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Shade effect on coffee production at the northern Tzeltal zone of the state of Chiapas, Mexico

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Abstract

The necessity of on-farm research to assess the relationship between shade ecological features and yields has been broadly recognised. On this basis, a more sustainable coffee system could be developed, with better conservation of natural resources. An on-farm research project was conducted in the municipality of Chilón, Chiapas, Mexico, with the objectives of investigating the effect of shade structure on coffee grain yield and assessing the potential uses of associated plant species.

Results showed that shade cover percentage and coffee shrub density had significant effects on yields. Maintaining coffee shrub density as a constant, a regression equation related yield to percentage shade by a quadratic polynomial. Coffee density had a significant effect on yields but shade tree density had no effect. Coffee cultivar, age of coffee stand, species richness, shade tree density, basal area, slope and aspect did not have significant effects on coffee yields. Shade tree cover had a positive effect between 23 and 38% shade cover and yield was then maintained up to 48%. Production may decrease under shade cover >50%. A total of 61 shade species were found, with an average density of 260 trees per hectare, the majority of them being indigenous species, used as food, construction materials and as firewood. The role of ecological features associated with shade on yields and availability of natural resources obtained from coffee systems are discussed.

Keywords: Coffee; Cover; Shade; Agroforestry; On-farm research; Mexico

1. Introduction

Shade coffee systems, especially those that maintain a dense natural shade have been found to maintain a high level of biodiversity (Perfecto et al., 1996). Because of the potential of shade coffee as a refuge of biodiversity, coffee producers have been encouraged to maintain a dense, high diversity shade in their plantations.

Most of Mexico's coffee production is based on shade tree agroforestry. Several systems have been recognised depending on the type of canopy and the density of trees: broad sunlight monoculture systems, monospecific shade systems, diverse planted shade and systems under dense natural shade (Jiménez-Avila and Martínez, 1979; Moguel and Toledo, 1999). According to available data (Moguel and Toledo, 1999), coffee monocultures are mainly associated

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with medium and large farms which cover up to 30% of land devoted to coffee production in Mexico. Traditional systems (with dense natural shade and low-dense coffee shrub density) are associated with medium and small farms, with either communal or private land tenure systems making up to 70% of the land under coffee cultivation (Nestel, 1995; Moguel and Toledo, 1999).

The state of Chiapas ranks first in coffee production in Mexico with 23% of the national production. Seventy seven of its 101 municipalities produce coffee making up 163,695 ha with an average yield of 739 kg/ha (Rice, 1997).

The age of coffee stand and altitude can influence yields. However, few studies have been carried out which describe the effect of natural environmental factors, specially constraining factors (soil fertility, water availability, temperature) and their interactions with coffee yields (Beer et al., 1998). Most of the studies on coffee stand structure in relation to production levels have been conducted in experimental fields. Studies on producer plots are scarce and of the qualitative type (Muschler and Bonnemann, 1997).

It has been assumed, and to some extent documented, that the shade tree-crop association is beneficial ecologically as well as economically (Jiménez-Avila and Martínez, 1979; Barradas and Fanjul, 1984; Beer, 1987). The role of trees in the conservation of soils and watersheds is well established (Nair, 1989). Furthermore, shaded coffee plantations have been proposed as refuges for biodiversity because they can potentially preserve high diversity of organisms such as birds, arthropods, mammals and orchids (Aguilar-Ortíz, 1980; Morón and López-Méndez, 1985; Nir, 1988; Ibarra-Núñez, 1990; Gallina et al., 1996; Perfecto et al., 1996, 1997; Greenberg et al., 1997). More recently, the role of trees in carbon sequestration has been proposed as a means to increase the income of small coffee farmers in Mexico (Jong et al., 1995, 1997). Also the role of trees as a source of cash income though their potential to produce wood and fruits has been well documented (Beer, 1987; Escalante, 1995; Hernández et al., 1997).

On the other hand, it has been assumed that a high tree density will result in significantly lower yields for coffee producers. However no on-farm studies have been conducted to determine the relationship between shade and coffee yields. The need to investigate this relationship has been recognised as a priority by specialists in coffee agroforestry systems (Muschler and Bonnemann, 1997; Beer et al., 1998). The purpose of this investigation was to analyse the effect of shade structure on coffee yields and to assess the resource potential of the coffee plantations at the municipality of Chilón (northern Tzeltal zone) in the state of Chiapas, Mexico. This on-farm research was carried out as part of a collaboration between El Colegio de la Frontera Sur (ECOSUR) and the Pajal Yak'actic Union of producers.

