

Biodiversity Conservation, Ecosystem Functioning, and Economic Incentives under Cocoa Agroforestry Intensification

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Abstract: *World chocolate demand is expected to more than double by 2050. Decisions about how to meet this challenge will have profound effects on tropical rainforests and wild species in cocoa-producing countries. Cocoa, “the chocolate tree,” is traditionally produced under a diverse and dense canopy of shade trees that provide habitat for a high diversity of organisms. The current trend to reduce or eliminate shade cover raises concerns about the potential loss of biodiversity. Nevertheless, few studies have assessed the ecological consequences and economic trade-offs under different management options in cocoa plantations. Here we describe the relationships between ant ecology (species richness, community composition, and abundance) and vegetation structure, ecosystem functions, and economic profitability under different land-use management systems in 17 traditional cocoa forest gardens in southern Cameroon. We calculated an index of profitability, based on the net annual income per hectare. We found significant differences associated with the different land-use management systems for species richness and abundance of ants and species richness and density of trees. Ant species richness was significantly higher in floristically and structurally diverse, low-intensity, old cocoa systems than in intensive young systems. Ant species richness was significantly related to tree species richness and density. We found no clear relationship between profitability and biodiversity. Nevertheless, we suggest that improving the income and livelihood of smallholder cocoa farmers will require economic incentives to discourage further intensification and ecologically detrimental loss of shade cover. Certification programs for shade-grown cocoa may provide socioeconomic incentives to slow intensification.*

Keywords: agricultural economics, agroforestry management, ants, cocoa certification program, cocoa plantations, land-use management

Conservación de Biodiversidad, Funcionamiento del Ecosistema e Incentivos Económicos en la Intensificación de la Agroforestería de Cacao

Resumen: *Se espera que la demanda mundial de chocolate se duplique en 2050. Las decisiones de cómo enfrentar este reto tendrán efectos profundos sobre los bosques lluviosos tropicales y las especies silvestres en los países productores de cacao. El cacao, “el árbol del chocolate”, tradicionalmente es producido bajo un dosel diverso y denso de árboles de sombra que proporcionan hábitat a una alta diversidad de organismos. La tendencia actual de reducir o eliminar la cobertura de sombra causa preocupación sobre la potencial pérdida de biodiversidad. Sin embargo, pocos estudios han evaluado las consecuencias ecológicas y económicas de las diferentes opciones de manejo de las plantaciones de cacao. Aquí describimos las relaciones entre la ecología de hormigas (riqueza de especies, composición de la comunidad y abundancia) y la estructura de la vegetación, las funciones del ecosistema y la rentabilidad económica bajo diferentes sistemas de uso de suelo en 17 plantaciones tradicionales de cacao en el sur de Camerún. Calculamos un índice de rentabilidad,*

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basado en el ingreso neto anual por hectárea. Encontramos diferencias significativas asociadas con los diferentes sistemas de manejo de uso de suelo en la riqueza de especies y abundancia de hormigas y en la riqueza de especies y densidad de árboles. La riqueza de especies de hormigas fue significativamente mayor en los sistemas de cacao viejos, de baja intensidad y florística y estructuralmente diversos que en los sistemas jóvenes intensivos. La riqueza de especies de hormigas se relacionó significativamente con la riqueza de especies y densidad de árboles. No encontramos una relación clara entre la rentabilidad y la biodiversidad. Sin embargo, sugerimos que el mejoramiento del ingreso y la forma de vida de los pequeños productores de cacao requerirán de incentivos económicos para desalentar la intensificación y la pérdida de cobertura de sombra perjudicial ecológicamente. Los programas de certificación de cacao de sombra pueden proporcionar incentivos socioeconómicos para aminorar la intensificación.

Palabras Clave: economía agrícola, hormigas, manejo de agroforestería, manejo del uso de suelo, plantaciones de cacao, programa de certificación de cacao

Introduction

Agricultural production, including the production of cocoa, can strongly influence biodiversity and ecosystem processes, often changing community composition, plant biomass, vegetation structure, and nutrient cycling because of the interactions between biological, social, and economic factors (Greenberg et al. 2000; Philpott et al. 2006; Philpott et al. 2008). Since the late 1980s, however, the cocoa sector has been subjected to several major economic shocks, leading to new institutional and organizational frameworks. Specifically in Cameroon, the drastic reduction in world prices of cocoa and other commodities in the late 1980s contributed to substantial domestic economic problems (Ndoye & Kaimowitz 2000). Cocoa farmers responded to this crisis by increasing their activity in production of food crops to compensate for the lost income (Sunderlin et al. 2000). This in turn led to a very significant increase in forest clearing, which has had profound negative environmental, economic, and political consequences.

