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REVIEW PAPER

Ecological, economic and social perspectives on cocoa production worldwide

Margaret Franzen · Monique Borgerhoff Mulder

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Abstract Cocoa is a crop grown largely by smallholder farmers in the lowland tropics, including parts of Latin America, West Africa, and Indonesia. Research suggests that it has the potential to provide biodiversity benefits when grown under certain shade conditions, especially when compared with alternative land uses. The primary literature on cocoa production reveals a range of objectives for improvement of cocoa production on small farms. These objectives are sometimes in direct opposition to each other, for example, increasing productivity through shade removal and chemical inputs, and the desire to increase biodiversity benefits. These opposing goals demonstrate some real trade-offs faced by cocoa producers. We summarize the current literature, drawing attention to some of these trade-offs and highlighting important ecological, economic, and social considerations. In considering strategies for ameliorating these negative tradeoffs, we make two primary policy recommendations. First, we suggest that outreach focusing on farm diversification may be the most effective way of optimizing ecological, economic, and social outcomes. Farm diversification may provide an effective means of achieving improved farmer security and dissuade farmers from abandoning or planting cocoa according to price fluctuations, thus reducing the use of new forest areas in cocoa production. Secondly, we suggest greater focus on determining effective economic incentives for maintaining shade in cocoa production. For example, price premiums associated high quality shade-grown cocoa may increase economic benefits while simultaneously providing incentives to farmers to maintain shade in production. Lastly, we identify some important areas of research for further informing policy in this arena.

Keywords Biodiversity conservation · Cacao · Cocoa production · Fair trade · Shade-grown cocoa · Small farmers

M. Franzen (✉) · M. Borgerhoff Mulder
Anthropology Department, University of California, Davis, CA 95616, USA
e-mail: mafranzen@ucdavis.edu

Introduction

Effective and well-informed cocoa policy is necessary from both a biodiversity and social perspective. Smallholder farmers are responsible for roughly seventy percent of total global cocoa production (Clay 2004; Donald 2004) and most of this production occurs in areas of high biodiversity. In addition, the importance of cocoa as a major global commodity makes the establishment of effective cocoa policy a high priority. In this paper we draw attention to some competing cocoa policy demands, such as improving productivity, reducing negative biodiversity impacts, and increasing the social and economic sustainability of production. We discuss the trade-offs faced by farmers associated with pursuing these competing goals, and propose strategies that might optimize ecological, economic and social outcomes.

While biodiversity benefits of cocoa are most commonly linked to cocoa grown under shade, and more specifically in the shade of native forest species, full-sun cocoa is replacing shade production in cocoa growing regions. For example, in Ecuador half of the new cocoa being planted is now of the full-sun, high-yielding variety (Bentley et al. 2004). Furthermore, cocoa price volatility (see Weymar 1968, as cited in Johns 1999; Ruf 1995, as cited in Belsky and Siebert 2003) and the devastating impact of disease on cocoa (see Krauss and Soberanis 2001) puts cocoa farmers in a vulnerable position. An estimated 5–6 million smallholder farmers earn most or all of their cash income from cocoa production (Clay 2004). Fields may be abandoned and converted to pasture (Johns 1999) or full-sun coffee (Saatchi et al. 2001) when prices are low, and when prices improve cocoa farmers plant new trees (Alger and Caldas 1994; Donald 2004), often by clearing new forest rather than replanting existing cleared areas (Rice and Greenberg 2000; Clay 2004).

Researchers and policy-makers with an interest in cocoa production clearly operate with different goals in mind. Some policy and research on small-farm cocoa production is focused on increasing productivity (for example see Johns 1999 on Brazil's modernization program; see also Gockowski and Ndoumbé 2004). Other researchers focus on the sustainability of cocoa production, with sustainability approached from either an agricultural/economic perspective or a biodiversity perspective. As an example of the former Hartemink (2005) looks at nutrient cycling and soil changes in cocoa, Osei-Bonsu et al. (2002) look at the agricultural merits of different inter-cropping strategies, and Krauss and Soberanis (2001) focus on the relationship between shade, disease, and the application of biocontrol on production potential in abandoned fields. As an example of a biodiversity perspective Rolim and Chiarello (2004) explore how improved management practices can increase biodiversity on cocoa farms, and Greenberg et al. (2000) propose including more plants with bird-dispersed fruits into cocoa farms to increase bird diversity. Lastly, whether a particular cocoa production system is considered economically and ecologically sustainable is affected by the time scale considered, with farmers and policy-makers alike typically facing trade-offs between shorter-term economic maximization and long-term ecological sustainability.

