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THE EFFECTS OF THE QUESUNGUAL AGROFORESTRY SYSTEM OF WESTERN HONDURAS ON SOIL MACROFAUNA

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ABSTRACT

Agricultural practices that promote increased diversity and abundance of soil macrofauna may improve soil quality and productivity, due to the influence of soil macrofauna on organic matter breakdown, nutrient cycling and soil structure. Southern Lempira department in Honduras is an environment where farmers could benefit greatly from such an increase in soil quality. The landscape is hilly, with steep slopes and shallow soils that are susceptible to erosion. The need for shorter fallow periods, a decrease in the use of slash-and-burn agriculture, and promotion by extension agents has resulted in the large-scale adoption of an indigenous agroforestry system known as the 'Quesungual System', based on slash-and-mulch of vegetation, rotation of maize, sorghum and beans and inclusion of naturally regenerated trees and shrubs within cropped fields. This paper presents research on the effects of four common land use types (secondary forest, recently cleared agroforestry fields, mature agroforestry fields and silvopastoral fields) in the Quesungual area on soil macrofauna abundance and community composition. Sampling methods recommended by the Tropical Soil Biology and Fertility Institute were used to collect soil macrofauna in three representative fields of each type of land use, giving 12 study sites in total. Soil macrofauna communities were highly variable, both within representative fields, between representative

fields of the same type, and amongst land uses. Soil macrofauna density ranged from an average of 1637 $\pm$ 359 individuals m^{-2} for young Quesungual fields to 831 $\pm$ 199 individuals m^{-2} in secondary forest sites. Silvopastoral fields and older Quesungual fields recorded intermediate values of 1508 $\pm$ 390 individuals m^{-2} and 1182 $\pm$ 233 individuals m^{-2} respectively. Myriapoda and Isoptera were consistently affected by conversion of forest to agricultural land uses, decreasing and increasing in abundance respectively. At depths below 10 cm, soil macrofauna communities appeared relatively similar in all three agricultural uses, but differed from secondary forest. All land uses surveyed contained substantial soil macrofauna communities, which may be the result of incorporation of diverse organic matter inputs in the form of mulch pruned from trees, diverse vegetation and a continuous litter cover.

INTRODUCTION

Concerns have been raised by many as to how agricultural areas will be able to meet and sustain increased demands for food by the world's people while avoiding further dramatic declines in biodiversity and soil fertility (Matson et al. 1997, Swift 1997). This concern is perhaps most urgent in developing tropical lands where rural populations with few resources continue to grow while available land becomes scarcer, and/or increasingly degraded and nutrient-depleted (Beare et al. 1997, Hauser et al. 1997, Cherrett 2001). Multiple cropping systems have been described as agricultural diversification in time and space (Altieri 1994). Based on the results of other studies, the use of multiple crops and structural forms is likely to create a more spatially and temporally heterogeneous soil environment in comparison to modern, mechanised, monocultural agriculture, which may lead to a diversification in soil fauna due to greater availability of habitats and organic matter (Lavelle and Pashanasi 1989, Netuzhilin et al. 1999, Vohland and Schroth 1999, Saetre and Bååth 2000, Lavelle et al. 2001, Barros et al. 2002, Barrios and Trejo 2003). Agricultural systems that promote diversity and abundance of soil fauna may promote increased soil quality and productivity, because soil fauna can improve soil fertility due to the effects of their activities on soil physical, chemical and biological properties (Beare et al. 1997, Lavelle et al. 2001). The soil environment represents one of the most biologically diverse habitats on earth (Giller et al. 1997), and the manipulation of soil fertility using soil's biological resources has the potential to increase productivity in poor areas (Swift 1997). However, the relationships and mechanisms of interaction between soil biodiversity, soil quality, environmental characteristics, land-use and management techniques remain unclear.

