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Shade-Productivity Interactions in Coffee Agroforestry Trials in Costa Rica and Nicaragua

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Abstract

Two long-term coffee systems experiments were established in Costa Rica and Nicaragua with shade of legume and timber species, or full sun, combined with organic and conventional managements. Production under full sun was significantly higher than under shade over the first two years in Costa Rica, but not subsequently. A weak negative correlation (r^2=0.33 p<0.01) was found between shade and production; the highest levels of shade were found with *Erythrina* (80%). In Nicaragua accumulated productivity over four years under full sun (24.9 t/ha) and under shade systems with *Tabebuia* (21.2 to 24.5 t/ha) were significantly higher than shade systems with *Inga* (16.3 to18.0 t/ha). In Costa Rica accumulated moderate conventional production over the four years (25.8 t/ha) was significantly greater than intensive organic production (18.8 t/ha), both under shade. In Nicaragua intensive organic production (21.6 t/ha) was not significantly different from intensive conventional production (24.6 t/ha), both of which were

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significantly more productive than extensive organic production (14.6 t/ha). Under the pruning and thinning regime employed *Inga* and *Erthrynia* showed indications of being competitive. *Erythrina* reduced growth of the other timber species, and tended to reduce coffee production when shade cover was high. Inga shade systems had lower coffee yields possibly linked to more shade in the dry season. During these first years it appeared that the timber shade systems created more favourable conditions for coffee production than the leguminous trees.

Resumen en español

Interacciones de producci n de sombra in ensayos agroforestales de caf en Costa Rica y Nicaragua

Dos ensayos de café de largo plazo fueron establecidos en Costa Rica y Nicaragua con sombra de leguminosas y maderables o pleno sol combinado con manejo orgánico y convencional. La producción bajo pleno sol fue significativamente mayor durante los primeros dos años en Costa Rica, pero no después. Se encontró una correlación negativa (r^2 =0.33 $p<0.01$) entre el grado de sombra y la producción; la sombra mayor fue con *Erythrina* (80%). En Nicaragua la producción acumulado durante cuatro años a pleno sol (24.9 t/ha) y con sombra de *Tabebuia* (21.2 a 24.5 t/ha) fue significativamente mayor que con sombra de Inga (16.3 a18.0 t/ha). En Costa Rica la producción acumulado del convencional moderado fue significativamente mayor (25.8 t/ha) que el orgánico intensivo (18.8 t/ha), los dos con sombra. En Nicaragua la producción del orgánico intensivo (21.6 t/ha) no fue significativamente diferente del convencional intensivo (24.6 t/ha), los dos fueron significativamente mas productivo que el orgánico extensivo (14.6 t/ha). Las sombras leguminosas mostraron indicaciones de ser muy competitivas. *Erythrina* demostró competencia con los árboles maderables, y posiblemente redujo la producción de café cuando la sombra fue densa. Las sombras con *Inga* tuvieron menor productividad

aunque los niveles de sombra solo fueron mayores en la época seca. Al menos durante los primeros años parece que los árboles maderables crearon mejores condiciones para la producción de café.

Introduction

In Central America high-input or modern coffee production technology has achieved high yields for a select group of favored producers who cultivate coffee in optimum growing conditions. This tripling or quadrulping in yields has been achieved by short-cutting ecological processes such as semi-closed nutrient cycles and food web diversity. These processes have been minimized or replaced by the use of petroleum-based fertilizers and pesticides in minimal shade or open sun coffee. For example, a healthy soil built up from leaf litter under shade has been replaced by nematicides and chemical fertilizers. Pesticides have replaced a buffered shade environment that helped keep pests at nondamaging levels. Efficient, organic nutrient cycles have been replaced by leaky, open inorganic fertilizer flows.

