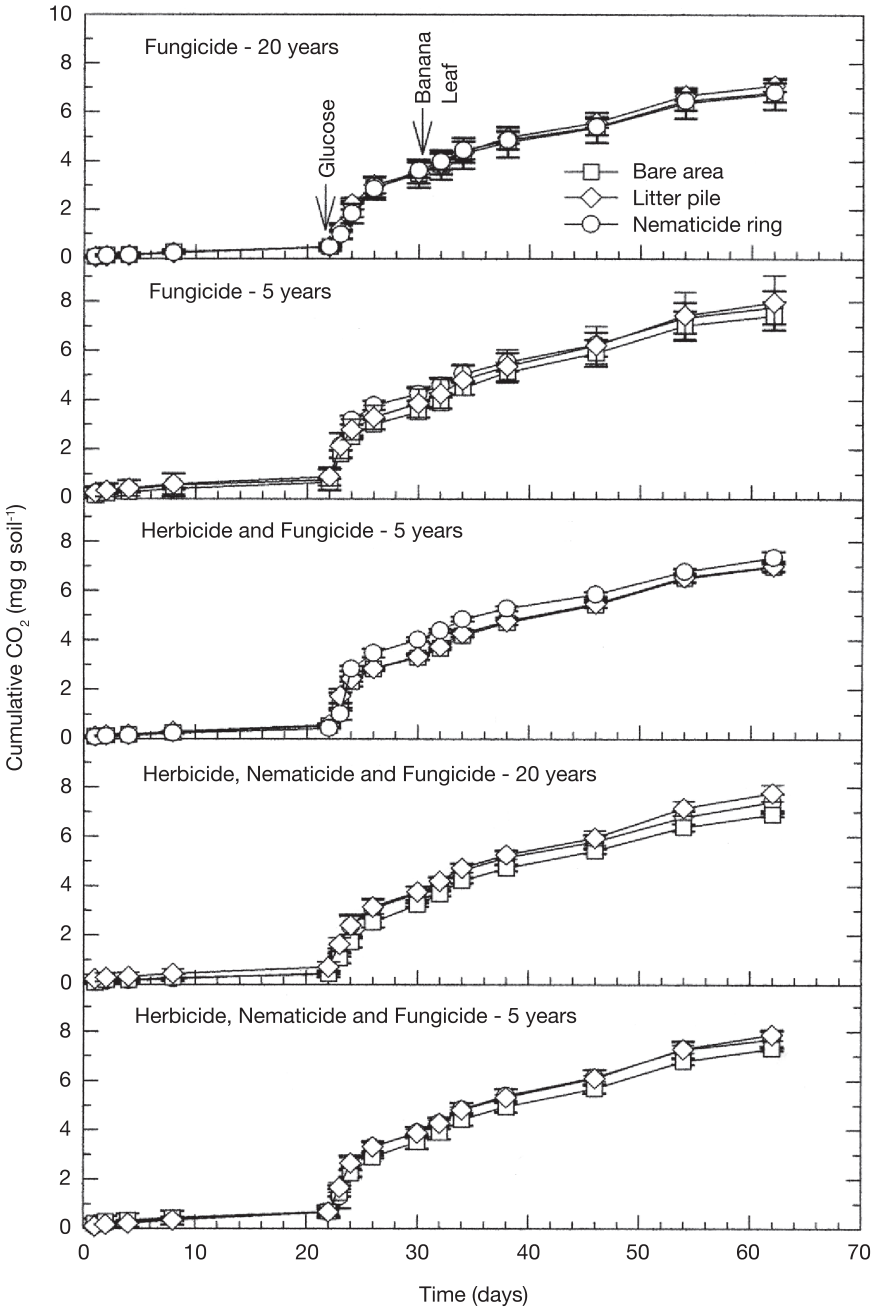
K_1 values for ground banana leaves were unaffected by site or microhabitat. For glucose amendment the greatest values for k_1 were obtained for young farms (5 years-old). Long-term banana cultivation decreased k_1 independent of crop protection product input, indicating an age effect on mineralization rate for readily decomposable organic material. Thus, soils with high soil organic matter contents maintain an active microbial population in the field only when readily degradable carbon sources are added. These results point to the need for a more careful management of fresh organic matter residues in order to avoid patchy distribution within banana plantations.

