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Shade over coffee: its effects on berry borer, leaf rust and spontaneous herbs in Chiapas, Mexico

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Abstract

The objective of this research was to determine the relationships between different ecological features of shade and the incidence of coffee berry borer, coffee leaf rust and spontaneous herbs in rustic coffee plantations in Chiapas, Mexico. Thirty-six 10 m by 10 m plots were established within coffee plantations. The following variables were measured or estimated: number of vegetation strata, percent canopy cover, direct, diffuse and total sunlight below the canopy, plant species richness and diversity, shade tree/shrub density, altitude, aspect, basal area, yields, percentage of coffee berry borer (*Hypothenemus hampei* Ferr), percentage of coffee leaf rust (*Hemileia vastatrix* Berk & Br.), percentage of spontaneous herb cover and the presence of paths and runoffs. Results showed a complex agroforestry system, composed of five strata. Coffee berry borer and coffee leaf rust incidence averages were 1.5% and 10.1%, respectively. Average spontaneous herb cover was 34.1%. Coffee leaf rust percentage correlated positively with the coffee berry borer. Number of strata of shade vegetation correlated negatively with leaf rust, while the presence of paths correlated positively with the leaf rust. Species richness and diversity correlated negatively to broad-leaf-herb cover and the presence of runoffs correlated positively to this last variable. Shade tree density (> 10 cm d.b.h.) correlated negatively to linear-leaf-herb cover. Percentage of shade cover, light, coffee density, aspect, stand age, basal area and yields were not correlated to pest, disease and weeds. Results support the ecological theory that postulates that diversity and structural complexity in mixed plant systems maintain a healthy system.

Introduction

Coffee (Coffea spp.) is among the most important cash crops in the world. Insect pests, disease and weeds are important factors that limit coffee yields. In Mexico the coffee berry borer, the coffee leaf rust and weeds are the most important pest and disease problems for coffee production. The coffee berry borer (*Hypothenemus hampei* Ferr.) is a Scolytid beetle that bores into both coffee berries and seeds; it is considered the most important insect pest and the greatest economic threat to this crop (Baker 1984). The leaf rust is caused by a fungus (*Hemileia vastatrix* Berk. & Br.). Weeds have been reported to be responsible for around 50% of the labour costs in organic coffee in Latin America (Püelschen and Lutzeyer 1993), especially when grassy weeds invade coffee plantations. In this work we prefer to call them spontaneous herbs instead of weeds, since producers do not perceive negative effects from these plants.

Worldwide the coffee agroecosystem has been experimenting with an intensification process for the past three decades (since the early 1970s). This process consists in the reduction or complete elimination of shade trees (Perfecto et al. 1996). Originally, it was based on the assumption that high levels of shade