The inherent dangers in developing policy with internally contradictory goals (Robinson and Redford 2004; Borgerhoff Mulder and Coppolillo 2005) have been examined most thoroughly by Agrawal and Redford (2006) in a discussion of the currently popular conservation strategy that aims to simultaneously alleviate poverty and enhance biodiversity. In their overview of 37 peer-reviewed studies of such programs they find several obstacles to understanding the potential trade-offs of these two goals. First, rarely are poverty alleviation and biodiversity conservation clearly defined. This means that measures of each are arbitrary. While positive outcomes for both poverty alleviation and biodiversity conservation might be observed, it is important to recognize that other undefined dimensions of poverty and biodiversity may be compromised. Second, evaluations of such programs generally focus *either* on the poverty outcomes *or* on the biodiversity outcomes, reflecting the different disciplinary backgrounds of researchers conducting the studies and the different perspectives of the institutions that endorse and fund the programs. Third, the *assumption* that poverty reduction and biodiversity conservation can be simultaneously achieved distracts attention away from understanding exactly what the trade-offs are and which aspects of poverty reduction are compatible with which aspects of biodiversity conservation. Research into the role of cocoa production in biodiversity conservation and small farmer well-being faces similar challenges.

In this paper we review the current literature on cocoa production to illustrate some of the key trade-offs faced by cocoa farmers. We examine these trade-offs and identify possible strategies for reducing the negative ecological and social consequences that result. We begin by summarizing the relevant findings from the literature concerning the ecological and social aspects of cocoa production. After giving a brief overview of the state of cocoa production in the regions of Latin America, West Africa, and Indonesia, we examine the sustainability of cocoa production using a framework from earlier work (Brooks et al. 2006), looking specifically at the ecological, economic, and behavioral aspects of cocoa production. We then illustrate some key trade-offs associated with different cocoa production practices using specific examples and highlighting cases where economic or ecological benefits are reported. We conclude by summarizing some of the policy implications of our findings and areas where future research is needed.

Cocoa growing regions

Cocoa is produced primarily in Latin America (Belize, Mexico, Ecuador, Peru, Costa Rica and Brazil), West Africa (Cote d'Ivoire, Cameroon, Ghana, Nigeria, and Sao Tome), and Indonesia (Sulawesi, Central Sumatra). Most smallholder farmers use a variable system of production termed ''agroforestry'' whereby forests are selectively thinned so that cocoa and other trees (e.g. fruit trees) can be planted beneath the remaining canopy (May et al. 1993, as cited in Clay 2004). Rice and Greenberg (2000) describe a spectrum of cocoa producing strategies. At one end of this spectrum is ''rustic cacao'' where primary or secondary forests are thinned and cocoa is planted beneath the remaining canopy of native tree species. A similar system, *cabruca*, is used in Brazil and typically has native trees thinned to approximately ten percent of their original abundance. ''Planted shade'' is used to refer to systems where there is greater intercropping of cocoa trees with fruit, commercial timber, or fast-growing shade trees to various degrees. In contrast, full-sun cocoa production uses no shade trees and is becoming increasingly common in some cocoa growing regions.

The western Amazon is the origin of cocoa (Clay 2004) and the crop is presently grown in both Central and South America. Cocoa is grown using the traditional form of cocoa production, known as ''rustic shade'', or cabruca in Brazil as well as under ''planted shade'' canopy which is often composed of planted fruit trees rather than remnants of the native forest (Greenberg et al. 2000; Bentley et al. 2004). Cabruca production systems may become ''planted shade'' over time due to undergrowth clearing (to access the cocoa) which leads to native seedling loss, and the fact that as native shade species die they are typically replaced with non-native shade species (Saatchi et al. 2001).