2. Materials and Methods

2.1. Study area and selection of sampling sites

The study was conducted in the municipality of Chilón, Chiapas Mexico (Fig. 1). The study area is located in the subtropical zone characterised by a gradient from 800 to 1200 m asl, mean annual rainfall of 2000 mm, annual temperature average of 22°. Soils are recent, thin and stony. Tzeltal indigenous people identify two generic types of soils, the jii'lum and the chavec'lum which correspond to names for loamy sand and loamy soils, respectively.

A diagnosis questionnaire was used to gather socio-economic and technical information from 50 coffee producers. This questionnaire was used to identify technological variation and a shade gradient, which was verified in the field in order to select the study plots. Censuses, maps and photographs were also examined.

The northern Tzeltal indigenous coffee production system may be classified as an agroforestry system, which combines coffee shrubs with multi-purpose shade species. Producers own between 0.5 and 3 ha, which they plant in coffee. They plant a mixture of coffee cultivars, with one predominating: 'Bourbon', 'Caturra', 'Arabica' and 'Mondonovo'. Farmers in the region maintain shaded coffee stands and some patches with less shade but they do not have unshaded coffee. The less-shaded patches were used to establish low-shade plots. A total of thirty-six 10 m×10 m plots were established within a shade gradient ranging from 23 to 70% shade cover and within an altitude gradient ranging from 600 to 1100 m. These plots were distributed equally in accordance with coffee

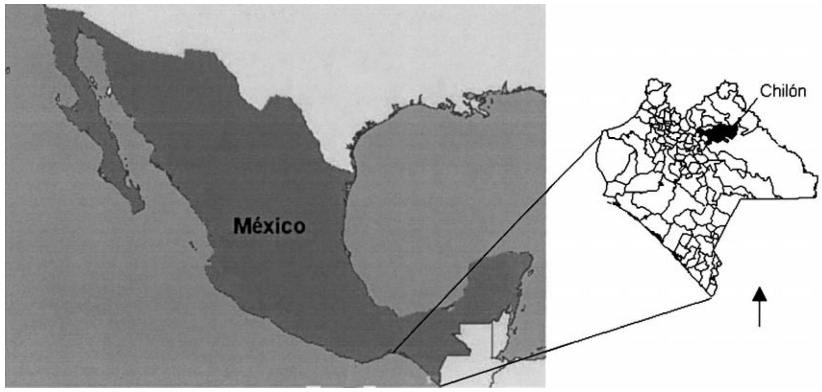

Fig. 1. Study area. Municipality of Chilón, Chiapas, Mexico.

plants age classes as follows: (1) from 2 to 6 years old; (2) from 7 to 11 years old; (3) from 12 to 15 years old; and (4) more than 15 years old. Altitude, slope and aspect were also recorded for each plot.

2.2. Coffee stand structure and measurements

At each of the 36 plots the following were measured: coffee bush density, plant species richness, shade species height and diameter at breast height (d.b.h). Basal area was calculated by means of multiplying diameter by height. Frequency, abundance and density of shade species were divided into live 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. A vertical profile was drawn for each plot to register the number of shade strata, and the treetop (crown) shapes and position within the canopy, according to Hutchinson (1988). Plant species uses were recorded based on in-site informal interviews with the producers. Samples of shade species present in each plot were collected, and voucher specimens were identified and deposited in the El Colegio de la Frontera Sur's Herbarium.

In 1997, two hemispheric photographs were taken upwards from the middle of each plot, from a height of 1.6 m, one in the drought season (February) and one in the rainy season (September). A Pentax K-1000 camera, hemispheric type Pentax lens, black and white Fuji ISO 100 film and a light sensor were used according to the methodology proposed by Anderson (1964). Photographs were turned into electronic images through a scanner and edited through Adobe Photoshop software. The Hemiphot computing package from Wageningen University (Steege, 1996) was used in order to calculate shade cover percentage, direct, diffuse and total photon flux density for each plot. This package computes for any plot aspect, latitude, longitude and altitude, the percentage of cover based on the surface black covered (vegetation) of the photo; it also computes photon flux density under the canopy by means of a model based on the movement of the sun over the canopy. The mean percentage of cover and the mean of total light under the canopy from both photos were used for the analysis.