Birds as indicators of the importance of forest fragments and reforestation areas to biodiversity

Agriculture has put pressure on wild areas, which has resulted in a mosaic of farmland and forest in Costa Rica. One alternative to mitigate their negative effects on conservation is to integrate conservation areas with economically viable agriculture. Forest fragments remaining in agricultural areas are not considered as ideal for forest wildlife conservation. However, they can provide some watershed protection (Greenberg 1996), population buffers around major conservation areas and as corridors connecting fragments and meta populations (Guindon 1996, Roberto Ruiz, Personal communication. 2003).

Concerns have been expressed that banana farms are responsible for widespread deforestation in Costa Rica. Costa Rica occupies an area of approximately 51000 km^2. Arable areas (including those covered by bananas) occupy about 12% of the land, cattle ranching occupies approximately 43%, while 33% is under forest (including 22% in protected areas). The area dedicated to growing banana for export currently occupies approximately 44000 ha or about 1% of Costa Rica's surface area, and less than 10% of all cultivated areas (Corbana and Latin American Crop Protection Association 1999).

Banana companies, in compliance with environmental legislation of Costa Rica, observe buffer zones along main rivers and other natural waterways, in which vegetation reforestation is



Source: Blume *et al*. (1998).

Fig. 6. Microbial respiration for 3 microhabitats (bare area, litter pile and nematicide ring) with the addition of 2 substrates (glucose and ground banana leaves) at 5 banana plantations with diverse crop protection products management. Error bars indicate standard deviations.

Table 6. Zero-order (K_0) and first-order mineralization (k_1) rates with 2 amendments for 5 sites.

Amendment	Site[a]	k_0 or k_1 mg CO_2 g $soil^{-1}$ day^{-1} k_0	r^2
Unamended	F (5 yr)	0.025 (0.003)[b]	0.857
	HF (5 yr)	0.020 (0.001)	0.954
	HNF (5 yr)	0.025 (0.002)	0.925
	F (20 yr)	0.019 (0.001)	0.984
	HNF (20 yr)	0.018 (0.003)	0.708
		k_1	
Glucose	F (5 yr)	0.512 (0.078)	0.877
	HF (5 yr)	0.349 (0.119)	0.780
	HNF (5 yr)	0.249 (0.080)	0.871
	F (20 yr)	0.210 (0.075)	0.908
	HNF (20 yr)	0.221 (0.084)	0.883
Banana leaf	F (5 yr)	0.017 (0.011)	0.961
	HF (5 yr)	0.016 (0.010)	0.963
	HNF (5 yr)	0.016 (0.009)	0.971
	F (20 yr)	0.017 (0.010)	0.961
	HNF (20 yr)	0.016 (0.009)	0.968

[a] F: fungicide; HF: herbicide and fungicide; HNF: herbicide, nematicide and fungicide.
[b] Values in parentheses indicate standard deviations.
Source: Blume *et al*. (1998).

allowed to develop. In addition, some companies maintain extensive areas in permanent forest. According to Laprade (1998), 4490 ha were under forest management. These areas are important in terms of protecting biodiversity and supporting wildlife reproduction. Attempts to evaluate the conservation value of these reforested and set-aside areas for wildlife are scarce.

Recent studies have contributed valuable information on habitat quality and crop protection product impacts on environment and its biodiversity within and outside banana plantations.

Matlock and Edwards (in press) examined the relationship between habitat and bird communities at 10 forest remnants and reforestation areas associated with banana plantations in the Costa Rican Atlantic lowlands (see Table 1 for site description).

A total of 133 tree species were recorded in the 10 census areas, species richness varying between 1 for CYP and FYP planted with monocultures of *Zygia longifolia* and 60 species at TRI. The canopy at BLK approached the 30-35 m mean height reported for primary forest (Hartshorn and Hammel 1994), but canopies were lower elsewhere.