Brazil and Ecuador are among the countries in Latin America with the greatest amount of land in cocoa production. Brazil has an estimated 697,420 hectares in production while Ecuador has 287,300 hectares (Clay 2004). Cocoa production has contributed to the destruction of the Atlantic Rainforest in Brazil with deforestation resulting from increasing, decreasing, and stagnant cocoa prices (May et al. 1993, as cited in Clay 2004). Clay (2004) describes how it is presently the abandonment of cocoa and conversion of cocoa to other land uses such as pasture and annual crops that is causing the destruction of the remaining shade trees and forest patches. Since these alternative land uses maintain almost no biodiversity benefits, the shade-grown cocoa production system is now seen by many as the best alternative for preserving some of the intact biodiversity of the Atlantic Rainforest. However, the effectiveness of cabruca as a conservation tool is dependent on the presence of native forest in the surrounding landscape (Faria et al. 2006; Harvey et al. 2006).

West Africa is known for the production of higher quality cocoa, though yields tend to be lower than in Asia. Cote d'Ivoire and Ghana are the two countries with the greatest amount of land in cocoa production worldwide and they are also among the three largest cocoa producers. Cote d'Ivoire has an estimated 2.4 million hectares in cocoa and produces 1.4 million metric tons (as of 2000), and Ghana has an estimated 1.5 million hectares in production and produces 436,600 metric tons. However, both Cote d'Ivoire and Ghana have little remaining forest for the expansion of cocoa production, as the original forest remains only in patchy fragments. Other West African producer countries include Nigeria (966,000 hectares in production) and Cameroon (370,000 hectares in production) (Clay 2004).

In parts of Indonesia such as Sulawesi and Central Sumatra, cocoa is responsible for the opening up of primary forests and the establishment of settlements in these previously forested areas. The yields achieved by farmers in Asia tend to be higher than elsewhere and Indonesia produces the second largest amount of cocoa in the world (465,700 metric tons), following Cote d'Ivoire. It has an estimated 360,000 hectares in production (Clay 2004). Akiyama and Nishio (1996) report that Indonesian cocoa farmers have relatively low production costs, price transparency, and receive a large percentage of export price relative to other agricultural commodities. They suggest that some of the advantages experienced by Indonesian cocoa farmers are due to the government's free marketing and pricing system, and they attribute the boom in cocoa production in Indonesia to low transport costs facilitated by government investments in road infrastructure in rural areas. Full-sun cocoa, which increases the fragmentation of primary forests and is considered agriculturally unsustainable, is becoming common in Indonesia (Belsky and Siebert 2003).

Ecological considerations

Rustic shade and cabruca cocoa production systems do not have the same biodiversity benefits as undisturbed forest habitat (Siebert 2002; Clay 2004; Rolim and Chiarello 2004) but research suggests that they are ecologically preferable to other land uses. Evidence for this is reported from Latin America, Indonesia and West Africa to varying degrees. For example, Harvey et al. (2006) find decreasing diversity of dung beetles and terrestrial mammals across land uses in Talamanca, Costa Rica with intact forests showing the highest diversity, cocoa and banana agroforestry systems showing intermediate levels of diversity, and plantain monocultures showing the lowest diversity. Siebert (2002) finds that cocoa grown in Central Sulawesi under primary, secondary, or agroforestry shade has higher biodiversity than full-sun cocoa, and fewer weeds, while Kessler et al. (2005) report that forest gardens in Central Sulawesi which retain some original canopy trees with cocoa have greater tree species richness than secondary forests or cocoa plantations. However, in a study of plant biodiversity in Cameroon comparing cocoa to original forest, secondary forest, fallow fields, and farmland, species richness in cocoa plantations is found only to be better than farmland (Zapfack et al. 2002).

In addition to measuring ecological benefits of shade-grown cocoa in terms of biodiversity and species richness, benefits are reported for specific species, as agricultural benefits, and in terms of habitat protection and connectivity. For example, benefits to specific species are reported for planted shade canopy in Mexico that is frequented by forest and woodland migrant bird species, but not by forest resident bird species, suggesting an important role in the conservation of migratory songbirds (Greenberg et al. 2000). One fruit-bearing tree species found within cocoa plantations on the island of Principe is the nesting site of parrots, and presumably provides them with nutrition (Juste 1996), and farmers in Ecuador claim that large cocoa trees themselves may provide nest sites for parrots and attract other birds as well (Bentley et al. 2004). Tamarins in the Atlantic rainforest of Brazil use cabruca for sleeping and foraging for fruit, flowers, and nectar, suggesting its importance as a habitat for the species, although locomotion within cabruca may be somewhat inhibited (Raboy et al. 2004). Agricultural benefits are reported from Nigeria where cocoa is shown to prevent soil erosion on farms, cause only low levels of depletion in soil nutrients, and cause little to no surface water pollution (Okuneye et al. 2003). Lastly, Saatchi et al. (2001) argue that cabruca may be an important corridor connecting forest fragments and, if managed properly, it could allow for the regeneration of native forest species (Rolim and Chiarello 2004).