Coffee yields over a 3-year-period were evaluated (1996–1997, 1997–1998, 1998–1999). The first and the last years were estimated by sampling three twigs (middle, high and low part of the bush) from five randomly selected plants in each plot and by counting the total number of both productive and non-productive twigs (Comisión Nacional del Café de Nicaragua, 1992). The 1997–1998 cycle coffee yield was estimated by counting the berries on all the twigs from five randomly selected plants in each plot. In order to estimate the dry weight of clean coffee from the number of berries, a kilogram randomly selected for each sample of berries, was counted, cleaned, dried and weighed (adjusted to 12% moisture content). The mean yield of 3 years was used for the analysis.

2.3. Statistical analyses

Questionnaires and strata profiles were analysed by descriptive statistical methods in order to characterise the selected plots and the coffee systems in the

Table 1
Coffee system features from 36 study plots in Chilón, Mexico

Variable	Mean of 36 plots	Minimum of 36 plots	Maximum of 36 plots	S.D.[a]
Coffee shrubs/ha	1927	800	3500	548.6
Shade cover (%)	46.7	22.9	70.0	12.7
<10 cm d.b.h. trees/ha	177	0	500	41.6
>10 cm d.b.h. tree/ha	286	100	900	214.0
Shade trees/ha	463	100	1000	221.9
Basal area (m^2/ha)	171.3	20	516	143.8
No. of species/plot	3.5	1	8	1.9

[a] S.D.: Standard deviation.

study area. Data on inventory and yields were analysed through general linear models and correlation analyses (SAS Institute Inc., 1989). Yield (3-year-mean) was used as the dependent variable, and altitude, shade cover, coffee bush density, total shade tree density, basal area and coffee stand age were entered as independent variables in the multivariate regression analysis. Total shade tree density, basal area, photon flux density and shade covers were independent variables. Coffee bush density was maintained as a constant in order to fit a regression equation relating shade cover and yields in which 25 plots between 23 and 70% shade cover were included. Yield data were analysed by coffee stand age classes. Yields were log-transformed to decrease variability (Steel and Torrie, 1985).

3. Results

3.1. Coffee stand's structure and species richness

Table 1 shows that coffee bush densities varied between 800 and 3500 plants per ha. The average shade tree density was 464 trees per ha ranging from a minimum of 100 to a maximum of 1000. Basal area averaged 171.3 m^2/ha, and species richness averaged 3.5 species per plot.

The shade vegetation showed a complex distribution in the vertical profile (Fig. 2). The average profile showed 26% of full sunlight trees; 10% of plenty of superiorly directly lit trees; 15% of some superior directly lit trees; 49% of diffusely lit trees/shrubs.

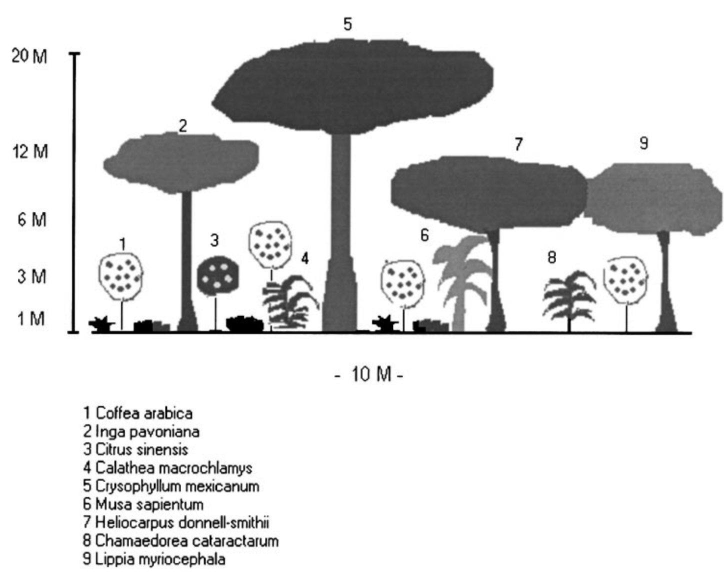

Fig. 2. A typical coffee stand profile from Chilón Mexico.

The coffee stands reveal five strata. The herbaceous stratum mainly comprise weeds, coffee seedlings and seedlings of woody species of natural vegetation. Two shrubby strata were observed; the first ranging from 1 to 3 m is mainly made up of coffee shrubs, tall herbs and some small fruit trees; the second shrubby stratum ranging from 3 to 6 m is 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). The fifth 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. These last two strata constitute the main shade for coffee in the region (Fig. 2). Treetops presented different shapes: 49% showed a complete circle shape; 14% irregular circle shape; 21% half circle shape; and the rest 16% showed less-than-half circle shape, few twigs or mainly spouts. Seven tallest species (>15 m high) were recorded (Table 2); they represented 6.9% of the total shade vegetation. A systematic disposition of shade trees was not revealed.