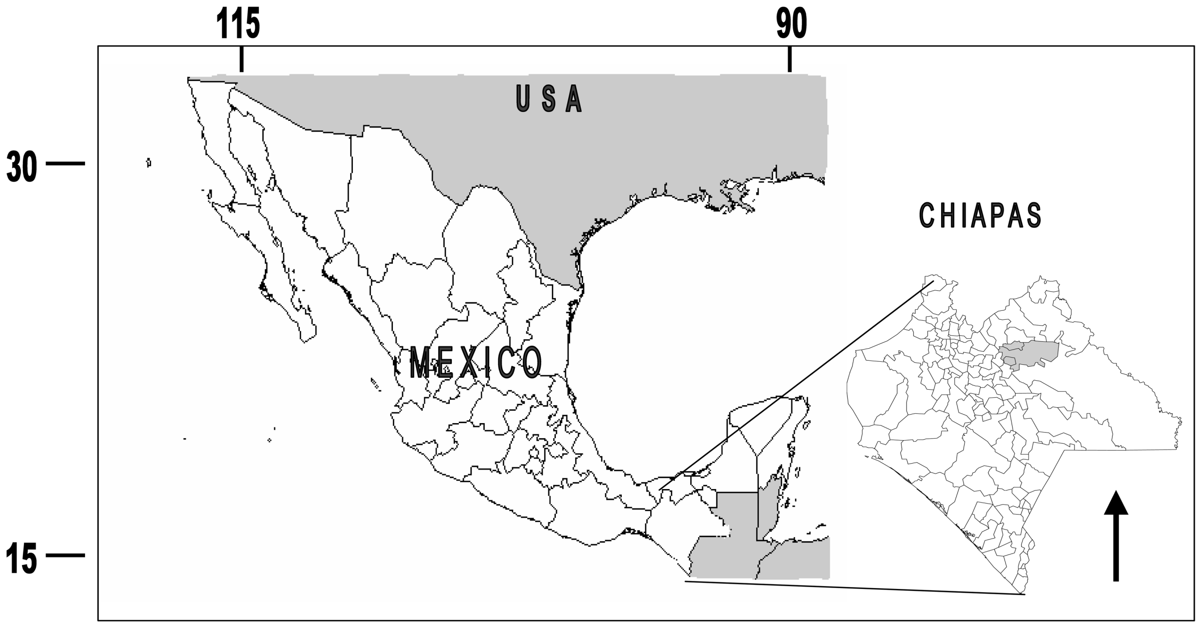

Figure 1. Study area. Municipality of Chilón, Chiapas, Mexico.

promote the incidence of leaf rust and that yields and shade were negatively correlated. Today the effects of shade cover on coffee pests, diseases and yield are less clear. Some authors have reported an increase in pest problems and diseases with increasing light (Wringley 1988), while others have reported the opposite (Eskes 1982). With respect to weeds, research to determine the effects of shade on weed biomass and composition have suggested that shade inhibits weed infestation and shifts weed composition (Jiménez-Avila 1979 Nestel 1992 Beer et al. 1998).

It seems that light is only one of the factors that affects productivity in coffee systems, but other factors related to physical shade structure and diversity can also affect the health of the system. It has been pointed out, for crops in general, that the complexity of physical structure and diversity of the plant canopy can decrease herbivore abundance and/or increase natural enemy abundance (Perrin 1977 Altieri and Letorneau 1982). There is also evidence that intercrops reduce diseases compared to monocultures (Moreno and Mora 1984). Unfortunately, relationships among ecological attributes of shade vegetation and incidence of pests, diseases and weed populations in coffee agroecosystems have been scarcely studied.

The objective of this research was to evaluate the effects of the ecological features of shade on the incidence of coffee berry borer, coffee leaf rust and spontaneous herb cover in rustic coffee plantations in the northern Tzeltal zone of Chiapas, Mexico. This work was conducted on-farms as part of the project developed by the Producer's Union Pajal Yak'actic and El Colegio de la Frontera Sur in Chiapas, Mexico.

Methods

Study area & selection of sampling sites

The study area included three communities from the Chilon Municipality in the state of Chiapas, Mexico (Figure 1): Muquenal, Alan K'antajal and Segundo Cololteel. These communities are located in the subtropical zone, at an altitude gradient ranging from 600 m to 1100 m a.s.l. The area has an average annual temperature between 22 °C and 24 °C and average annual rainfall of 2000 mm. The natural vegetation corresponds to tropical forest and mountain rainforest. Soils are generally recent, thin and stony. Local people (Tzeltal Mayan-descendants) identify two soil types, the 'jii'lum' and the 'chavec'lum' which correspond to sandy and loamy soils, respectively. Most of the population is devoted to agriculture, particularly to the cultivation of maize, beans and coffee.

Coffee is grown under the shade of natural vegetation by small producers (<5 ha), in low-input farming systems. Farmers do not fertilise, nor use any other chemical inputs nor control shade by means of pruning. The agricultural practices consist of hand weeding twice a year, irregular coffee bush pruning, and coffee harvesting. In addition, farmers collect fuelwood and other goods from coffee plantations for domestic consumption (Soto-Pinto et al. 2000). Farmers have on average a coffee plot of one hectare with a mixture of four coffee varieties: Bourbon, Caturra, Mundo Novo and Typica, planted at an average density of 1900 shrub per hectare.