The information presented in this paper is part of a broader research project that investigates the interaction between multi-crop agriculture and soil macrofauna, by looking at the relationship between land-use and soil macrofauna diversity and abundance in an area of western Honduras. Soil macrofauna (soil-dwelling organisms between 2 and 20 mm in length) are highly influenced by human activity and play an important part in maintaining a healthy soil ecosystem through their effects on soil structure and distribution of food resources and habitats for other organisms, particularly microorganisms (Jones et al. 1994, Beare et al. 1995, Lavelle et al. 1997, Matson et al. 1997, Lavelle et al. 2001). The dominant land use of the study area is an agroforestry system, called the "Quesungual System" after the locality where it was first found (Hellin et al. 1999). The Quesungual agroforestry system is found in the zone surrounding the village of Candelaria, in southern Lempira Department, western Honduras, close to the El Salvador border. The landscape in this region is very hilly, with steep slopes and shallow soils that are susceptible to erosion (Hellin et al. 1999). Annual rainfall, which falls primarily between early May and October, varies between 1400 mm and 2200 mm (Cherrett 1999). Farm sizes are small, averaging around two hectares (Cherrett 1999). The system incorporates crop rotation of maize, sorghum and beans, slash-and-mulch of vegetation, and a diverse array of naturally regenerated trees and shrubs within the cropped fields (Cherrett 1999, Hellin et al. 1999). Some of the trees are pollarded, and some left to grow due to their value for fruit or timber (Cherrett 1999, Hellin et al. 1999). Material pruned from trees is left on the ground as mulch through which the crops are sown (Hellin et al. 1999). The system appears to have been locally successful in combating seasonal soil water deficits, erosion, soil degradation and low crop yields, which were significant problems under the previous system of slash-and-burn agriculture (Ruben and Clercx 2003). Quesungual agroforestry is the dominant land use in a mosaic landscape of agroforestry fields of varying ages, pasture fields, newly slashed/mulched fields, fallow of varying ages, secondary forest, bare rocky areas, human settlements, roads and drainage lines. Pasture fields are used for grazing cows, and generally also include many trees (hence the term silvopastoral).

The overall hypothesis of the research project is that the Quesungual agroforestry system, through its use of structurally and taxonomically diverse plant species, diverse organic matter inputs, and crop rotation is creating a spatially and temporally heterogeneous soil environment, which leads to multiple niches for soil macrofauna and allows for increased soil biota abundance and diversity. This paper addresses the question of whether the Quesungual agroforestry system has a significantly different effect on soil macrofauna than other common land uses in the area, using a set of farms from four land uses: secondary forest or guamil (the local term used for fallow), Quesungual fields cleared from forest less than two years ago; fields cleared more than 10 years ago, and fields converted to pasture that were previously under Quesungual agroforestry.

Other researchers have found evidence that land use does affect soil macrofauna, through changes in vegetation structure, organic inputs and levels of physical disturbance (Lavelle and Pashanasi 1989, Black and Okwakol 1997, Netuzhilin et al. 1999, Barros et al. 2002). Barros et al. (2002) sampled macrofauna in disturbed forest and four common land use types (fallow, annual cropping, agroforestry and pasture) in the Brazilian Amazon. They found lower density of invertebrates in forest and pasture systems compared with fallow, agroforestry and annual cropping systems. Lavelle and Pashanasi (1989) also found a reduction in macrofauna density in pastures compared to other land uses in the Peruvian Amazon. Black and Okwakol (1997) noted that termites are often more abundant and diverse in older fallows than in crops or younger fallows. In an indigenous shifting cultivation system of Venezuela, soil arthropod communities in recently cleared plots were similar to those found in forests, and became increasingly dissimilar over time (Netuzhilin et al. 1999). Based on the results of these studies, pasture fields should be characterised by relatively high earthworm density, and low overall abundance and diversity of other macrofauna in comparison to agroforestry. Passing through a chronosequence from secondary forest to young agroforestry fields to older agroforestry fields, overall macrofauna density should increase with a change from forest to agroforestry, decreasing with time under cultivation. Such an increase could be the result of increased organic matter inputs due to mulching. Agroforestry fields and secondary forest are expected to retain a high proportion of animals in the litter layer and upper soil, due to physical protection from mulch and litter.