Researchers and conservation organizations have recently paid considerable attention to diverse agroecosystems such as traditional cocoa forest gardens (TCG) with the objective to combine conservation and development goals (Schroth et al. 2004; Philpott & Armbrrecht, 2006; Bos et al. 2007). In these traditional plantations, cocoa is grown under a structurally and floristically diverse canopy of shade trees that provide habitat for a high diversity of flora and fauna (Zapfack et al. 2002; Bobo et al. 2006). These traditional plantations are enriched by nontimber forest products (Duguma et al. 2001) and maintain many of the ecological characteristics of natural forests. Such multiresource land-use practices that create new landscape elements can help conserve biodiversity (at both the species level and landscape level) can help regulate pests and diseases and can be efficiently adapted to changing socioeconomic conditions, ecological conditions, household needs, and marketing opportunities (Perfecto et al. 2005). They also may provide opportuni-

ties for developing new approaches in the conservation of tropical rainforests and biodiversity and may increase the public's awareness that indigenous land-use systems can be useful for sustainable development (Donald 2004; Schroth et al. 2004).

Cocoa production in southern Cameroon, where much pristine forest remains, is likely to contribute to deforestation at the forest-agriculture interface because cocoa acreage is increasing (due to the international market price recovery, ICCO 2006). On the other hand, many cocoa growers are reducing or eliminating shade cover to increase yield. Although these changes in land use will likely reduce biodiversity (Philpott & Dietsch, 2003; Dietsch et al. 2004), there are very few studies of the trade-offs between biodiversity loss and agricultural intensification (Perfecto et al. 2005; Steffan-Dewenter et al. 2007). Conversely, O'Brien and Kinnaird (2003) and Rappole et al. (2003a, 2003b) suggest that intensification conserves biodiversity by minimizing the demand for natural habitat. Nevertheless, assessment of these two opposing land-use models will depend on the nature of the relationship between species richness and yield (Green et al. 2005).

Because of the sociopolitical and economic dimensions of cocoa, policy makers and smallholder cocoa farmers need to be familiar with the role of biodiversity in cocoa farming and the cost-benefit ratio associated with maintaining or reducing the shade canopy (Donald 2004; Steffan-Dewenter et al. 2007). Greenberg (1998) argued that the conservation of shade-grown cocoa plantations requires financial incentives for the grower and ecosystem services for the consumer. Incentives from such production systems could be from the marketing of environmentally friendly products, from the ecological services and from noncrop plants arising from shade production, or from subsidies from national or international programs. Synergistic interactions between biodiversity and profitability have been demonstrated in many agroecosystems and include the control of pest populations by a diverse community of beneficial arthropods,

increased pollination services by native pollinating insects, increased soil nitrogen availability provided by the N-fixing microbes of leguminous plants, and increased carbon sequestration (e.g., Klein et al. 2003a, 2003b; Perfecto et al. 2004; Philpott et al. 2006).

Previous studies provided evidence for the complexity of the relationship between biodiversity and profitability in cocoa agroecosystems in Indonesia (Steffan-Dewenter et al. 2007). This relationship may include synergies and trade-offs. If the two parameters (biodiversity and profitability) are well understood in cocoa, land-use management, agronomic practices, and economic policies can be designed to generate significant returns for smallholder cocoa farmers and to conserve tropical rainforest biodiversity.

We evaluated the economic implications and ecological consequences (in terms of species richness and ecosystem functions) of agricultural intensification of TCGs in southern Cameroon. We hypothesized that land-use intensification in TCGs reduces the diversity of ants, increases insect herbivory, and reduces aboveground plant biomass; ant species richness and abundance are positively related to tree species richness and density; and ant species richness is positively related to yield and income (expressed as net income).

Methods

Study System

We conducted our study in semideciduous rainforests of southern Cameroon in five major cocoa-growing regions between 2°35'N and 4°15'N and 11°48' and 11°15'E. The elevation varies between 450 and 715 m asl and is characterized by a subequatorial climate, with a bimodal rainfall regime. The mean annual temperature is around 25 °C with a relatively small thermal variation. The mean annual

rainfall is around 1900 mm. The soils are Oxisols/Ultisols, which make up about 80% of the soils in the humid forest region of Cameroon, and the pH of the soil varies from 4.29 to 5.43 (Kotto-Same et al. 1997; Kanmegne et al. 2006).