In August 1997 a total of thirty-six 10 by 10 m sampling plots were established in a gradient between 23 to 70% of shade cover, since producers do not have plots with un-shaded coffee. The square size was determined in order to relate community structure and canopy cover (Anderson 1964), based on the assumption that resulting image from hemispherical photographs gives an almost 180 degree view in all directions, with the zenith at the centre and the horizon at the edges of the photograph (Roxburgh and Kelly 1995). The plots were distributed within an altitudinal gradient ranging from 600 to 1100 m. Vegetation variables as well as pest and disease and spontaneous herb densities were measured or estimated in each plot. In addition, altitude, slope and aspect were recorded for each plot. Aspect was measured in grades and transformed to a numerical scale between zero and one. Zero was assigned to south aspects (dry hills) and number one to north aspects (humid hills). The following formula was used (Roberts 1986):

$$e_t = \frac{(cos(e_0 - 30°) + 1)}{2}$$

Where:
e_t = transformed aspect
e_0 = observed aspect

Vegetation variables

In order to characterise shade structure, a forest inventory at each of the 36 plots was conducted measuring the following vegetation variables: coffee bush density, shade species richness, shade species height and diameter at breast height (d.b.h).

Frequency, abundance and density of shade species (coffee shrub not included) were divided into three form classes: herbs as tall as or taller than the coffee bushes; shrubs or trees <10 cm d.b.h; shrubs or trees >10 cm d.b.h. A vertical profile was drawn for each plot to register the number of shade strata by means of dividing the plot in four sub-quadrants. Margalef diversity index for the vegetation (not including coffee) was calculated by the following formula (Margalef 1958):

$$D = S - 1/\log N$$

Where:
D = diversity index
S = species number
N = number of individuals

In 1998 two hemispherical photographs were taken upwards from the middle of each plot, at a height of 1.60 m according to Anderson (1964). The first photograph was taken during the dry season (February, 1998) and the later one was taken in the rainy season (September, 1998). A Pentax K-1000 camera with Pentax fish eye-lens, light sensor, and black and white Fuji ISO 100 film were used.

Photographs were scanned and edited in order to estimate canopy coverage, and direct, diffuse and total photon flux density below the canopy using the Hemiphot computing program (See Soto-Pinto et al. (2000)). This program is based upon the principles of solar geometry and atmospheric physics, combined with the geometry of hemispherical lenses for any data of aspect, latitude, longitude and altitude. It includes the use of grey scales to estimate penumbra effects. The mean percentage of cover and the mean of total light under the canopy from both photos were used for the analysis.

Estimates of berry borer, leaf rust incidence and spontaneous herbs

The percentage of the coffee berry borer incidence (BB) was estimated by counting the total number of fruits, including infected berries of five randomly selected plants in each plot during the 1997–1998 and 1998–1999 seasons. The percentage of coffee leaf rust (LR) infected leaves was estimated for the 1998–1999 season, by counting the total number of leaves, including those leaves attacked by rust observed from four twigs taken at random from five plants.

Spontaneous herb cover (SH) was obtained by placing three 50 by 50 cm square frames randomly in each sub-quadrant, totalling 3 m sampled in each 10 × 10 m plot, and visually estimating the percentages covered by linear-leaf and broad-leaf spontaneous herb before the second hand-weed cleaning in 1998.

Voucher specimens were collected and deposited in ECOSUR's Herbarium. The presence of paths near the sampling plots and water runoffs were recorded for each plot.

Statistical analyses

In order to decrease the variability, percentile variables such as coffee berry borer, coffee leaf rust and spontaneous herb cover were square root transformed before performing statistical analyses.

Data on vegetation attributes, incidence of coffee berry borer, coffee leaf rust and spontaneous herb cover were analysed through Correlation Analyses. Variables significantly correlated were analysed through Stepwise Regression, in order to fit curves. Duncan's Multiple Range Test by number of strata for variable leaf rust incidence was run. Mean difference between presence and absence of paths and runoffs for leaf rust, berry borer and spontaneous herb cover were analysed though T Test. The relationship between shade structure and yield was analysed previously by Soto-Pinto et al. (2000).

Results

Vegetation structure

Rustic coffee plantations showed a complex vegetational structure. Five strata composed the associated vegetation (Figure 2). The herbaceous stratum was mainly composed of spontaneous herbs, coffee seedlings and seedlings of woody species of natural vegetation. Two shrubby strata were observed under the canopy: the first ranging from 1 to 3 m was mainly made up of coffee shrubs, tall herbs and some small fruit trees; the second shrubby strata ranging from 3 to 6 m was made up of fruit trees and thin woody trees (<10 cm d.b.h). The fourth stratum corresponds to large trees with canopies between 6 and 12 m (>10 cm d.b.h), receiving mainly lateral illumination or some direct illumination. The top stratum which ranges from 12 to 20 m high is made up of emergent trees (>10 cm d.b.h.) representing the upper canopy of the coffee stand. The mean shade tree height was 7.6 m (including shrubs and tall herbs), but there were trees up to 20 m high. A widespread distribution of shade trees was observed.