Although research supports the view that the conservation importance of shade cocoa is potentially very high, especially when compared to alternative land uses, we find that the biodiversity benefits are often only measured through selective species. In addition, the apparent biodiversity advantages of shade production systems depend on what other land uses these systems are being compared to as well as current management practices, such as the removal of native seedlings (Rolim and Chiarello 2004), that are likely to diminish the conservation value of these systems over time. Furthermore, the greater landscape in which these cocoa systems are found is an important factor in determining the conservation value of such agricultural systems. For example, cabrucas in Bahia, Brazil that are located in a landscape dominated by remnant forest are found to contain species of bats and birds similar to those found in the interior of intact tracts of native forest (Faria et al. 2006). In contrast, the same study finds that cabrucas in a landscape dominated by cabrucas, rather than native forest, host impoverished communities of bats and birds. It remains unclear whether interior forest species can be supported by cabruca systems or whether individuals of those species are simply present due to constant re-colonization from nearby source forest patches (see also Harvey et al. 2006).

Even so, the prevalence of rustic shade or cabruca production systems in Latin America suggests the potential for high biodiversity benefits when compared to other cocoa growing regions where farmers are switching to full-sun production or other land uses dominate the landscape. Shade cocoa also has the potential to be an important salvage conservation strategy in Ghana and Cote d'Ivoire due to the large proportion of woodland dominated by cocoa agroforests (Donald 2004), and the fact that little intact forest remains (Clay 2004). Donald (2004) predicts that cocoa expansion will continue contributing to deforestation in pristine areas of Indonesia, however the presence of protected areas may reduce this trend. For example, Belsky and Siebert (2003) report that by 1999 only 5% of the cocoa planted in Moa, Central Sulawesi, was planted in recently cleared primary forest. They attribute this low percentage in part to the proximity of Moa to the Lore Lindu National Park and the presence of park guards. This is in contrast to much greater estimates of deforestation caused by cocoa expansion in the 1980s and 1990s in Sulawesi, which have also been linked to logging activities (Rice and Greenberg 2000). Yet, government regulations protecting the remaining forest in Indonesia are thought by some to be ineffective (Murray Li 2002).

Economic considerations

Cocoa plays a very important economic role for small farmers. As a cash crop it can provide necessary income for the purchasing of food (Bentley et al. 2004) and is especially important in areas where food security has been a problem (Belsky and Siebert 2003). For example, cocoa appears to provide a main source of income in southern Cameroon. In a sample of 21 villages in southern Cameroon, farming makes up two-thirds of the total income in each village (Sonwa et al. 2002) and Gockowski and Ndoumbé (2004) report that in households where cocoa is an important source of income, it contributes roughly one-third of revenue within them. Furthermore, species inter-cropped with cocoa tend to be medicinal, timber, edible, or fertilizer trees with the potential to increase farmer revenue (Zapfack et al. 2002). An interesting finding by Gockowski and Ndoumbé (2004) is that cocoa revenues in southern Cameroon are positively linked to a household's use of monocrop horticultural production for other commercial crops. This type of monocrop production system is associated with greater use of fertilizers, pesticides, modified soil tillage, and improved seeds than the traditional mixed crop systems. Farmers appear to be using cocoa revenues to purchase the inputs for this intensive monocrop farming. Specifically, they report that farmers with intensive monocrop fields sell double the amount of cocoa than farmers using non-intensive agriculture and the inputs they use cost 29 times the cost of inputs for non-intensified agriculture.

Smallholder farming strategies appear to vary locally and may not be driven strictly by economic considerations. For example, Pomp and Burger (1995) find that the majority of Indonesian cocoa farmers they surveyed do not have a good idea of the price or yield of cocoa prior to their first planting. In this case farmers appear to be planting cocoa for a variety of reasons. They find that one important reason is that neighbors are seen adopting the crop. Other reasons for planting include securing property rights, future income, high price, low labor, quick maturation, and yields throughout the year (Belsky and Siebert 2003). In some areas of Indonesia the rapid rise in cocoa production and influx of migrants is leading to displacement of households lacking resources to invest in cocoa themselves. For example, in the Luje hills the introduction of cocoa has changed much of the land from a collective resource used for rotating swidden to land that belongs to those farmers with enough resources to plant cocoa trees. This newly privatized land is then sold by some farmers needing quick cash, leaving them landless (Murray Li 2002).