We selected 17 TCGs within the studied regions with a range in canopy cover that produced 25–95% shading. We selected the farms according to a land-use intensity gradient based on density, plant diversity, height of shade trees, percentage of shade, herb cover, number of chupons (young growth beneath mature cocoa trees that farmers sometimes leave and that later enter into production) and the age of cocoa trees, respectively (Philpott et al. 2006). The selected farms represented individual land holdings. In all our study sites, cocoa production was the main cash crop, occupied most of the landscape, and accounted for more than half of the total cocoa production in southern Cameroon. We used a management index to summarize vegetation variables per TCG (Mas & Dietsch 2003; Philpott et al. 2006) (Table 1) in which all variables affected by management were converted to a scale from zero to one and then summed. We divided values for each variable in each site by the highest overall value and then subtracted this from one. All values were summed for a possible total of seven (because seven vegetative variables were included in the index), where seven was most and zero was least intensively managed. Management strategy was later grouped as follows: (1) least intensively managed old cocoa forest gardens (EO, approximately 50 years old) with the lowest management index; (2) least intensively managed mature cocoa forest gardens (EM, approximately 30 years old); (3) intermediate, less managed, home-garden cocoa forest (HG, approximately 40 years old), where cocoa plantations were located very close to the houses in the village; (4) most intensively managed mature cocoa forest gardens (IM, 15–20 years old); and (5) most intensively managed young cocoa forest gardens (IY, 8–15 years old) with

Table 1. Management index (MI) from vegetation variables sampled in five cocoa-growing regions.

Vegetation variables	Management strategy (SE) ^a				
	EO	EM	HG	IM	IY
Tree species richness (no.)	11.0 (0.0)c	6.5 (0.7)a	9.0 (0.6)bc	7.5 (0.7)ab	5.3 (1.8)a
Herbaceous species richness (no.)	33.0 (3.0)c	25.8 (2.4)b	25.0 (2.5)b	16.0 (1.8)a	25.5 (1.8)b
Canopy cover (%)	87.8 (7.4)c	73.5 (5.7)b	83.6 (0.8)c	75.7 (2.8)b	44.5 (6.7)a
Herbaceous cover (%)	84.7 (15.3)c	78.2 (4.8)c	22.2 (5.8)b	8.2 (1.5)a	32.7 (8.0)b
Tree height (m)	55.5 (3.3)b	43.9 (3.3)a	64.0 (3.6)b	65.6 (2.9)b	44.2 (1.5)a
Number of chupons ^b	0.2 (0.01)a	0.4 (0.1)a	0.9 (0.2)b	0.3 (0.01)a	0.1 (0.0)a
Cocoa tree density (tree/ha)	1250 (80.5)ab	1182.5 (80.5)a	1600 (208.2)b	1075 (96.8)a	1095 (69.1)a
Total management index (MI) ^c	2.98 (0.14)a	3.63 (0.12)b	3.45 (0.10)b	4.29 (0.10)c	4.55 (0.03)c**

Abbreviations: EO, least intensive old cocoa forest gardens; EM, least intensive mature cocoa forest gardens; HG, intermediate, less-managed home garden cocoa forests; IM, most intensive mature cocoa forest gardens; IY, most intensive young cocoa forest gardens.

^aLetters show significant differences between regions based on Tukey's post hoc tests (**p < 0.01).

^bChupons are young growth beneath mature cocoa trees that farmers sometimes leave and which later enter into production.

^cA high MI shows more intensive cocoa management.

the highest management index (Bisseleua & Vidal 2008). Two cocoa plantations were EO; four each were EM, IM, and IY; and three were HG. These 17 study sites had a minimum size of 1 ha. In each TCG we assessed, between July and December 2005, floristic and structural diversity, sampled ant diversity, and assessed ecosystem functioning and yield.

Plant and Ant Surveys

We characterized vegetation in 600-m² plots (20 × 30 m) in each TCG. For each TCG, all forest tree species (i.e., trees that were not cocoa trees) with diameter at breast height (dbh) ≥ 10 cm were individually counted, numbered, and identified to species, and the density per plot of each species was estimated. Their crown class, dbh, and full height were measured, and their basal area was calculated. The basal area (BA) per quadrat (600 m²) was calculated as follows: $BA \text{ (cm}^2\text{)} = \Sigma 0.005454D^2$, where D is the dbh per tree. Basal area has been used to approximate plant biomass production, which usually increases with age (Carrière et al. 2002). We calculated the aboveground tree biomass with the equation $\ln B = -3.375 + 0.948 * \ln (D^2 * H)$ (Steffan-Dewenter et al. 2007), where B is the aboveground biomass, D is the dbh, and H is the total tree height. Shade intensity above cocoa trees was measured at 10 points per site with a hand-held concave spherical densiometer (Lemmon Canopy Forest Densimeters, Bartlesville, Oklahoma), and canopy cover was inferred from shade intensity (Philpott et al. 2007).