The high cost of purchased inputs coupled with the volatile prices for coffee have contributed to greater economic vulnerability of intensive coffee production, even for successful farmers. In the open-sun system, costs of production cannot easily be reduced, even when coffee prices are low, without substantial deterioration in yield potential in future years. Second, the model has not proven widely applicable for farm families with a small land base and limited resources. The majority of coffee-producers continue to harvest 5–15 hundredweights per hectare in most of Central America, only a third or less of potential yield. Third, the elimination or simplification of shade has generated concern for the loss of biodiversity (Perfecto et al. 1996). Finally, excessive pesticide and fertilizer use, soil erosion and inadequate coffee waste processing have contributed to pollution and environmental deterioration in fragile, yet vital, upper watersheds. Coffee growers have begun to experiment with alternative production technologies to reduce costs, to access specialty markets and to diversify income. These include organic production, often with leguminous shade trees, which have been used traditionally in coffee. Conventional farmers have cut back on fertilizer and pesticide use. Farmers have also continued to look for economic diversification of the tree component with non-leguminous timber and fruit trees.

To contribute to this search for more viable coffee production technologies, CATIE and national partners in Costa Rica and Nicaragua established a long-term experiment of alternative coffee production systems with the following objectives:

1. Determine the effects of shade composition and structure, type and level of nutrient inputs, pest control approaches, and varieties on pest dynamics and other flora and fauna, coffee growth, yield, and quality, and nutrient cycles and soil organic matter.
2. Measure the growth and development of different tree strata in terms of biomass accumulation, timber and firewood production, and litter contribution and their effect on microclimate, nutrient inputs, and soil biology and organic matter.
3. Contrast interactions among shade, nutrient and pest strategies, and varieties for distinct coffee producing zones by rainfall, altitude, and soil fertility.
4. Develop methods for the identification of ecological efficiencies and the evaluation of economic, ecological, and productive sustainability for coffee systems.

The study should contribute to the design of systems that make use of ecological efficiencies for lower costs, higher quality coffee and additional income.

Materials and Methods

In 2,000, two experiments were set up in a low, wet coffee zone and in a low, dry coffee zone. Turrialba, Costa Rica, represents a low, wet coffee zone with fertile soils. Annual rainfall is 2,600 mm with a period of lower rainfall, although no dry season. Altitude is 685 meters above sea level. Masatepe, Nicaragua, is a low, dry coffee zone with fertile soils. Annual precipitation is 1,386 mm. The six-month dry season receives only minimal rain. Altitude for Masatepe is 455 meters above sea level. Main treatment plots were tree strata with subplots for input levels for nutrient and pest management. A different set of timber and service tree species was used for each site, drawn from the most common species used in association with coffee (Tables 1 and 2). Trees were planted at four times their expected final density and have been reduced by 50% by one thinnings approximately six years after planting.

Each experiment has an open-sun treatment and different combinations of the tree species to develop a gradient of nitrogen fixation and contrasting combinations of evergreen/deciduous and canopy type (Table 3).

Four input regimes for nutrient and pest management were designed (Table 4).

Coffee cherry production data was taken from a measurement plot that had at least four rows of coffee buffer between different treatments. Tree height and basal and breast-height diameter were measured annually (Nicaragua) or biannually (Costa Rica). Shade levels were measured twice per year in Nicaragua using a densiometer and using a LiCOR light meter in Costa Rica.

Table 1. Tree species to be used in coffee systems comparison in Masatepe, Nicaragua.

Species	Phenology	canopy shape	N-fixer	Use
Simarouba glauca (SG)	Evergreen	high narrow	No	Timber
Tabebuia rosea (TR)	Deciduous	high narrow	No	Timber
Samanea saman (SS)	Briefly deciduous	high spreading	Yes	Timber
Inga laurina (IL)	Evergreen	low spreading	Yes	Service

Table 2. Tree species to be used in coffee systems comparison in Turrialba, Costa Rica.

Species	Phenology	canopy shape	N-fixer	Use
Terminalia amazonia (TA)	evergreen	high compact	No	Timber
Chloroleucon eurycyclon (CL)	Briefly deciduous	high spreading	Yes	Timber
Erythrina poepiggiana (EP)	evergreen	low compact	Yes	Service

Table 3: Main plot and subplot treatments (see Table 4 for key to subplot treatments).