Fair trade systems appear to serve in at least some cases to buffer households from some of the risks of cocoa production. For example, fair trade has brought economic benefits to Ecuadorian small farmers including; higher prices, transparency in weighing and grading, market information, cash payments, and capacity building (Nelson et al. 2002). Doherty and Tranchell (2005) discuss The Day Chocolate Co., a fair trade company in Ghana founded by a farmers' cooperative (Kuapa), as an example of how fair trade can benefit small farmer households. The company has increased their sales from 103,500 pounds (in 1998/99) to 5.5 million pounds (in 2004). Two million dollars of this income has been received by the cooperative since 1993; this money has gone to farmers as extra income, towards the establishment of credit unions, medical care, new schools, and increasing access to clean water (Ronchi 2001, 2003, as cited in Doherty and Tranchell 2005). Many of these benefits assist non-members as well. Between 2001 and 2003 there was a 13% increase in membership at the credit union. Kuapa today has 45,000 members in 1124 villages and produces 10% of Ghana cocoa. Despite apparent benefits of fair trade there is some concern over the risk of creating dependency on the fair trade market (Nelson et al. 2002).

Lastly, cocoa farmers may experience some economic (as well as ecological) benefits from using shade in their production. For example, shade trees may attract birds into cocoa fields which may aid in insect control, although the possibility of crop damage exists with increasing bird populations (Greenberg et al. 2000). Shade has been shown to reduce the incidence of some diseases while it may increase others; for some diseases, such as moniliasis, the effects of shade remain unclear (Krauss and Soberanis 2001). According to Krauss and Soberanis (2001) ''economic disease control methods'' are lacking and are sorely needed to decrease losses from disease. Duguma et al. (2001) predict that developing integrated pest and disease management that is cost effective and environmentally sustainable would likely help to promote cocoa agroforests.

Behavioral considerations

Across cocoa growing regions we find some commonalities in the behavior of small scale cocoa farmers. Although some farmers are switching to full-sun production, many farmers acknowledge the benefits of maintaining shade in production. For example, benefits that Ecuadorian farmers attribute to shade include maintaining soil moisture, improving soil fertility, and weed suppression (Bentley et al. 2004). Farmers in Brazil recognize the benefits of shade production as exemplified by their non-compliance with a previous government tree removal program. Johns (1999) describes how this program was initiated in the mid-1970s under the Executive Commission for Planning Cocoa Agriculture (CEPLAC), and was intended to increase the productivity on Brazilian cocoa farms. As part of this ''modernization'' program farm workers were trained to poison trees on cocoa farms, resulting in a supposed loss of 25.8 million canopy trees. However, many farmers kept their shade trees intact, attributing ecological benefits to the trees and expressing concern over the risks associated with tree removal, such as dependency on chemical inputs. Some of the farmers did occasionally apply chemical fertilizers while keeping the shade on their farms intact. According to a survey by Alger and Caldas (1994), large farmers were less likely to adopt the government recommendations, limiting tree removal to small areas, whereas small farmers were more likely to clear-cut trees and plant bananas and manioc in their place. Johns (1999) finds that since the tree removal program was carried out, farmers in the area report a drier climate which they attribute to the loss of forest cover in the region. CEPLAC has since changed its policies and now embraces the traditional cabruca system for the environmental benefits associated with shade production.

Although many farmers appreciate the benefits of shade, native species are often gradually lost from shade production systems over time. Despite the fact that cabruca is a common production system in Brazil, the regular clearing of undergrowth to access the cocoa trees causes seedling loss and the eventual loss of native shade species over time (Saatchi et al. 2001; Rolim and Chiarello 2004). Furthermore, some Brazilian farmers have begun cutting native shade trees and replacing them with low-shade species (Saatchi et al.

2001). In Ecuador, Bentley et al. (2004) find that only one farm out of twenty-one surveyed maintains shade trees that are remnants of the natural forest. The other farmers have all cut the native forest and some have replanted with alternative trees, such as fruit trees, timber, or commercial citrus, clearly reducing the biodiversity benefits associated with maintaining remnant forest species. Further evidence of farmer management decisions having an important biodiversity consequence comes from Tabasco, Mexico, where the trees planted in cocoa fields and farmer management of re-growth limit the abundance of bird-dispersed fruit making the fields less attractive to small fruit-eating bird species (Greenberg et al. 2000). Greenberg et al. (2000) suggest that inclusion of more plants with bird-dispersed fruits into cocoa farms would lead to increased abundance and diversity of birds.