The coffee stands of the area presented an average density of 463 shade tree or shrub per hectare, varying from 100 to 1000 plants/hectare. The thin tree-density (understory trees <10 cm d.b.h. coffee shrubs not included) averaged 177 trees/shrubs per hectare and the thick tree-density (overstory trees >10 cm d.b.h.) averaged 286 trees or shrubs per hectare. The species list was presented by Soto-Pinto et al. (2000). Photon flux density varied between 7.9 and 37.1 mol m^{-2} day^{-1} and the mean yield of coffee production was of 835.8 g $plant^{-1}$ (approximately 1500 kg ha^{-1}) (Table 1).

Berry borer (BB), leaf rust incidences (LR) and spontaneous herb cover (SH)

The average coffee BB percentage for all plots was 1.5% (varying between 0.1% and 18.7% (Table 1). Most of the plots (89%) showed BB percentage to 4%, of these, 42% presented BB <1% and 47% presented between 1.1 and 4%; only 11% of the plots showed BB percentage >4%.

The percentage of coffee LR varied between 5.1% and 20.2% with an average of 10.1% (Table 1). More than a half of total plots showed LR incidence <10%; 37% had 10%–15% incidence; and only 6% had higher percentages of LR.

A mean of 34.1% spontaneous herb cover was found, varying between 0% and 86.6%. Of the total of spontaneous herb, 69% were broad-leaf herbs (in general Dicotyledons) and 31% were linear-leaf herbs (in general Monocotyledons). The linear-leaf-herb group was mainly composed by plants in the family Poaceae (Gramineae), while the broad-leaf-herb group was constituted by 23 families of plants, mainly represented by Asteraceae (Compositae), Fabaceae (Leguminosae), Amaranthaceae, Malvaceae, Solanaceae, and Verbenaceae.

Factors affecting BB, LR and SH

No significant correlation was found between the incidence of the BB and any of the vegetation variables (Table 2). A stepwise regression analysis showed a significant and negative estimate parameter for the relationship between BB and altitude ($r^2 = 0.40$; $p < 0.05$), suggesting that at higher elevation the BB is less of a problem.

For the incidence of the LR the only significant correlation was a negative correlation in number of shade strata (Table 2). Figure 3 shows the distribu-