METHODS

In August and September of 2004, a set of representative Quesungual agroforestry farms of varying ages (less than two years of continuous cropping, and more than ten years of continuous cropping), silvopastoral farms and fallow sites were chosen. Three farms were included within each category. A transect of 90 metres with a random origin was set up to cover a representative area of the farm, and sampling points were located every ten metres along this transect. Sample points were marked permanently with a stake and co-ordinates were recorded with a GPS unit. Soil macrofauna were sampled at each point using a 'soil monolith' of 25 x 25 x 30 cm, based on standard methodology endorsed by the Tropical Soil Biology and Fertility Programme (TSBF) (Anderson and Ingram 1993, Swift and Bignell 2001). At each sampling point, a quadrat of 25 cm by 25 cm was marked out using a wooden frame. The litter layer was carefully collected from within this area, and placed in a plastic bag with a corresponding label. A trench was then dug around the quadrat, starting a few centimetres away from the quadrat, with the wooden frame left in place for reference. Once the trench had reached a depth of 30 cm, the sides of the monolith were quickly but carefully cut down. Three layers of soil of 10 cm in depth were then cut from the block using a sharp knife, and placed in plastic bags. In this way, four samples were collected from each sample point: the litter layer, 0-10 cm, 10-20 cm and 20-30 cm. The litter and soil samples were then hand sorted for invertebrates on site, and all invertebrates larger than 2 mm were removed and stored in 70% alcohol. Earthworms were kept separate and stored in 10% formol. In the laboratory, invertebrates were sorted to a broad taxonomic grouping (generally to Order level), counted and weighed. A correction factor was applied to biomass values due to the loss of weight from specimens during fixing (19% for earthworms, 9% for ants, 11% for beetles, 6% for arachnids, millipedes and centipedes and 13 % for other macrofauna) (Decaëns et al. 1994).

In addition to soil macrofauna, at each sample point measures were taken of litter properties, topography, soil properties and vegetation. Detailed results for these properties are not reported here. Litter measurements were taken including litter cover, litter depth and litter type. Topographical features were assessed, including slope, aspect, hillslope position, plan-form of hillside and cross-slope hillside position. Representative soil profiles were described for each site. Soil samples were air-dried and stored for later analysis of organic matter content, soil texture and soil aggregate stability. The tree and shrub component of the vegetation was also quantified. All trees and shrubs within a radius of 5 metres of the sample point were identified, noted as pruned or free-growing (form) and the diameter recorded. The distance to the closest tree was also noted, as was its species, form and diameter.

RESULTS

General vegetation characteristics

The four types of land use surveyed differ in the abundance and diversity of tree species. Mean tree densities in relatively new farms (2262 ± 227 ha^{-1}) are similar to those found in secondary forest (2274 ± 224 ha^{-1}), while tree density falls sharply in older farms (1053 ± 114 ha^{-1}) and further in silvopastoral farms 492 ± 60 ha^{-1}). A similar drop in species richness occurs along the same sequence, from 35.0 ± 6.4 species per transect in secondary forest, 25.7 ± 4.3 per transect in young Quesungual farms, to 13.3 ± 0.8 species in older Quesungual farms and 14.3 ± 1.8 species per transect in silvopastoral sites.

Overall invertebrate abundance and density

During the wet season of 2004, a total of 9673 invertebrates were sampled from the 12 sites with a net biomass of just over 167 grams. On a per farm basis, the number of individuals ranged from an average of 600.0 ± 218.8 per m^2 at one of the fallow/secondary forest sites, to 2945.6 ± 916.3 per $m^2$for one of the recently cleared Quesungual agroforestry fields, with considerable variation both within and between sites, as shown in Table 1. Highest macrofauna density occurred in younger Quesungual farms, followed by silvopastoral farms, older Quesungual farms and finally fallow sites. Biomass was also highly variable, from a low of an average 2.12 ± 0.48 grams per m^2 at one of older Quesungual fields, to a high of 101.10 ± 24.05 grams per m^2 at another recently cleared field. Biomass tended to be greatest in Quesungual farms of less than two years of age, followed by older Quesungual farms, silvopastoral farms and finally fallow sites. Sites with high biomass had large numbers of earthworms.

Table 1: Average abundance and biomass of invertebrates for each of the sites sampled.