Low, dry zone in Nicaragua	
Main plot treatments	Subplot treatments
Open sun	IC, MC
S. glauca, T. rosea	IC, MC, IO, EO
T. rosea, S. saman	MC, MO
S. glauca, I. laurina	MC, MO
I. laurina S. saman	IC, MC, MO, EO
Low wet zone in Costa Rica	
Main plot treatments	Subplot treatments
open sun	IC, MC
E. poepiggiana	IC, MC, IO, EO
T. amazonia	IC, MC, MO, EO
C. eurycyclon	MC, IO
T. amazonia, C. eurycyclon	MC, IO
T. amazonia, E. poepiggiana	MC, IO
C. eurycyclon, E. poepiggina	IC, MC, IO, EO

Results

Accumulated production over the first four years in Costa Rica was significantly higher for full sun coffee (37.6 t/ha) than shaded coffee (30.0 t/ha) under conventional management. When analyzed by year, this difference was only significant in the first two years of production (first year 3.5t/ha sun vs 1.5t/ha shaded, $p<0.01$, second year 15.7t/ha sun versus 11.3 shaded, $p<0.01$) (Figure 1b). In Nicaragua accumulated productivity over four years under full sun (24.9 t/ha) and under the two shade systems with *Tabebuia* (21.2 and 24.5 t/ha) was significantly higher than the two shade systems with *Inga* (16.3 and 18.0 t/ha). There were no significant differences in coffee production between the different shade systems in Costa Rica. Percentage light intercepted in Costa Rica in the fourth year was highest in shade combination with *Erythrina*, then *Terminalia* and lowest with *Chloroleucon* (80%, 51% and 40% respectively, $p<0.01$) (Table 5). Although there was not significant effect of shade treatment on production, there was a weak negative correlation (r^2 $=0.33$ $p<0.01$) between percentage light intercepted and production. Wet season shade cover in Nicaragua was not significantly different among the shade combinations. Only in the dry season when

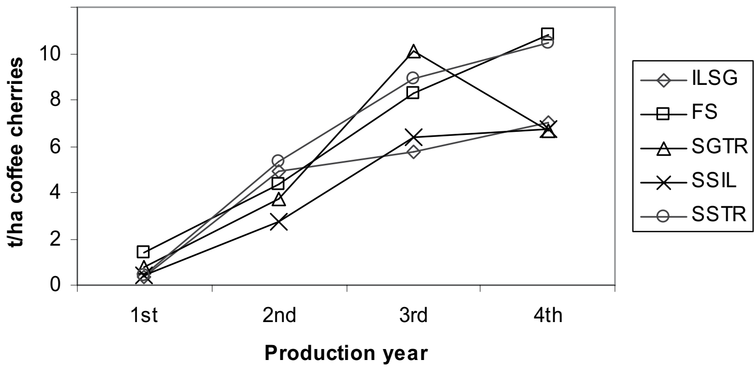
Table 4. Input levels for nutrient and pest management in coffee systems experiments.

	Extensive organic (EO)	Intensive organic (IO)	Moderate Conventional (MC)	Intensive Conventional (IC)
Type of soil amendments	Organic, primarily coffee wastes	organic-coffee wastes, chicken manure, and ground rock	Chemical fertilizer	Chemical fertilizer
Level of soil amendments	Return of nutrients removed during harvest	greater than nutrients removed in harvest	Greater than nutrients removed in harvest	Far in excess of nutrients removed in harvest
Disease management	None	use of botanical and mineral foliar applications	Use of infrequent commercial fungicide applications	Regular use of commercial fungicides
Insect pest management	Gleaning of berries after harvest	manual practices and use of botanical and biological applications	Manual practices and infrequent use of commercial insecticides	Manual practices and regular use of commercial insecticides
Weed management	2-4 routine machete weedings per year	manual selective weed management between row and clean within row area	Selective weed management between row and clean within row area with manual and herbicide	Bare soil with herbicides