We sampled arboreal ants active on the cocoa tree surface between 09:00 and 13:00 with a beat-and-collect method. Thirty randomly selected pod-bearing trees per TCG were struck five times at the base of the stem and five more times at the base of the canopy so that ants fell into a suspended white cloth (2 × 2 m) placed beneath the tree canopy. The size of the cloth assured that a high percentage of ants that fell were captured. All ants on the cloth were collected with an aspirator and later identified. We randomly selected five forest tree species with dbh ≥ 10 cm within each 600-m² plot per TCG and placed bait, composed of pieces of tinned tuna fish, honey, and cookie crumbs, weighing about 4 g, 2 m above the ground on tree trunks. We then collected ants that foraged on or near baits. In addition, we collected ants moving between the ground and the canopy; forceps were used to collect these ants as they moved on 10-cm white stripes of cloth. We were careful to select trees that were at least 15 m apart to assure independence of samples. We also placed baits on the ground 2 m from the five randomly selected trees (with dbh ≥ 10 cm) to monitor and collect ground-foraging ant species.

Biodiversity and Herbivory

To evaluate the functional consequences of variations in species richness and composition associated with

shade cover, we quantified standing aboveground plant biomass in each TCG. Herbivory rates were quantified in each TCG by assessing the number of pods damaged by pod borers and mirids, specifically *Salpbergella singularis* Hag. (Hemiptera: Miridae) on 30 randomly selected cocoa trees per TCG. Each selected tree was carefully inspected from the base up to hand-height level (the highest level to which the assessor's fully stretched hand could reach (i.e., between 2 and 2.5 m high). We also examined the relationships between ant richness and herbivory.

Biodiversity and Yield

We examined ant species richness and cocoa yield in relation to shade cover in each TCG. This approach allowed us to compare the response of ants to cocoa intensification. From these data, we calculated the mean yield as average harvest of dry cocoa beans per management strategy because the strategy is related to percent shade cover. Cocoa yields (3 year mean from 2003, 2004, and 2005) were evaluated by weekly harvest of all mature pods from the 30 randomly selected cocoa trees (same cocoa trees as above) in each TCG. We weighed and counted harvested pods. We counted the number of beans per pod and cleaned, dried, and weighed (adjusted to 12% moisture content) to estimate mean yield per management strategy.

Economic Survey

Between August and December 2005, farm owners were interviewed during one-on-one meetings to gather all economic data necessary to calculate net revenue. We questioned farmers about area in cocoa production and age of fields; total cocoa yields and revenue from cocoa production; cocoa prices for the year 2003, 2004, and 2005 harvests; alternative products (native and exotic fruits) collected from cocoa plantations and sold; costs and use of agrochemicals; costs of labor; and off-farm incomes (trading, remittances). The first author, assisted by local workers, interviewed 20 cocoa farmers per management strategy, for a total of 100 farmers. Interviews were conducted in French and local languages.

Statistical Analyses

We used multiple linear regression analysis to describe the relationship between ant and vegetation variables, with ant species richness and ant abundance as dependent variables. Ant abundance was computed based on the number of individual ant species. To compare tree and ant richness in TCG sites, we generated sample-based rarefaction curves (MaoTao estimates) with EstimateS (version 7.5; Colwell & Coddington 1994). We rescaled sample-based rarefaction curves to the number of individuals (or occurrences for ants) to best compare richness between sites (Gotelli & Colwell 2001; Longino

et al. 2002). Statistical comparisons of richness were made with MaoTao estimates, and the corresponding 95% confidence intervals were produced by using analytical formulas.

We used multivariate analyses of variance (MANOVA) to test for differences in the seven vegetation variables and a separate ANOVA to examine differences in management strategy. Data on species richness, herbivory rates, aboveground biomass, and yield were analyzed by simple regression against canopy cover. General linear model and correlation analyses conducted in Systat 11 (SPSS 2000) were used to analyze data on yields. We used yield as the dependent variable and vegetation variables (Table 1) as independent variables in the multivariate regression analysis to separate the influence of management strategy from confounding factors such as age. Density of cocoa trees was maintained as a constant in order to fit a regression equation relating shade cover and yields that included the 17 plots ranging from 25% to 95% shade cover. Data on yield were log transformed before analysis (Soto-Pinto et al. 2000).