Farmers show sensitivity to the relative prices of different cash crops, although price effects tend to be complex. In Brazil crashes in cocoa prices and disease have led to abandonment of cocoa and conversion of cocoa to pasture (Johns 1999), which often includes conversion of adjacent remnant forest patches (Alger and Caldas 1994). Falling cocoa prices have also led to selective logging of hardwood trees, most often from forest remnants on large cocoa plantations (Alger and Caldas 1994). In response to high prices and demand for plantains, farmers in Talamanca, Costa Rica have been abandoning their cocoa and banana agroforestry systems and planting plantain monocultures instead, which support significantly less biodiversity than the agroforestry systems they replace (Harvey et al. 2006). Increases in crop prices have generally been shown to increase the rate of forest clearing in Cameroon, threatening biodiversity, yet a clear difference is seen between perennials (cocoa) and annuals (food crops). Although there is evidence that increases in cocoa and coffee prices during the oil boom led to increases in forest clearing, the link to increased forest clearing is weaker for perennials than it is for annuals (Gbetnkom 2005). For example, in the period after 1989, a decline in the government purchase price of cocoa and a reduction in government subsidies for inputs led to a drop in cocoa and coffee prices that spurred a switch from growing cocoa (and coffee) to growing food crops, resulting in an increase in the rate of deforestation in that period (Ndoye and Kaimowitz 2000; Sunderlin et al., 2000). Some researchers expect cocoa to continue contributing to deforestation in the remaining pristine forests of Cameroon (Donald 2004).

With respect to net profits, shade grown cocoa shows sensitivity to the costs of labor and pesticides. An increase in the cost of labor may motivate farmers to abandon their cocoa, and some farmers respond by switching to logging or full-sun coffee (Saatchi et al. 2001). Alternatively, labor often replaces the use of pesticides when costs of such inputs are high. For example, Sonwa et al. (2002) report that after the removal of a pesticide subsidy in Cameroon farmers began increasing the diversity of their crops and incorporating integrated control methods based on traditional knowledge to fight pests such as capsids and black pod disease. Half of the farmers they interviewed in southern Cameroon claim to know these methods, and half of the farmers reporting knowledge of the methods report using them as well. In Ghana farmers cannot afford pesticides and rely on traditional insect control methods, such as weeding, pruning, and disposal of waste, which are associated with the production of higher quality cocoa (Leiter and Harding 2004; see also Olujide and Adeogun 2006). Interestingly, a high price premium for quality cocoa, relative to a low standard price, is found to motivate the production of such higher quality beans in Nigeria (Berry 1975, as cited in Leiter and Harding 2004). Here, low levels of surface water pollution found near cocoa farms are attributed to the low use of agrochemicals by farmers (Okuneye et al. 2003).

Given the sensitivities discussed above it is not surprising that we see some farmers switching to full-sun production because of lower labor costs and higher short-term yields.

For example, Sulawesi cocoa farmers are switching from long-fallow shifting cultivation of food crops to intensive full-sun cocoa (Siebert 2002; Belsky and Siebert 2003). Siebert (2002) reports that between 1990 and 1999 in Moa cocoa production rose from one household to all households, replacing shifting cultivation farms with full-sun cocoa, and suggests that in the long-term this replacement may result in decreased soil fertility and require the use of chemical inputs if shifting back to the cultivation of food crops becomes necessary. Some farmers began adding shade and fruit trees to their full-sun cocoa after a drought caused widespread mortality of cocoa seedlings (Siebert 2002; Belsky and Siebert 2003). However, those farmers that have added trees oftentimes remove them when fruiting begins in order to maximize sun and yield (Belsky and Siebert 2003). Full-sun production is being adopted in other areas as well. Whereas previously 94% of the cocoa farms in Ecuador used traditional shade-grown cocoa, half of the trees planted in the last 5 years are of the modern full-sun varieties (Bentley et al. 2004). This change is attributed to the collapse of the quality grading system that had been in place prior to the 1960s (Arosemena 1991, as cited in Bentley et al. 2004). With all varieties fetching the same price, the incentive for growing high quality cocoa has disappeared.