Avian richness totaled 206 species ranging from 43 species at TRI to 125 at ER. Migrant birds represented 16% of individuals detected, of which

67% were insectivores. Greenberg *et al*. (2002) reported similar results in surveys conducted in cacao plantations located in humid tropical areas.

Bird community composition was highly correlated with forest structure and tree species composition. Signs of correlations with canopy height and understory density were typically positive for indicators of primary forest and species moderately susceptible to disturbance, but negative for opportunistic species (migrants and indicators of disturbed habitats). Hughes (2002) found that edge habitats containing tall trees supported roughly twice as many bird species than surrounding pasture and coffee in the vicinity of the Las Cruces Biological Station in Southwestern Costa Rica, indicating the importance of canopy height. Estrada *et al*. (1997) studied forest fragments, agricultural habitats, live fences and pastures. Foliage height diversity (canopy height x canopy cover) and tree species richness were strongly correlated and when partial correlations were performed, only the effects of foliage height diversity were significant. Thus, positive correlations between bird species richness and canopy height appear most consistent across tropical sites. Relationships with understory, DBH, basal area, canopy cover, and foliage height diversity all being more variable.

Using La Selva's avifauna as a benchmark, the effects of land use change by planting bananas and the impact of forest fragments and reforested areas were evaluated. Two hundred and six species of birds were encountered in the current survey, representing approximately 25% of the total Costa Rican avifauna and 50% the species recorded from La Selva (Stiles and Levey 1994). Greenberg *et al*. (2000) and Estrada *et al*. (2000) also found that habitats associated with agriculture support an important component of bird species. Thiollay (1995) reported 143 species of birds in 3 traditional agroforests under low-intensity management in Sumatra. Bird diversity was higher than commercially managed forest or agricultural crops with lower structural complexity and plant species diversity. Thus, there appears to be consensus that arboreal agricultural habitats can preserve an important component of avian diversity, but are not viable replacements for primary forest. Most protected areas in Costa Rica occur below 50 m elevation or above 1000 m, with intervening regions dominated by agriculture such as banana plantations. Lowland forest fragments and reforested waterways in agricultural landscapes provide potential sanctuaries for bird protection and reproduction as well as corridors connecting the fragments together.

Avian communities in forest fragments and reforestation areas associated with banana plantations in Costa Rica

Several studies suggest that the species richness supported by forest fragments varies with the matrix habitat that surrounds them (Laurance 1991 a, b, Stouffer and Bierregaard 1995, Warburton 1997). Banana plantations are generally extensive and homogeneous, offering little habitat diversity, and are intensively cultivated. Like any agricultural crop, bananas have potential crop losses due to insect defoliators, insects infesting fruit, nematodes, disease (black Sigatoka) and weeds. Estimated losses, considering a range of locations and time of year range between 10-12; 1-15; 20-50; 50-100 and 5-10%, respectively. In order to control black Sigatoka disease alone, farms may receive 35-45 fungicide applications annually.

To compliment previous studies and to explore the risk of expose such crop protection product to birds visiting banana plantations, Matlock *et al.* (2002) used the approach of Stoltz *et al*. (1996) to classify the avifauna in forest fragments and bananas as indicators of pristine and disturbed habitats. In addition, those species potentially exposed to crop protection products in banana plantations were identified together with the age structure of their populations as an indicator for any impacts. For this purpose point observations were made at 42 locations in conserved forest and 30 locations in reforested

areas and mist netting at 29 of the 72 point counts locations.

The study evaluated the proportion of the Atlantic lowland avifauna preserved by the surveyed habitats. Point-count and mist-net species lists were then compared with existing species lists for the La Selva Biological Station (Stiles and Skutch 1989, Stiles and Levy 1994). Coleman rarefaction curves were used to compare species richness among sites (Colwell and Coddington 1994). These curves plot cumulative richness vs. the number of individuals sampled (Colwell and Coddington 1994, Brewer and Williamson 1994).