Farm Type	Farm Site Name	Average Abundance per m^2	Average Biomass per m^2 (grams)	Number of samples
Quesungual < 2 years	Young Farm Site 1	814.40 ± 95.12	101.10 ± 24.05	10
	Young Farm Site 2	1152.00 ± 322.63	9.08 ± 2.76	10
	Young Farm Site 3	2945.60 ± 916.30	15.39 ± 3.98	10
	All sites	**1637.33 + 358.78**	**41.86 ± 11.09**	30
Quesungual >10 years	Mature Farm Site 1	1585.60 ± 553.64	12.50 ± 3.32	10
	Mature Farm Site 2	1112.00 ± 246.01	48.69 ± 12.72	10
	Mature Farm Site 3	849.60 ± 355.31	2.12 ± .048	10
	All sites	**1182.40 ± 232.87**	**21.20 ± 5.62**	30
Silvopastoral	Silvopastoral Site 1	1510.40 ± 709.94	7.34 ± 2.31	10
	Silvopastoral Site 2	2332.80 ± 886.8	30.70 ± 7.22	10
	Silvopastoral Site 3	681.60 ± 175.27	5.31 ± 2.06	10
	All sites	**1508.27 ± 390.31**	**18.13 ± 3.31**	30
Fallow (Guamil or 2º Forest)	Fallow Site 1	600.00 ± 218.81	13.23 ± 4.56	10
	Fallow Site 2	1214.40 ± 545.47	12.90 ± 4.22	10
	Fallow Site 3	680.00 ± 115.78	9.62 ± 1.62	10
	All sites	**831.47 ± 199.21**	**11.91 ± 2.09**	30

Vertical distribution

The vertical distribution of individuals was relatively similar for all land uses (Figure 1). The fields surveyed had an average of just over 50% of individuals at depths of 10 cm or below. This was driven largely by high numbers of Isoptera and Hymenoptera at depths greater than 10 cm (almost 70% of all termites and around 50% of all ants). Almost 80% of earthworms were found at depths of 0-10 cm. The proportion of all macrofauna in the litter decreased from 9.8% in secondary forest to 1.4% in Silvopastoral sites.

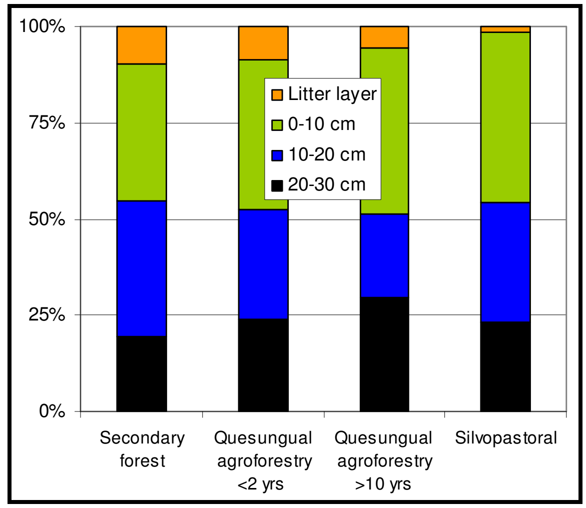

Figure 1: Relative proportions of macrofauna in each soil and litter layer sampled.

Figures shown are total figures for all three sites in each farm type.

Community composition

There was also a high degree of variation in the composition of the macrofauna community at each site sampled. Overall, Isoptera (termites) were the most abundant group, making up 50.5% of invertebrates sampled. Hymenoptera (ants) were the second most abundant, at 21.5%, followed by Oligochaeta (earthworms) at 11.8%, Coleoptera (beetles) adults and larvae at 4.9%, and Myriapoda (millipedes and centipedes) at 4.8%. Earthworms in particular tended to be locally very abundant with a patchy distribution, with some sites recording over 400 individuals m^{-2} and others recording fewer than 20 m^{-2}.

The data shown in Figure 2 demonstrate how relative proportions of the major groups vary with land use. For the whole depth of soil and litter to 30 cm, of the three agricultural uses, young Quesungual farms had the highest abundance of most taxonomic groups, with the exception of Hymenoptera and Isoptera, where silvopastoral farms scored highest. Abundance of Myriapoda was highest in secondary forest, and decreased under agricultural use. Conversely, Isoptera consistently increased in number with conversion to agriculture. Oligochaeta were more abundant in Quesungual fields than in either forest or pasture. In the litter layer, young Quesungual farms had the highest abundance for all groups, except for Myriapoda, which were most abundant in secondary forest. Silvopastoral farms had the lowest abundance for all groups in the litter layer. For the upper soil layer of 0 to 10 cm, the relative abundance of Hymenoptera, Isoptera and Coleoptera was generally high in the three agricultural uses compared with secondary forest. Younger Quesungual farms had the highest abundance of both Isoptera and Hymenoptera, and pasture sites scored highest for Oligochaeta. At soil depths between 10 and 30 cm, the three agricultural uses showed very similar patterns of relative abundance for most groups, although these are notably different from those in secondary forest sites. Secondary forest sites had the highest abundance of Hymenoptera, Myriapoda and adult Coleoptera at these depths.