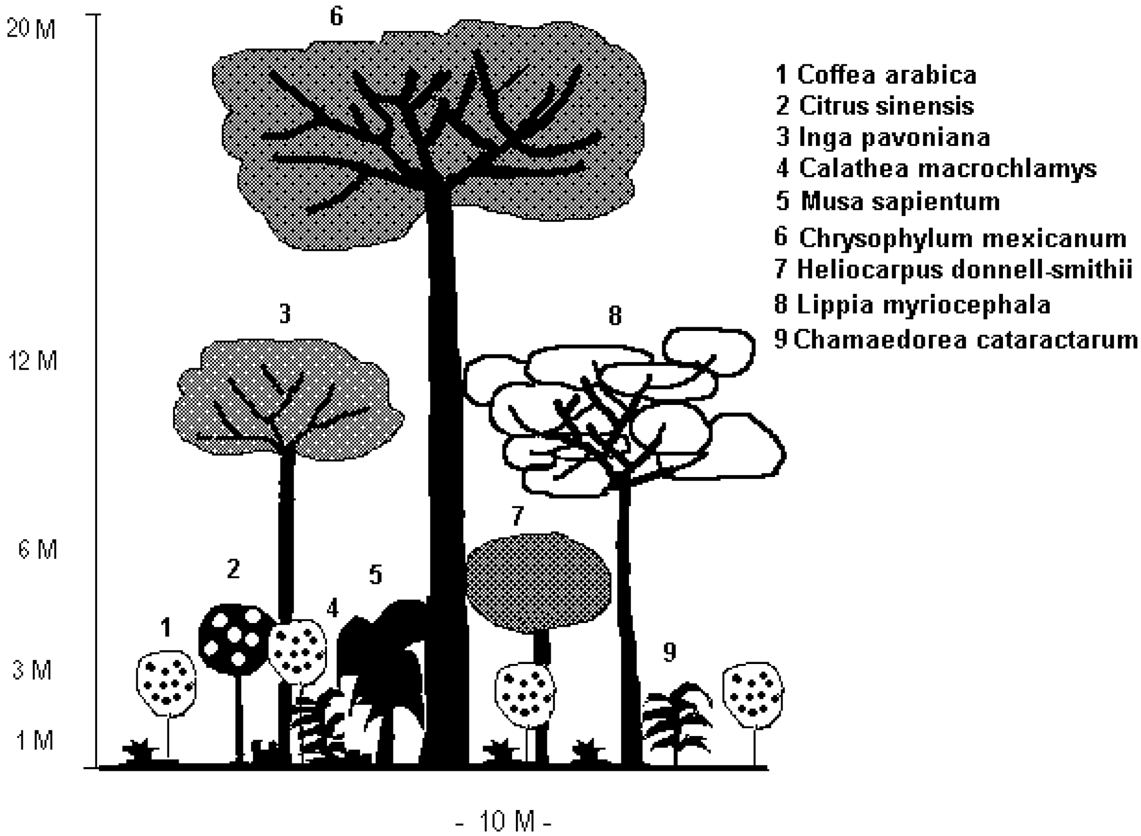

Figure 2. Average vertical profile of coffee stands, Chiapas, Mexico. Source: Reprinted Soto-Pinto et al. (2000) with permission from Elsevier Science.

Table 1. Parameters measured in 36 traditional coffee plots in Chilón, Chiapas, Mexico.

Variables	Mean	Minimum	Maximum	S.D.[1]
Coffee berry borer(%)	1.5	0.1	18.7	3.2
Coffee leaf rust (%)	10.1	5.1	20.2	3.6
Broad-leaf-weed cover (%)	23.6	0	63.3	14.7
Linear-leaf-weed cover (%)	10.5	0	73.3	14.0
Shade cover (%)	46.8	22.9	70.0	12.7
Total sunlight below canopy (mol m^{-2} day^{-1})	25.1	7.9	37.1	22.5
Mean shade tree height (m)	7.6	3.2	12.1	2.7
Non-coffee-thin trees <10 cm. d.b.h. (trees/ha)	177	0	500	142
Non-coffee-thick trees >10 cm. d.b.h. (tree/ha)	286	0	900	214
Total non-coffee-tree (tree/ha)	463	0	1000	222
Number of shade strata	2.6	1	4	0.86
Shade species richness in 100 m^2	3.5	1	8	1.9
Diversity index in 100 m^2	3.5	0	6.72	1.85
Coffee yields (gr. of clean coffee/plant)	835.8	58.6	2781	559.5

[1] Standard deviation.

tion LR incidence in relation to the number of shade vegetation strata. According to Duncan's Multiple Range Test, coffee plantations with 4 strata had significantly lower incidence of LR than coffee plantation with less than 4 strata ($p < 0.05$). In addition, LR incidence was significantly higher in plots where

Table 2. Correlation analysis between variables: Pearson Correlation Coefficients/Significance, in coffee plantations, Chiapas, Mexico.

Independent variables	Dependent variables			
	Berry borer (%)/p value	Leaf Rust (%)/p value	Broad-leaf-weeds (%)/p value	Linear-leaf-weeds (%)/p value
Coffee shrub density	0.24/0.15	0.12/0.46	−0.14/0.41	0.03/0.84
Number of shade strata	0.10/0.56	−0.34/0.04*	−0.20/0.23	0.01/0.95
Shade species richness	0.02/0.876	−0.18/0.29	−0.41/0.01*	−0.09/0.57
Shade species diversity	−0.03/0.85	−0.16/0.33	−0.34/0.04*	0.01/0.94
Shade cover	0.23/0.17	0.02/0.89	−0.02/0.86	0.08/0.60
Basal Area	−0.25/0.14	−0.09/0.61	−0.08/0.64	−0.19/0.25
Thick tree (>10 cm d.b.h.) density	−0.02/0.93	−0.11/0.49	−0.22/0.19	−0.32/0.05*
Thin tree (<10 cm d.b.h.) density	0.03/0.84	−0.02/0.90	−0.05/0.76	0.22/0.20
Total tree density	0.01/0.97	−0.12/0.46	−0.24/0.14	−0.17/0.31
Altitude	−0.40/0.05*	−0.24/0.14	−0.18/0.27	−0.07/0.67
Aspect	−0.26/0.12	0.05/0.73	0.03/0.81	−0.08/0.63
Total sunlight	−0.16/0.33	−0.12/0.47	−0.03/0.86	−0.08/0.62
Leaf rust	0.50/0.001*	1.00/0.0	0.08/0.60	0.11/0.51