To document birds that have potentially been exposed to crop protection products, the species and numbers of individuals visiting banana plantations were tallied from point counts. Bird reproduction during the breeding season was studied by monitoring the proportions of adults and juveniles in the population by mist-netting at 6 of the 10 different forest tracts comprising of reforestation plantings of different ages, riparian forest strips and non-riparian forest remnants adjacent to plantations.

During the survey, banana plantations surrounding the study habitats received, on an annual basis, an average of 6 herbicide applications (principally paraquat and glyphosate), 3 nematicide applications (typically alternating cycles of organophosphates and carbamates) and 25-35 fungicide applications (benzimidazoles, ethylene bisdithiocarbamates, morpholines and triazoles). The fungicides were applied using aerial spraying. The applied herbicides were of low toxicity to birds, whereas the nematicides and chlorpyrifos had moderate to high avian toxicity (Brooks and Gates 1973, Kidd and James 1991). Both herbicides and nematicides were manually applied so exposure of forest edge habitats and animals adjacent to plantations from drift was probably low. Thus, birds foraging within plantations probably experienced the highest risk of exposure.

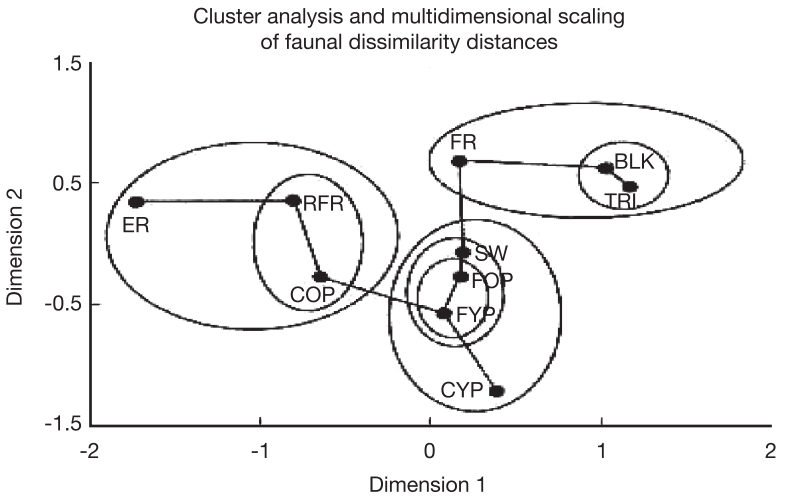
A total of 11361 birds in 194 species and 47 families were observed in the point-count survey and 1035 birds (351 immatures, 678 adults, 6 not aged) in 73 species and 23 families in 911 net hours of mist-net operation. Twelve species not recorded in the point-counts were captured in the mist-nets, bringing the total study to 48 families and 206 species. The 2 monitoring methods are complementary in providing an inventory of species in habitats. Point counts are most efficient identifying conspicuous species in canopies while mist netting detects inconspicuous species in the understory. The proportions of immature birds in the population of species observed to use the plantations edges are an indication that birds are reproducing successfully under the conventional pest management practices, albeit for species largely classified as indicators of disturbed habitats and of those that are susceptible to low disturbance.

Figure 7 shows the dissimilarity in composition of avifaunas within the 10 study areas.

Habitats increased in maturity as dimension 2 increased. The most mature habitats with the oldest standing trees, ER, RFR, FR, TRI and BLK, all plotted towards the top of the figure. Least mature habitats, the 4 reforestation plantings CYP, FYP, FOP and COP, plotted as nearest neighbors towards the bottom.

Species accumulation curves showed significant saturation, suggesting that most of the species occurring within the study habitats were recorded. Overall species richness was higher in the riparian habitats (riparian 2-1º forest strips along main drainage canals and rivers adjacent to banana plantations), the 2 older plantings (reforested areas with *Zinga longifolia*) and the swamp than in the 2 young plantings (newly reforested areas with *Z. longifolia*, and pristine low-land evergreen forest). Thirty-five species were classified as indicators of disturbed habitats. Species highly susceptible to disturbance and indicators of intact lowland evergreen forest were scarce. Seventy eight species observed in the survey were classified by Stolz *et al*. (1996) as moderately susceptible to disturbance.