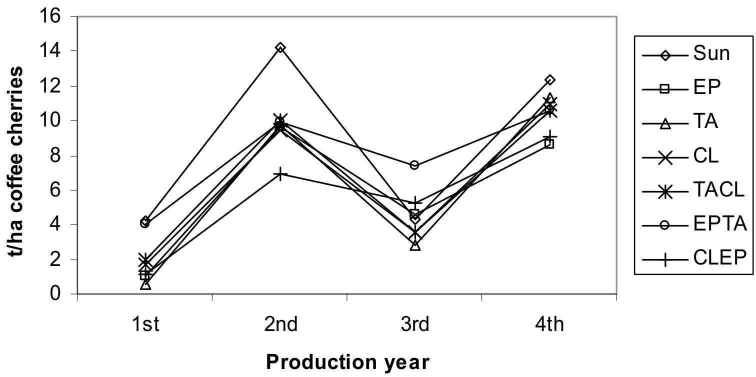
Tabebuia is deciduous was shade cover significantly lower (28% cover) in systems with this species than with *Inga* (50–62% cover). In Costa Rica accumulated moderate conventional production over the four years (25.8 t/ha) was significantly greater than intensive organic production (18.8 t/ha), both under shade, but this difference was only significant in the first and second year, when analyzed on a per year basis (Figure 2). In Nicaragua (Figure 3) intensive organic production (21.6 t/ha) was not significantly different from intensive conventional production (24.6 t/ha), both of which were significantly more productive than extensive organic production (14.6 t/ha).

Table 5. Light interception by different shade types in fourth production year in Costa Rica experiment, values followed by different letters are significantly different, p<0.05 (for key to species, see Table 2)

	Shade Type					
	EP	TA	CL	EPTA	CLEP	CLTA
% light interception	80.2a	53.1c	40.6e	86.2a	66.8b	33.5e



a. Nicaragua FS=full sun.



b. Costa Rica.

Figure 1. Coffee production (MC and IO) under different shade types (see Table 1 for tree species).

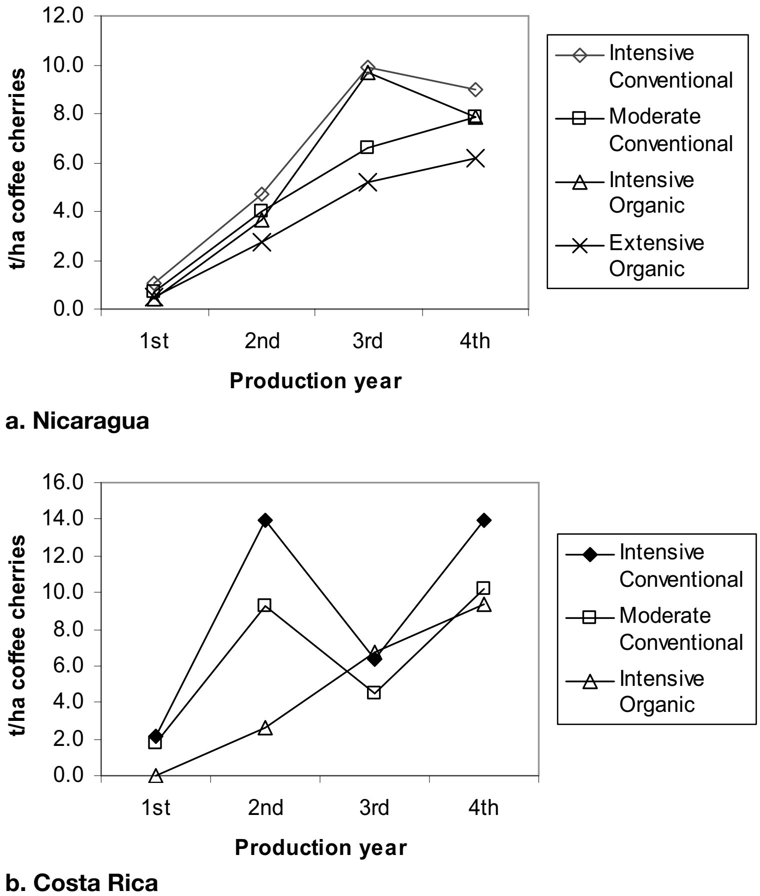


Figure 2. Coffee production under different input regimes.

Basal area per tree when five years old in Nicaragua was least for *Samanea*, which was two years younger than the other species, intermediate for *Simarouba* and similar between *Inga* and *Tabebuia*. The combinations with *Samanea* had least basal area, but there was no significant effect between the presence of *Inga* or *Tabebuia* (Table 6).