The shade vegetation comprised: trees 65.6%, shrubs (coffee not included) 24.6%, woody herbs 4.9% and palms 4.9%. Each coffee stand had its own species diversity, because the coffee stands are, in general, established from different-aged secondary vegetation by eliminating the lowest strata and some trees of superior strata. From the total shade species, 67.2% had less than 1% relative abundance (RA); 28% had 1–5% RA and only three species had more than 5% RA: *Inga pavoniana*, *Chamaedorea cataractarum* and *Inga punctata* (Table 2). Six species presented the highest frequency: *Inga pavoniana* (62%), *Inga punctata* (28%), *Musa sapientum* (13%), *Calathea macrochlamys* (10%), *Eugenia jambos* (10%), and *Citrus sinensis* (10%).

Inventory and informal on-site interviews with producers revealed 61 useful species of shade trees and shrubs; of this total, 88.5 % were indigenous species. The shade trees and shrubs are mainly used for food (25.8%), firewood (29%) and construction (15%); the rest (30.2%) had other uses for forage, handicrafts,

Table 2
Shade species in coffee stands from Chiapas, Mexico

Local name	Species	Use (s)[a]	Living form	Relative abundance
Ashin'te	*Solanum aphyodendron* Knapp	1	Shrub	0.5
Atsam'te	*Myrica cerifera* L.	3, 5	Tree	0.5
Baas	*Desmoncus schippii* Burr.	1, 4	Tall Herb	0.5
Cacao	*Theobroma cacao* L.	1, 7	Shrub	1.4
Cacaté	*Oecopetalum mexicanum* Gr. & Th.	1	Tree	2.4
Cantelal tzi	*Senna papilosa* (B. & R.) I. & B.	5	Tree	0.5
Cedro	*Cedrela mexicana* Roe	3, 4, 7	Tree	0.9
Coquil'te[b]	*Inga pavoniana* Donn.	1, 5, 7	Tree	21.7
Chac'taj'mut	*Miconia* aff. *ibaguensis* (Bonpl.)Triana	3, 5	Tree	0.5
Chacaj or Luluy	*Bursera simaruba* (L.) S.	3	Tree	0.5
Chapay or act	*Astrocharium mexicanum* Liebm.	1	Palm	1.4
Chi'b	*Chamaedorea cataractarum* Liebm.	1	Tree	10.4
Chi'ch bat	*Croton draco* Schlecht.	7	Tree	0.9
Chii't[b]	*Chrysophyllum mexicanum* (Brand) Standl.	1, 5	Tree	2.4
Chinino	*Persea schiedeana* Nees	5	Tree	0.9
Guarón	*Cecropia obtusifolia* Bert	3	Tree	0.5
Guayaba	*Psidium guajava* L.	1, 5, 6	Tree	1.4
Hule	*Castilla elastica* Cerv.	1, 8	Tree	0.9
Ik'bat[b]	*Belotia mexicana* Shum.	7	Tree	2.4
Ichil'te	*Zanthoxilum* aff. *kellermanii* P. Wilson	3	Tree	0.5
Joma or Mojtó	*Chamaedorea tepejilote* Liebm.	1, 2	Palm	0.9
Jono 'ha	*Heliocarpus donnell-smithii* Rose	9	Tree	0.5
Juun	*Sapium* sp.	3, 4	Shrub	0.5
Jaal'te	*Clibadium arboreum* Donn. Sm.	5	Tree	0.5
Jitit'ul	Non identified	4, 5	Tree	0.5

Table 2 (*Continued*).