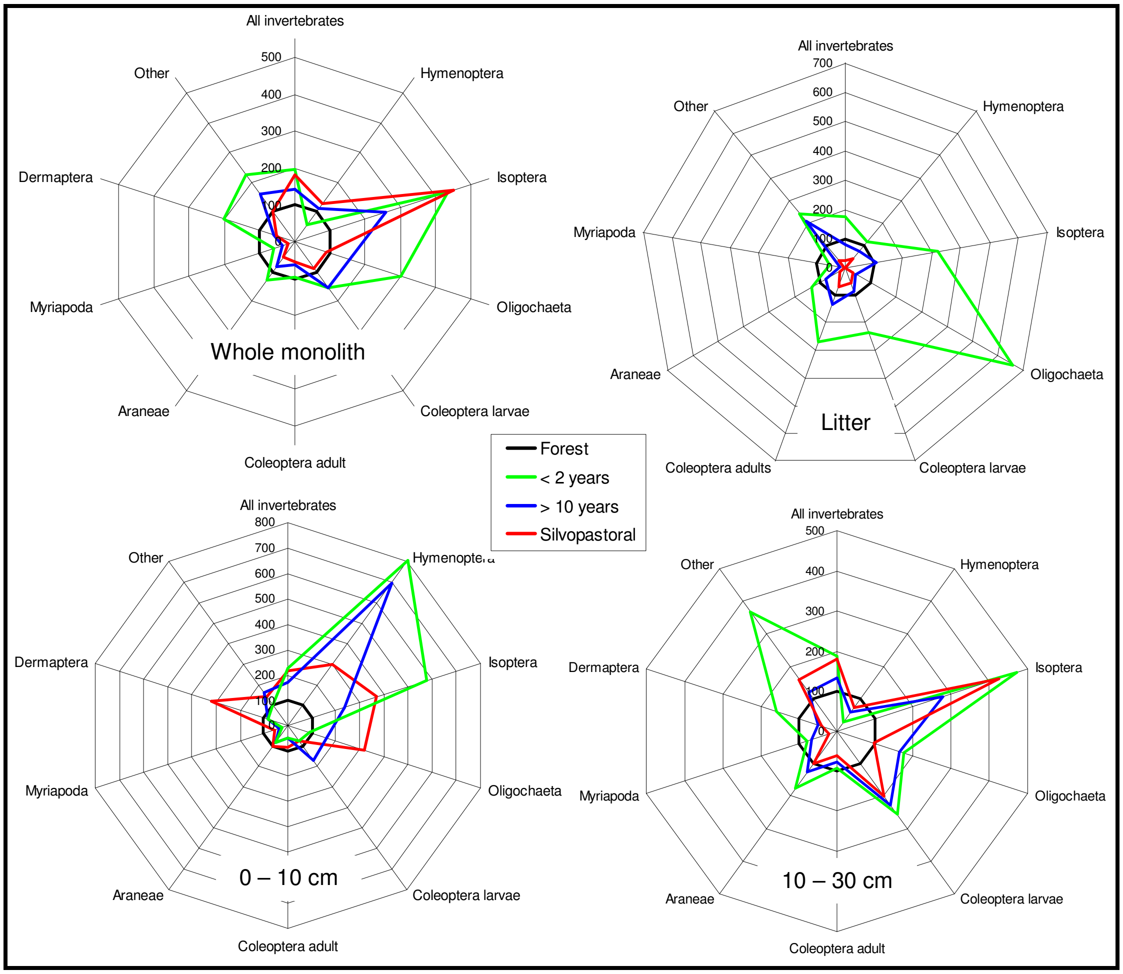

Figure 2: Relative abundance of the all invertebrates and the major groups at varying depths for the four land uses.