To examine the relationship between biodiversity and profitability, we performed a simple linear least square regression analysis with profitability and biodiversity variables and used ANOVA to test for the statistical significance of these relationships. We performed a separate analysis with ant species richness and abundance data. Net income calculated in terms of U.S. dollars per hectare per year was used as the index of profitability. To calculate net income, we included only the most significant annual operating expenditures and revenues. We calculated net income by subtracting management costs from total revenue. Management costs were the sum of pesticide costs plus labor costs. Labor and pesticide costs accounted for over 95% of the annual operating costs reported by cocoa farmers. Total revenue was the sum of cocoa revenue and revenue from native and exotic fruits generated by the plantation. We calculated native forest and exotic fruits revenue by multiplying the quantity of fruit harvested and sold per year by the current market price (US\$1 = 500 Franc de la Communauté Financière Africaine—FCFA).

Cocoa revenue was calculated by multiplying the production (kilograms per hectare) of unprocessed cocoa beans by the price under four different scenarios. Each of these scenarios was based on recent market fluctuations and actual market prices received by producers in this region: scenario 1, \$1.10/kg dry beans (price in January 2001 at the lowest level in the recent cocoa price recovery); scenario 2, \$1.50/kg dry beans (price of cocoa beans in southern Cameroon at the time of survey); scenario 3, \$2.30/kg dry beans (price in January 2003, which was high because of political instability in Côte d'Ivoire); and scenario 4, \$3.50/kg dry beans (assumption being this price could be paid as the premium price for organic cocoa; none of the farms in our study were organically

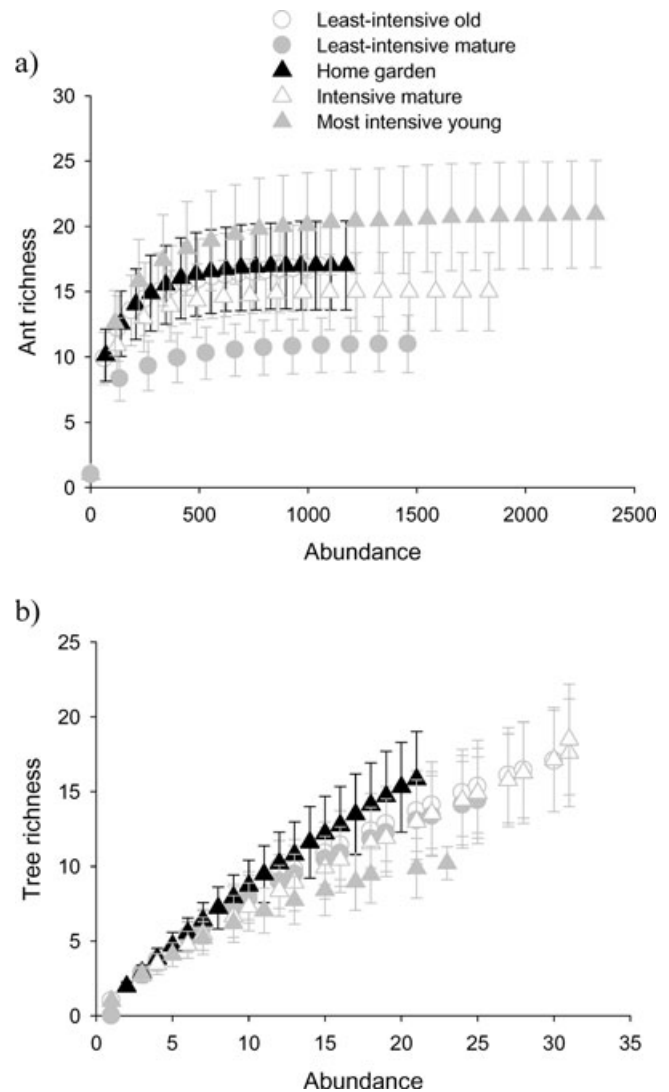


Figure 1. Species accumulation curves for (a) ants and (b) trees in traditional cocoa forest gardens (TCG) in southern Cameroon. Error bars show 95% CI, and nonoverlapping bars show significant differences between TCG.

certified). We estimated the relative drop in income between the highest (net income used here as 100% mark) and other management systems with different scenarios.

Results

Ecological Surveys

A total of 10,763 specimens of ants were collected, including 38 species of ants (Fig. 1a). We observed a significant difference in ant species richness ($F = 3.56, p = 0.03, df = 4$) and ant abundance ($F = 5.60, p = 0.009, df = 4$) with management strategy (one-way ANOVA, $p < 0.01$). Species richness of ants was highest in EO (management

Table 2. Correlation coefficients between and among ant and vegetation variables.

	Tree species	Tree density	Canopy height	Shade (%)	Ant species
Tree density	0.67				
Canopy height	0.51	0.38			
Shade (%)	0.69	0.57	0.56		
Ant species	0.46	0.74	0.39	0.34	
Ant abundance	0.29	0.23	0.10	0.08	0.74

index = 2.98) and lowest in EM (management index = 3.63). Ants were most abundant in IY (management index = 4.55).