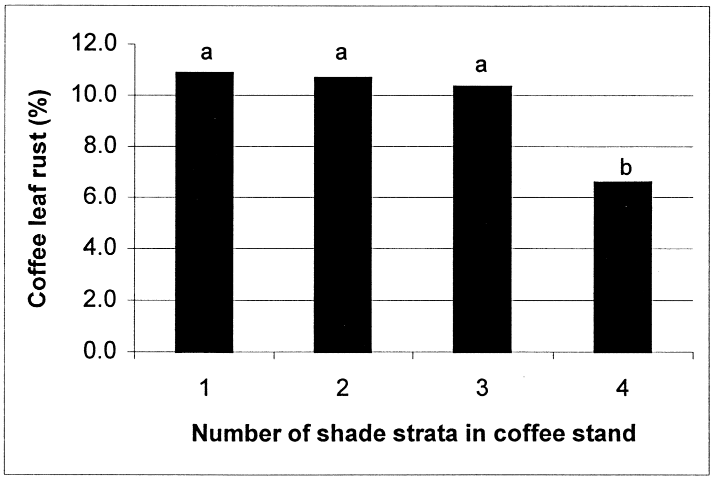

Figure 3. Coffee leaf rust in relation to number of shade vegetation strata in traditional coffee plantations. Mean separation based on Duncan's Multiple Range Test.

paths were present as compare to plots without paths (T-test; $p < 0.05$) (Figure 4).

By the other hand, tree species richness, diversity and tree density (of trees >10 cm d.b.h.) were all significantly and negatively correlated with percentage of SH (Figure 5, Table 2). Finally, the presence of runoffs significantly increased broad-leaf-herb cover (T-test; $p < 0.05$).

The effect of altitude, age, varieties and other structure variables on yields was discussed previously by Soto-Pinto et al. (2000).

Discussion

The incidence of BB and coffee LR were low in comparison to that reported by other authors. Avelino et al. (1991) reported 24% of coffee LR in Mexico; Brown et al. (1995) found 18% of coffee LR in Papua New Guinea; Barrera (Pers. Comm., 1999) found between 4 and 21% of BB in Mexico (Soconusco).

Total sunlight and shade cover did not have a significant effect on the incidence of coffee BB and coffee LR, although previous research has shown an ef-

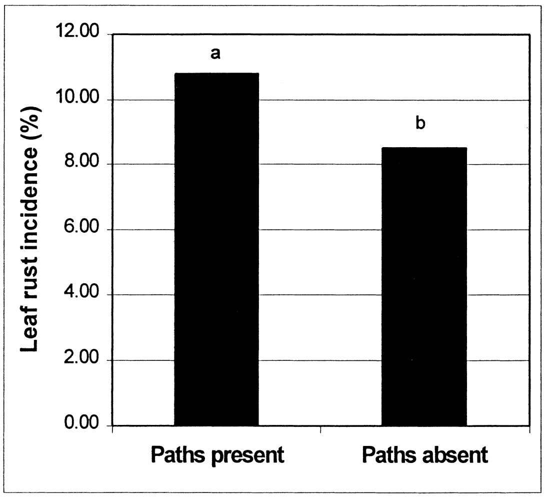

Figure 4. Percentage of coffee leaf rust in relation to the presence of paths inside the coffee stands.

fect. Wringley (1988) found that the incidence of the BB was favoured when shade was increased. Some authors have demonstrated an increase in coffee LR with increasing light (Wringley 1988) but, others have found the opposite (Eskes 1982). However, our results for LR coincide with those presented by Godínez (1997) who obtained a lesser incidence of LR in mixed shade coffee systems than in *Inga* monoculture shade and the same trend with *Mycena citricolor* due probably to vegetation structure and composition complexity.