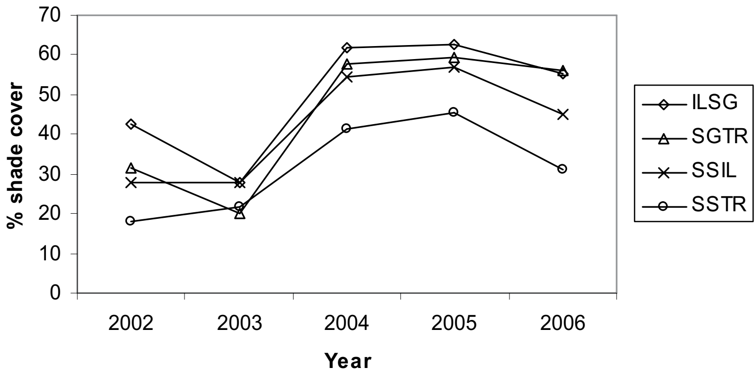


Figure 3. Percentage shade cover during the wet season of different shade tree combinations at the Nicaragua site.

Table 6. Basal area of trees by treatment at Nicaragua site (for basal areas per stand values followed by different letters are significantly different $p<0.05$).

	Basal area per tree cm^2				Basal area per stand
Shade treatment	*Inga*	*Simarouba*	*Samanea*	*Tabebuia*	m^2/ha
ILSG	199	119			13.4a
SGTR		128		198	13.7a
SSIL	233		29		11.1ab
SSTR			42	167	8.9b
Average	222	125	33	188	13.4

In Costa Rica six-year old *Erythrina* had the greatest basal area, followed by *Chloroleucon* and then *Terminalia* (18.2, 8.3 and 3.8 m^2/ha, respectively). However, basal area of *Chloroleucon* and *Terminalia* were significantly reduced when in combination with *Erythrina* (7.0 versus 4.25m^2/ha and 4.0 versus 2.2 m^2/ha, respectively, $p<0.05$). Furthermore, crown diameter of *Erythrina* was significantly greater when combined with these species (11 m) compared to *Erythrina* alone (5.7 m).

Discussion and conclusions

Coffee productivity was higher under full sun than shade under some circumstances. At the Costa Rica site this was just during the first years, and in Nicaragua only compared to some shade types. The decline in relative productivity of the full-sun coffee at the Costa Rica site is related to higher levels of plant exhaustion and greater frequency of regenerative pruning (Merlo, 2006).

Intensive organic production was found to be equally productive as conventional at the Nicaraguan site, and equal to moderate conventional production in Costa Rica from the third harvest on. This contrasts with an average of only 1.7 t/ha for organic production, but 5.6t/ha for conventional production in the same region of Costa Rica, compared to 4.7t/ha and 6.4t/ha respectively in the experiment (Porras, 2006). We attribute this to higher levels of organic fertilization and better maintenance of plant vigor in the experiment, than is usually achieved on farms.

Under the pruning and thinning regime used in the experiment, the leguminous shade trees showed indications of being competitive. At the Costa Rica site, despite partial biannual pruning, *Erythrina* developed a more dense shade and was found to reduce the other timber species—and possibly reducing coffee production when shade cover was high. It should be noted that in the moderate conventional and intensive organic treatments, *Erythrina* was pruned twice per year to remove some branches so as to provide a constant shade. This is contrary to the traditional management of pollarding the tree twice per year, removing all branches, which was implemented for the intensive conventional treatment. When *Erythrina* is managed in this traditional intensive manner ,Fassbender (1993) found higher productivity of coffee with *Erythrina* than with timber trees. Muschler (2001) also found that lack of regulation of *Erythrina* shade led to a decline in productivity. *Inga* shade systems had lower coffee productivity, possibly linked to higher shade levels in the dry season. Immediately after these results were taken, *Erythrina* tree density was halved at the Costa Rica site and all tree species were thinned to 50% of original density at the Nicaragua site. At least during these first years it appeared that the timber shade systems created more favourable, or at least more easily managed, growing conditions for the coffee production than the leguminous shade trees.

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