In the vegetation surveys we recorded 102 forest trees. Tree species richness significantly decreased with increasing cocoa intensification (one-way ANOVA, $p < 0.01$). In addition, tree species richness was higher in TCG, as was tree density ($F = 23.94$, $r^2 = 0.61$, $n = 17$, $p < 0.001$) (Fig. 1b).

The four vegetation variables in our analysis of ant-vegetation relationships revealed a complex pattern of correlations (Table 2). We therefore performed a multiple linear regression analysis with models that included only those vegetation variables with statistically significant effects ($p < 0.05$); this clarified which vegetation variables were most associated with ant species richness. Ant species richness responded positively to two vegetation variables: tree species richness (coefficient = 0.60, $t = 3.60$, $p[t] = 0.003$) and tree density (coefficient = 0.03, $t = 4.35$, $p[t] < 0.001$). Tree density had the most significant effect on ant species richness ($t = 4.35$, $p[t] < 0.001$). When ant species richness was the dependent variable, the model was robust and highly significant ($r^2 = 0.25$, ANOVA, $p < 0.001$). The relationship between the vegetation variables and ant abundance was not significant.

Biodiversity, Yield, and Income

Herbivory significantly increased with reduced shade cover ($y = 111.67 - 0.60x$, $r^2 = 0.28$, $F_{1,16} = 5.85$, $p = 0.03$), whereas percentage of aboveground plant biomass significantly decreased with reduced shade cover ($y = 1.08x - 34.87$, $r^2 = 0.36$, $F_{1,16} = 8.52$, $p = 0.011$). In addition, herbivory increased significantly with reduced ant richness ($y = 99.26 - 5.11x$, $r^2 = 0.40$, $F_{1,16} = 10.07$, $p = 0.006$).

Yield (3-year mean) differed significantly ($F_{1,16} = 50.75$, $p < 0.0001$) among TCGs. The highest yield was recorded in IY (2230 ± 58.46 kg/ha) and the lowest in EO (897.4 ± 15.58 kg/ha). Yield in IM was two-fold that of EO. Yield significantly decreased with increased shade cover ($F = 10.3$, $r^2 = 0.41$, $p = 0.006$). In the multivariate regression analyses, cocoa yield was significantly affected by the percentage of shade cover, shade cover

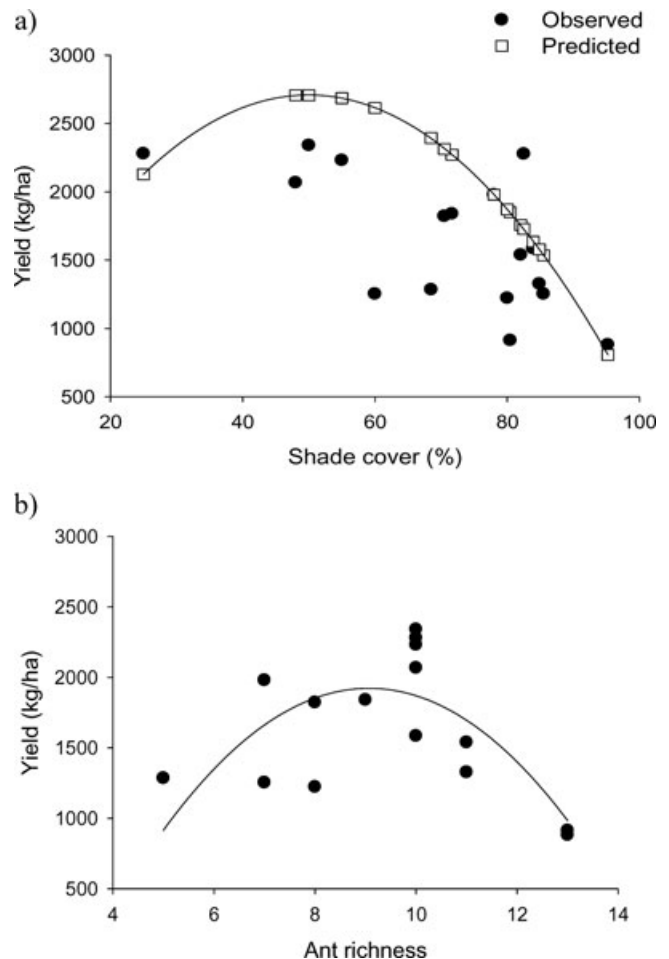


Figure 2. Effect of (a) shade cover, with cocoa tree density at 1220 cocoa trees/ha, and (b) ant richness on cocoa yield.