Local name	Species	Use (s)[a]	Living form	Relative abundance
Limón	*Citrus aurantifolia* Osb.	1	Shrub	1.9
Mandarina	*Citrus nobilis* Lour.	1	Shrub	0.5
Mango	*Mangifera indica* L.	1	Tree	0.5
Mistel	*Amphitecna macrophylla* (Seem.) Miers.	1	Tree	0.5
Momun	*Piper auritum* Kunth	1	Tall herb	1.4
Mot'e	*Erythrina* sp.	1, 3	Tree	1.4
Naranja	*Citrus sinensis* Osb.	1, 6	Shrub	3.8
On'te	*Nectandra globosa* (Aublet) Mez.	5	Tree	0.9
Pajul'te[b]	*Zanthoxilum* aff. *microcarpum* Griseb	3	Tree	1.4
Papaya	*Carica pennata* Heilb.	1	Tree	0.5
Pimil	*Calathea macrochlamys* Woodson & Standl.	9	Tall herb	1.9
Plátano roatan	*Musa sapientum* L.	1, 7	Tree	4.7
Pom'te	*Neurolaena lobata* (L.) R. Br.	5	Shrub	1.4
Pomarrosa	*Eugenia jambos* L.	1, 7	Tree	1.9
Sac juluchay	*Bernardia* aff. *interrupta* (Schel.) Muell-Arg.	5	Tree	0.5
Sac Mumus	*Lippia myriocephala* Schlech. & Cham.	3	Tree	1.9
Sajal Bat	*Heliocarpus mexicanus* (Turcz) Sprague	5, 9	Tree	0.5
Saquil Bat	*Heliocarpus appendiculatus* Turcz.	5, 9	Tree	0.5
Shin'te[b]	*Lonchocarpus* sp.	5, 7	Shrub	1.4
Sitit	*Vernonia deppeana* Less.	5	Shrub	0.5
Sun	*Tithonia rotundifolia* (Miller) Blake	1	Shrub	0.5
Tanchit	*Casearia corymbosa* Kunth	3, 5	Tree	0.5
Toj'pos'te	*Cupania dentata* D.C.	5	Tree	0.5
Tumin'te	*Croton billbergianus* Mull Arg.	5	Tree	0.5
Tzajalobal	*Musa sapientum* L.	1, 7, 9	Shrub	0.5
Tzelel[b]	*Inga punctata* Willd.	5, 7	Tree	9.9
Tzost'e	*Liquidambar styraciflua* L.	3, 5	Tree	0.5
Ujchum	Non identified	7	Shrub	0.5
Ulusí	*Myriocarpum longipes* Liebm.	5	Tree	0.5
Weel	*Orthion subssesile* (Standl.) Steyerm. & Stadl.	5	Tree	0.5
Xacaxte	*Blepharidium mexicanum* Standl.	3, 5	Shrub	0.5
Xaxib'te	*Senna multijuga* (L.C. Rich.) I. & B. var *doylei*	3, 5, 7	Tree	0.9
Xoch'bat	*Heliocarpus reticulatus* Nash	5, 9	Tree	0.5
Ya can chamel	*Dendropanax arboreus* (L.) Dacne & Planchon	5	Shrub	0.5
Yash'ajal'te	*Eupatorium chiapensis* Rob.	7	Shrub	0.9
Zapote	*Calocarpum zapota* Merr.	1, 7	Tree	0.9

[a] Use Key: 1) Food, 2) Forage, 3) Construction, 4) Handicrafts, 5) Firewood, 6) Medicinal plant, 7) Shade, 8) Gum, 9) Other uses or services.

[b] Tallest species.

medicine, shade, gum, condiment and domestic uses. Many of the species are multipurpose species (Table 2), some providing enough firewood to satisfy domestic needs. The introduced plants are mainly used for food. Among those plants used for food, farmers reported 15 different products, mainly fruits. Other products reported were leaves, stems and flowers, all used for consumption summing up to a total of 13 additional goods derived from seven shade shrubby species. Farmers also reported additional products derived from the herbaceous stratum. In addition to the plants that are used in some form by the local community, other resources with potential commercial or domestic use were identified, including fungal species and plant species of the families Araceae and Cycadaceae and the epiphytic bromeliads, ferns and orchids. Some 3% of the total shade vegetation was recorded as dead trees or shrubs, that could be important for bird habitat (R. Greenberg, Personal Communication, 1999).

On the other hand, the species richness of shade species within the altitudinal band where the study plots were located showed a significant correlation with altitude ($p<0.001$, $r^2=0.43$). The coffee stands of greater species richness are found in the ecozone at the higher elevation, corresponding to montane rainforest; poorer species richness was found at lower altitudes corresponding to sub-perennial rainforest.

3.2. Coffee yields

The sampled plots averaged 835.8 g per coffee bush for the 3-year-period. The percentage of shade cover and the density of coffee bushes significantly affected coffee yields ($p<0.001$; $r^2=0.68$). The function that describes the relation between shade cover, coffee density and yields was the following:

$$Y = 5 + 0.13\ (\text{shade cover}) - 0.0013 \times (\text{shade cover})^2 - 0.054\ \left(\frac{\text{coffee density}}{100}\right)$$

Where Y=Log Yields (grams of clean coffee per plant), shade cover=Percentage of shade vegetation cover (%),Cofee density=Coffee shrubs per hectare.