The abundance in fallow/secondary forest sites was used as the standard value of 100%, as all farms pass through this stage prior to being cleared. Figures shown are derived from the total abundance at each of the three sites for each type of land use. For example, if a total of 500 Hymenoptera were counted from the 10 monolith samples at the three fallow/secondary forest sites (n=30), 750 were counted at the three silvopastoral farms, and 100 were counted at Quesungual farms of less than two years, Hymenoptera would receive a score of 100% in the fallow site, 150% at the silvopastoral site, and 20% at the Quesungual farm site.

DISCUSSION

A variety of biophysical factors are likely to influence the distribution of soil fauna, with the result that soil fauna communities are highly variable both within fields, between replicate fields, and between land use types. Despite the highly variable nature of the data, some observations can be made by way of comparing this system with other studied systems. Biomass was not highest, nor was density lowest, under pasture, as expected from previous studies. This may be due to the inclusion of trees within pasture fields, which may not have been present in such high numbers in pasture fields in other studies. It may also be due to the location of pasture fields within a mosaic landscape of agroforestry fields and forest, which may act as habitat refuges for invertebrate populations. The relatively low density and biomass values ascribed to secondary forest in comparison with agroforestry concur with Barros et al.'s (2002) findings, and may also be a result of increased organic inputs into agroforestry systems, in the form of mulch from pruned trees. This is also in line with the results of a seven-year study in New Zealand, which showed that agricultural intensification was not consistently detrimental to soil fauna, and that soil macrofauna responded to changes in the quality and nature of organic matter input associated with agricultural use (Wardle et al. 1999).

Engaging only in broad-scale analysis of the type of data presented here is likely to miss many of the subtle patterns that emerge by looking at the data in a more detailed manner, as shown in the descriptions of vertical distribution and relative proportions of invertebrate groups. Different ecological and taxonomic groups of soil fauna can be expected to respond in different ways to changes in environmental conditions. The large proportions of individuals present at soil depths between 10 and 30 cm for all land uses was higher than expected, and seems to have been a result of high levels of ant and termite activity at depth in many farms. The dominance of earthworms in the 0-10 cm layer, particularly in pasture sites, may indicate high soil turnover and availability of organic matter at this depth. The decrease in the proportion of litter invertebrates along a gradient from secondary forest through agroforestry and pasture may reflect migration by litter fauna to greater depths as physical protection from environmental fluctuations decreases, as noted by Lavelle and Pashanasi (1989).

With regard to the abundance of taxonomic groups in land use types, myriapods are consistently reduced in the litter and at all soil depths under agricultural land use, while termites consistently increased in abundance, particularly in agroforestry systems. Ants greatly increased their number in agricultural uses compared to forests in the upper soil, while differences were not as great at other depths. Other studies have also found that myriapod density is significantly affected by land use (Sevilla Guío et al. 2004), and that social insects such as ants and termites increase with cultivation (Barros et al. 2002). Both changes are likely to be related to changes in quantity and diversity of organic matter inputs and habitat availability. The similarities amongst agricultural land uses in the relative proportions of individuals at depths of 10 to 30 cm are very interesting, as it suggests that community structure and availability of food resources is fairly similar amongst all agricultural uses at greater soil depths. This would indicate that there is a substantial and consistent difference in the soil ecosystem between secondary forest and agricultural uses. This may be related to the removal of particular strata of the forest and changes in microclimate related to vegetation structure change, or it may be related to the loss of other forest components such as vertebrate fauna or other predators. It is possible that at lower soil depths, the seasonal fluctuation in available organic matter from pruning is not as great as it is in the upper soil level, and accordingly the soil fauna community does not fluctuate to the same degree.

The patterns of distribution and abundance of soil fauna are unlikely to be easily explained by any one variable, but rather a combination of biophysical and management factors will play a role in shaping soil macrofauna dynamics. Multivariate analysis of the data is now required to determine the combination of variables that bears the greatest influence over macrofauna distribution. The greatest challenge, and the most important in terms of local management of soil biological resources, remains to translate the results of this study into a set of management guidelines that can be used by local farmers to manage soil macrofauna abundance and diversity within their fields, with the goal of improving soil quality and soil fertility.

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