height, and density of cocoa trees ($p < 0.01$, $r^2 = 0.41$). Tree richness, herbaceous richness, herbaceous cover, and number of chupons did not have significant effects on cocoa yields in the multivariate regression analyses. Nevertheless, when considered alone, tree richness ($r^2 = 0.34$), herbaceous species ($r^2 = 0.22$), and herbaceous cover ($r^2 = 0.49$) have negative effects on yield ($p < 0.05$). Shade cover positively affected yield between 28 and 47% shade (Fig. 2a). Yield was maintained between 49 and 55% shade, but decreased with shade cover $> 60\%$. Cocoa yield was not linearly related to ant species richness (ANOVA, $p = 0.31$). The relationship between yield and ant species richness was convex in that yield was highest with intermediate richness but lowest with high or low levels of richness (Fig. 2b).

Species richness of ants was not correlated with the profitability of cocoa plantations (Fig. 3). The linear correlation between net income per unit area and ant species richness and ant abundance for all the four pricing scenarios was negative and not statistically significant.

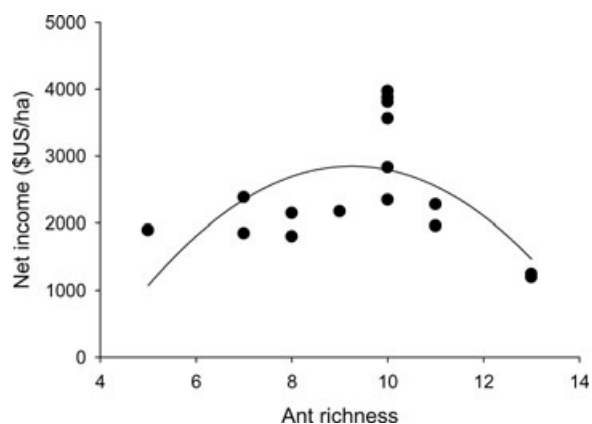


Figure 3. Relationship between profitability and ant species richness. Net income calculation assumes a price of \$1.5/kg of dry beans.

The profit generated by cocoa farmers was significantly affected by cocoa price (Table 3). Net income was much more sensitive to changes in cocoa prices on farms with higher management index values. The EO system was the least profitable for all four pricing scenarios; it showed the highest drop in income (Table 3). Nevertheless, with a premium cocoa price for EO (price scenario 3), EO became more profitable than IM under normal price scenario 2. The relative contribution of products other than cocoa (forest and exotic fruits) to total income increased as the price for cocoa declined.

Discussion

Ant Diversity and Relationship with Vegetation

Our results indicate that changing from extensive to intensive management may significantly decrease ant diversity in cocoa plantations in southern Cameroon. Sampling methods, however, influenced assessment of ant communities, and our results may only apply to ant species that are active on the trunk and surface of cocoa trees

and that can be dislodged by beating or to those species attracted to bait (Delabie et al. 2000). These results highlight the importance of natural shade trees as reservoirs of ant species of conservation concern (Delabie et al. 2007) and forest biodiversity in TCGs (Zapfack et al. 2002; Bobo et al. 2006). Nevertheless, studies with different taxa are needed to corroborate that TCGs effectively conserve biodiversity (Greenberg et al. 2000; Bisseleua & Vidal 2008).

Because management intensity affects ant species richness and the richness and density of forest trees, ant species richness was closely related to the richness and density of forest trees. In cocoa plantations with low species richness of forest trees, ant diversity may be reduced because of high interspecific competition and competitive exclusion (Ribas et al. 2003). In cocoa plantations with high species richness of companion trees, ant diversity may be high because the heterogeneity of resources may reduce interspecific competition and increase coexistence (Sperber et al. 2004; Delabie et al. 2007). Ant species richness significantly decreased with decreasing canopy cover, which suggests that the shade caused by the canopy is a major factor influencing ant community in TCGs as reported Perfecto and Vandermeer (1996) and Armbrecht and Perfecto (2003).

Biodiversity, Herbivory, and Yield

Insect herbivory increased and aboveground plant biomass decreased as shade cover declined. Declining shade cover in cocoa plantations may result in an increase of insect pest pressure, such as cocoa mirids. These patterns have been documented by Rice and Greenberg (2000) in cocoa plantations in West Africa. We suggest that the transition from extensive systems with prevailing shade to intensive ones with reduced shade is likely to result in more regular pest outbreaks and a decline in ecosystem functioning, such as biological control (Klein et al. (2006). By selecting TCGs at the forest margin or in the forest, we were able to quantify the effect of land-use management on TCG biodiversity and profitability; however, we also showed that biotic interactions vary

Table 3. Net income per hectare (\$US) based on cocoa price fluctuations in traditional cocoa forest gardens in southern Cameroon.