The point-count survey recorded 53 species and 918 individuals within banana plantations. Forty of these species were in the low susceptibility to disturbance category and 21 were indicators of



Source: Matlock *et al*. (2002).

Fig. 7. Cluster analysis and multidimensional scaling. Fitted coordinates (dimensions 1 and 2) produced by multidimensional scaling for each census area connected by a minimum spanning tree; distances between points reflecting the distinctness of their avifaunas (superimposed nested circles display cluster analysis groupings). See Table 1 for site description.

disturbed habitats, representing 95 and 85% of total observations, respectively. Only 13 species and 38 individuals in the medium susceptibility category and no species with high susceptibility to disturbance or lowland evergreen forest indicators were recorded from banana. More birds were observed in banana adjacent to less pristine habitats. Except for opportunistic species most birds visited only the edges of plantations, venturing less than 60 m from the margins.

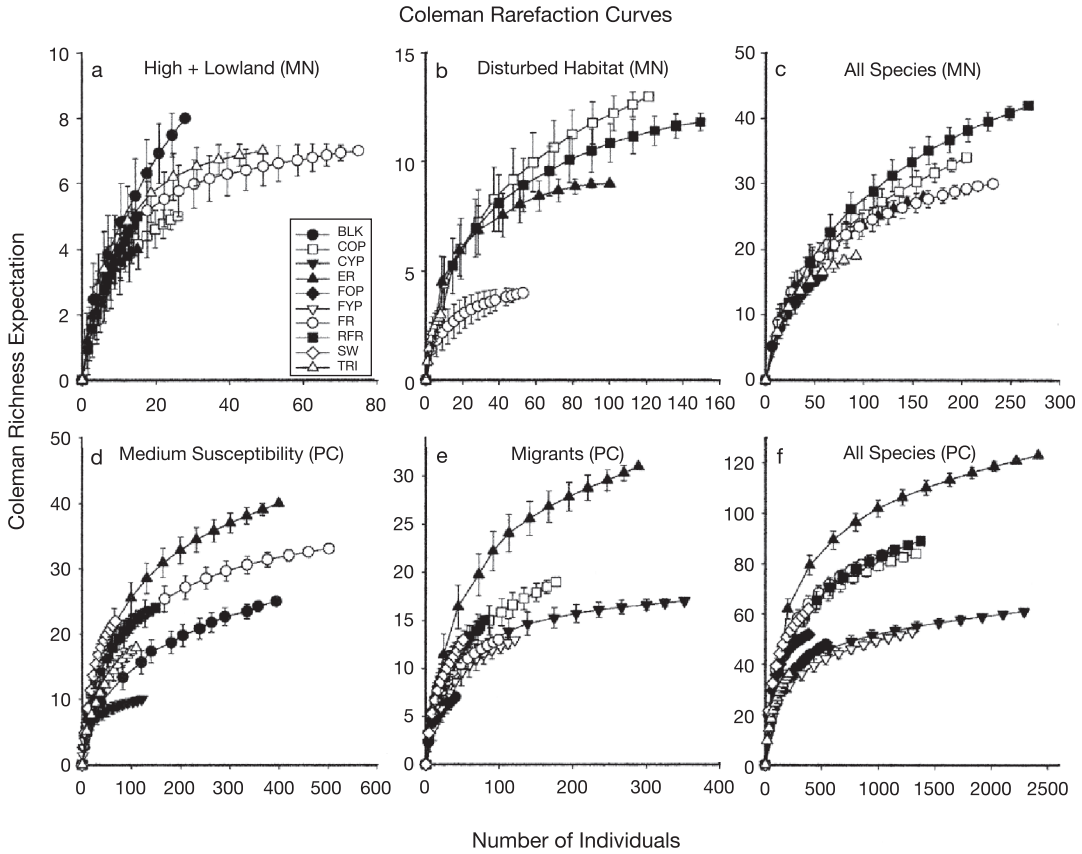
Coleman rarefaction curves displayed species richness versus the number of individuals observed (Figure 8). Curves for sites with the same species richness and relative abundance should trace coincident paths.