Fig. 3 presents the distribution of yields in relation to shade cover percentage maintaining the coffee bush density as a constant. Shade tree cover had a positive effect in the range between 23 and 38% shade cover.

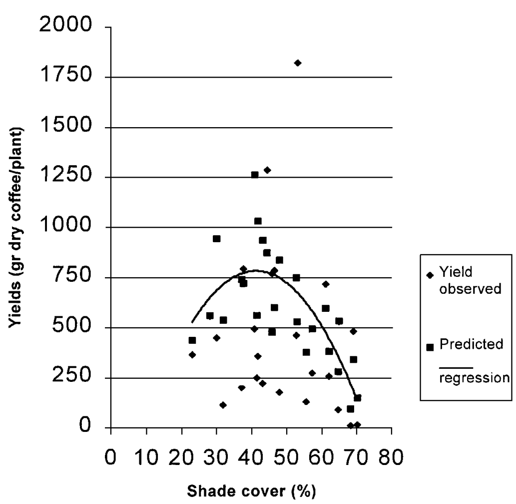

Fig. 3. Effect of shade cover on coffee yields, maintaining coffee density as constant, at 2200 coffee plants/hectare.

Between 38 and 48% shade yield is maintained. Production decreases with shade cover greater than 50%. Altitude did not have significance in the multivariate regression analyses, but alone, it showed a negative correlation on yields ($p<0.005$, $r^2=-0.43$). Variables such as age of coffee stand, cultivar, species richness, shade tree density, basal area, photon flux density, slope and aspect did not have significant effects on coffee yields ($p<0.05$).

4. Discussion

The results show a more complex relationship among density, shade cover and yields than that has been assumed and reported in the literature. Other authors have reported that an increase in shade tree density will result in coffee yield decreases, including Nolasco (1985) who reported that more than half the coffee stands in Mexico are overshaded which possibly reduce yields. She reported that more than 50% of 1008 coffee stands under study in Mexico gave poor yields (between 54 and 540 kg/ha) with shade tree densities between less than 100 and 998 trees per ha. In Costa Rica, after 10 years of experimentation, Hernandez et al. (1997) concluded that a density of 100 trees of *Cordia alliodora* per ha maintained the same yields as without shade control, but with higher densities a decrease in yields was observed. Similarly, in Venezuela, Escalante (1995) found that by increasing the number of shade and woody trees from 259 to 353 per ha yields were reduced by 26% and by increasing shade trees, wood trees and fruit trees from 419 to 561 per ha, yield was reduced by 100%. However, density of shade trees does not necessarily correspond to shade cover as shown here.

Although this study did not detect an effect on tree density per se on yields, shade cover did have an influence. It seems that the coffee plant is sensitive to light to the extent that the effect of shade cover on coffee yields is more important than the shade tree density, especially in these traditional low density-coffee-shrub systems where the constraining factor is likely to be light.

The highest yields found in the present study corresponded with a shade cover between 30 and 45%. This is similar to that reported by Muschler (1997) in Costa Rica, who found the best yields at 40% cover shade.

Rayner (1942) explained the need and importance of shade to control high temperatures and light intensity for the optimal growth and yield of coffee in Latin America. Nevertheless, other authors (Huerta, 1954; Alvim, 1960) have observed favourable effects, particularly on the photosynthesis rate, in plants grown in full sunlight.

In recent years, because it has been suggested that a higher incidence of coffee berry borer (Bergamin, 1946) and coffee leaf rust (Agrios, 1982) occur in coffee crops under shade, practices now advocate a reduction in shade, with increased reliance on new high-yielding cultivars, use of chemical inputs, pruning, and high coffee plant density (Coyner, 1960; Perfecto et al., 1996). Naturally, this decreases landscape and species diversity.

The features of the coffee systems described here, on the other hand, promote conservation of natural resources and landscape diversity, both of which may be of particular value to preserve the montane rain forest and sub-perennial rain forest.

The coffee production system described here appears to be robust when managed under shade. The results suggest that producers may continue keeping coffee stands under shade trees with around 50% shade cover and 460 trees per ha (60% trees/40% shrubs) with no significant decrease in yields, and with the added economic benefits derived from other products extracted from the plantations.

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