Management index ^a	Price scenarios ^b			
	lowest price in 2001 (%)	2005 price at the time of survey (%)	highest price in January 2003 (%)	price including organic premium (%)
2.98 (EO)	858 (29)	1218 (32)	1935 (35)	3012 (36)
3.63 (EM)	1346 (46)	1847 (49)	2849 (51)	4354 (53)
3.45 (HG)	1598 (55)	2191 (58)	3378 (60)	5158 (62)
4.29 (IM)	1587 (55)	2379 (63)	3963 (71)	6338 (77)
4.55 (IY)	2910	3802	5585	8261

^aAbbreviations: EO, least intensive old cocoa forest gardens; EM, least intensive mature cocoa forest gardens; HG, intermediate, less-managed home garden cocoa forests; IM, most intensive mature cocoa forest gardens; IY, most intensive young cocoa forest gardens. Data are presented in terms of net Franc de la Communauté Financière Africaine (FCFA) generated per hectare per year. Prices are calculated based on realistic market price situations expressed in FCFA per kilogram of unprocessed dry cocoa beans purchased by farmers (see text for details).

^bPercentages represent relative drop in income.

significantly along the intensification gradient. Klein et al. (2003a) report a positive relation between functional group diversity and biological pest control in agroforestry systems. Pertinent to these findings is the “insurance hypothesis,” which suggests that a high level of species richness in TCGs will contribute to its high overall resilience (Perfecto et al. 2004; Philpott & Armbrrecht 2006).

A significant decline in plant biomass may result in a significant loss of carbon (Kotto-Same et al. 1997), a decline in the rate of biomass accumulation, and a decline in plantation longevity, which will increase the vulnerability of small cocoa farmers to market fluctuations (Duguma et al. 2001). More diverse, lower-input systems, such as EO and those with sources of revenue other than cocoa, incur less economic risk and protect smallholder cocoa farmers against drastic price drops.

Our findings indicate that shade trees have more influence on cocoa yield than density of cocoa plants. The highest yield we recorded corresponded with shade cover between 40% and 50%. Steffan-Dewenter et al. (2007) reported similar findings in cocoa agroforestry in Sulawesi, Indonesia. Shade-grown cocoa may contribute to higher levels of biodiversity because of lower levels of pesticide use and a better pest control and pollination (Clay 2004). This suggests the possibility of establishing premium prices for shade cocoa with the purpose of conserving biodiversity. Nevertheless, different components of biodiversity may differ in their sensitivity to this shade management. Therefore, conservation of highly sensitive taxa should take into account lower yields resulting from increased shade. Furthermore, analyses of the relationship between yield and species richness suggest that increasing premium values may generate a dramatic shift from a plantation with high yield but low species richness to a plantation with low yield and high species richness. Nevertheless, high yields realized by intensification in TCGs do not necessarily reduce ant biodiversity if a proper shade-vegetation structure is maintained. Policies and incentives aimed at helping cocoa farmers overcome the costs of conversion from low-biodiversity systems to more diverse systems may, therefore, generate simultaneous increases in biodiversity and net income.

Biodiversity and Net Income

Our models indicate that there is no simple trade-off between biodiversity and net income. Therefore, highly diverse TCGs are not necessarily less profitable than less diverse ones (Fig. 3). To prevent further intensification resulting in ecologically unacceptable loss of shade cover and diversity and to improve the income and livelihoods of small cocoa farmers, the government or other agencies should create economic incentives. Incentives may be in the form of organic and fair-trade certifications, whereby farmers directly receive a high premium price or pay a low certification cost (Perfecto et al. 2005). Moreover,

because farmers in southern Cameroon have a long tradition of managing forest trees in their farm yards (Duguma et al. 2001), they prefer low-shade TCGs to open plantations, which suggests that even modest incentives could encourage preservation of shaded TCGs. Despite the high yields of intensified TCGs, their profitability depends on a high cocoa price on the international market. Because the high production costs do not ensure high revenues, intensified TCGs are economically risky.

Conclusions

For a successful certification program in cocoa, shaded cocoa agroforestry systems need to be encouraged and farmers need to be educated on the ecosystem services provided by shaded systems. The market and consumers need to appreciate more environmentally friendly products, and low-intensity systems need to be subsidized. This approach could help guide management decisions by both farmers and certification agencies and will educate farmers and consumers about how TCGs can maintain tropical biodiversity and provide valuable ecosystem services.

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