Overall species richness was higher in the riparian habitats ER, FR and RFR, the 2 older plantings COP and FOP and the swamp, than in the 2 young plantings, CYP and FYP, and pristine lowland evergreen forest, BLK and TRI (Figure 8f). This is particularly encouraging as it can be expected that as the young plantings mature along the rivers and canals the avifauna can be expected to increase. With immatures present in the population, the impact of crop protection products on colonizing populations is unlikely to be significant for the potentially most exposed species.

CONCLUSIONS

The present review has demonstrated that while biodiversity in banana plantations can be influenced by crop management products and other practices, the system as a whole supports a diverse community and is certainly not a "green desert".

There was no consistent evidence that the plantations and microhabitats receiving greatest crop protection product inputs (*i.e*. conventional and nematicide ring), to control weeds, nematodes, fungi and insects, harbored fewer ant species, lower ant diversity, or ant communities with unique ecological attributes. The absence of any indirect effect of herbicides, such as paraquat, on the ant community structure on the conventional farms was unexpected.



Source: Matlock *et al*. (2002).

Fig. 8. Rarefaction analysis. Coleman rarefaction curves displaying estimated species richness vs. number of individuals observed (± 1 S.E.M.) for point-count (PC) and mist-net (MN) avifaunas and for representative indicator groups from both surveys.

Comparisons among low and high-input banana farms in terms of ants and hymenopteran parasitoid community structure showed that insecticides are the most impacting compounds in terms of number parasitoids present at any time; while fungicides and herbicides show no negative effects.

More research is needed to clearly identify community responses after nematicide applications in terms of time and space. Some nematicide molecules can reduce levels of parasitism of the White Fly (*Aleurodicus dispersus* Russell), producing insect outbreaks of economic significance (Laprade 1998, Sergio Laprade and Helga.Blanco, personnal communication. 2003).

For IPM programs new alternatives to insecticide impregnated fruit bags (mechanical barriers, new insecticide molecules and toxic or repellent plant extracts) should continue to be evaluated.

Based on the results of analyzed biological indicators crop protection products currently used in banana can be ranked in terms of their impact as follows: herbicides< fungicides< insecticides < nematicides.

The low microbial numbers recorded in soils cultivated with bananas are attributable to lack of carbon sources for rapid population buildup and also to the limitation imposed by low pH resulting from frequent fertilizer applications. Other crop protection products such as herbicides, nematicides/insecticides and fungicides were not directly related with obtained results.

High respiration rates were obtained in soil samples from the NR areas amended with labile carbon sources and the litter piles. These observations provide evidence that where weeds are controlled with herbicides, such as glyphosate and paraquat, microbial respiration in banana plantation soils is not affected by their application. Thus, it is concluded that organic matter is the limiting factor for microbial activity in banana plantation soils.

Mineralization of crop residues occurs as a result of an active and a well structured microbial population as long as readily fresh organic materials are continuously added.

The relatively high bird species diversity and the consistent presence of immatures in habitats so closely associated with intensive agriculture are encouraging. Thus, while research on the long term population viability and crop protection product risk assessment proceeds, the conservation efforts associated with banana production (conservation of forest patches and reforestation of non-cultivated areas) should be continued and whenever possible expanded.

RECOMMENDATIONS

Future research on risk assessment of crop protection products should focus on the insecticides/nematicides currently used for pest control. Proper understanding of community structure and function should provide the basis for stability improvement to enhance biological control of insect pests.

Weed control should be based on the management of population thresholds with the aid of contact and systemic herbicides. Whenever, possible mechanical weeding should be included.

Contact (Paraquat) and systemic (Glyphosate) herbicides may continue to be used in sustainable banana crop production because there is no evidence, based on current research, of effects on biological structure and stability of communities within and adjacent to banana plantations.

For crop management and nutrition, fresh crop residues should be homogenously distributed within the plantation to maintain adequate microbial activity for sustainable banana productivity in terms of time and space, and for crop protection product residues degradation.

Management of forest habitats along rivers and canals to connect forest fragments need to be encouraged with greater emphasis on the tree height and understory density together with long-term monitoring to measure the response in terms of avian productivity and biodiversity.

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