The majority of plots (80%) showed low cover of spontaneous herb. There was not a decreased spontaneous herb cover with shade, as has been reported by other authors (Jiménez-Avila 1979 Beer et al. 1998). Furthermore, we found broad-leaf-herbs dominating over grassy herbs, coinciding with results of other authors who have reported a shift in weed species composition with increasing shade (Jiménez-Avila 1979 Beer et al. 1998). Additionally farmer herb management (two hand-weeding yearly), the use of herbs as food, medicine and forages among other uses, plus shade vegetation (average of 46.8%) promoted the presence of broad-leaf-herbs instead of Graminaceous flora. This could be due to the increase in environmental heterogeneity caused by differential canopy structure and composition and can promote an environmental patchiness resulting in niche differentiation for spontaneous herbs which does not let the dominance of one or few groups of herbs.

The presence of paths inside the coffee stands can act as a mean of dispersion for the fungus *H. vastatrix* and the presence of runoffs can add humidity to the soil, promoting the emergence of broad-leaf-herbs. In addition to environmental and management factors such as altitude and the presence of runoffs and paths, other factors given by ecological attributes such as, number of strata, shade tree density, plant species richness and diversity affect the incidence of the organisms studied. Results suggest that environmental and management factors, as well as shade diversity and physical structure may be responsible for the lower incidence of pest, disease and weeds, as has been previously suggested by Altieri and Letorneau (1982). Low percentages of coffee BB and coffee LR have been found in similar rustic systems in the region, which are characterised by diversity and structural complexity and low input of synthetic chemicals and low yields (Godínez 1997 Jarquín et al. 1999). Low percentages of BB could be due to the presence of generalist natural enemies, mainly generalist predators which are abundant in rustic coffee plantations such as ants, spiders or birds (Perfecto et al. 1996). In addition, the complex vegetation mosaic can provide habitats for antagonistic organisms such as fungi, bacteria or protozoa, which may control pathogenic organisms like coffee LR (Hodges et al. 1993).

Increases in number of strata, shade plant species richness, diversity and tree density will be translated into complexity. This complexity may act as a physical barrier for spore dispersal, mainly reducing wind speed, since it has been demonstrated that wind is the prime factor affecting spore transport (Aylor 1990 Nagarajan and Singh 1990).

Traditional coffee systems have been thought to possess a high capacity for resistance. Their structural and management attributes perform a variety of renewal processes and ecological services applicable in pest, disease and weed management as was proposed by Altieri (1993) and Moguel and Toledo (1996).

The fact that these coffee stands do not require additional control for BB, LR and SH due to the their low incidence suggests that these growers could potentially be certified as organic, a market whose demand is increasing (Püelschen and Lutzeyer 1993). Furthermore, these producers could in the future obtain shade coffee certification due to the structural complexity and diversity they maintain in the coffee agroecosystems.

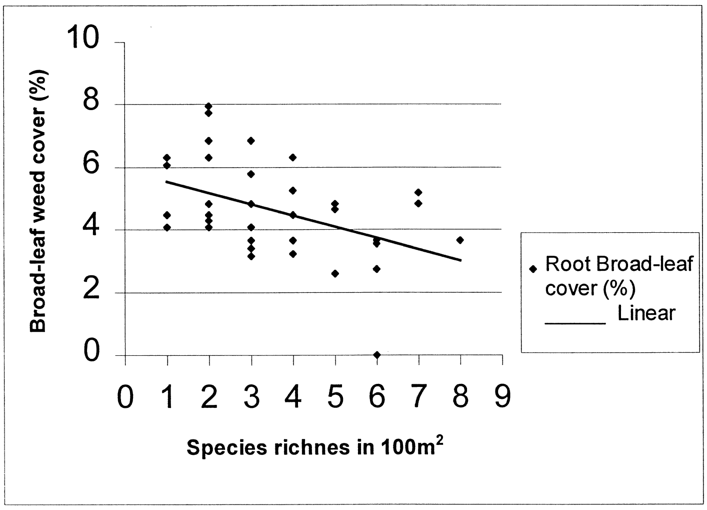

Figure 5. Effect of shade species richness on broad-leaf-weed cover percentage.

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