Discussion

Comparison of different production systems

Cocoa grown under the canopy of original forest is considered the most environmentally sound form of production. Even though shade-grown cocoa results in some loss of biodiversity, shade systems have been shown to have higher biodiversity than full-sun systems. Lower levels of pesticide use in shade may also contribute to higher levels of biodiversity, and this increased biodiversity is associated with better pest control and pollination and more efficient nutrient cycling (Whinney 2001, as cited in Clay 2004). Additionally, shade cocoa may have biodiversity benefits in the form of providing corridors to connect forest patches for dispersing animals (Alves 1990, as cited in Saatchi et al. 2001), and possibly in restoration projects as well (Rice and Greenberg 2000).

Although shade trees may compete with cocoa, they provide a multitude of benefits, including: inhibiting weed growth (Siebert 2002), reducing soil erosion, buffering the cocoa against adverse climatic conditions and pests, and increasing the efficiency of nutrient use by the cocoa trees (Rice and Greenberg 2000; Hartemink 2005). Cocoa benefits as well from the wind protection offered by forest cover (Laird et al. 1996, as cited in Clay 2004). As mentioned earlier, shade has been shown to reduce the incidence of some diseases, yet it may increase others. Shaded cocoa also appears to have an advantage over full-sun in terms of its production potential after rehabilitation of abandoned fields (Krauss and Soberanis 2001). Compared with annual cropping systems cocoa ecosystems have less nutrient loss through leaching, less soil erosion, a small fraction of nutrient loss through yield (beans), better carbon storage, and typically lower levels of nutrient and metal pollution due to the generally low levels of fertilizer use among cocoa growers (Hartemink 2005).

Alternatively, full-sun production results in increased yields in the short-term but requires the use of chemical fertilizers to maintain high yields (Ahenkorah et al. 1974, as cited in Rice and Greenberg 2000). Full-sun conditions also encourage the growth of weeds leading to greater use of herbicides (Clay 2004). There are an estimated thirty-two common pesticides used in cocoa production, some of which are banned in consuming countries, and nine of which are included in the ''dirty dozen'' identified by the Pesticide Action Network (Laird et al. 1996, as cited in Clay 2004). Improper use of these chemicals not only causes damage to the local environment but can also be very harmful to farm workers.

As discussed by Clay (2004), high-yield varieties used in intensive production systems, and planting at high densities with or without intercrop species, may serve as a means of alleviating the pressure to clear primary forest in order to expand production. Yet this may only be a short-term solution. Such varieties grown intensively tend to produce for a much shorter time period, often only 6–8 years (Clay 2004), whereas shade varieties are reported to continue producing for 80–100 years (Bentley et al. 2004), though with yields declining 15 to 20 years after planting (Clay 2004). Although some areas of intensive production may be replanted when productivity declines after six years, new plantings will not always be confined to the same areas, and the claim that such intensive production systems will reduce the clearing of new forest cannot be guaranteed. In addition, while the shade cocoa uses little to no chemical inputs, intensive production systems require these inputs and farmers using such production techniques will be dependent on chemical inputs but not always able to afford them (see Leiter and Harding 2004). Furthermore, farmers may face a reduction of future food production potential on land where full-sun cocoa is grown (Belsky and Siebert 2003).

In an effort to address some of the challenges faced by cocoa farmers, plant breeders are attempting to breed cocoa varieties so as to improve resistance of plants to disease, pests and adverse environmental conditions (Laird et al. 1996, as cited in Clay 2004). In addition, trees are sometimes being grafted so that they will produce sooner than the three to four years it takes traditional cocoa trees to produce, although grafting is typically associated with full-sun production (Clay 2004).

Trade-offs

The attraction of full-sun production is clearly the ability to increase yields and therefore increase the economic benefits of cocoa production in the short-term. Yet full-sun cocoa provides very little benefit in terms of biodiversity conservation. One consequence of this reduced biodiversity is less resistance to pests, and the need for fertilizer and other chemical inputs. These inputs cost, and depending on the relative prices of inputs and cocoa, farmers will not always be able to afford inputs. This dependence on inputs may ultimately cause a decline in yield if the inputs cannot be purchased. Regardless, full-sun cocoa tends to produce for a shorter amount of time than does shade cocoa. Shade cocoa may provide fewer economic benefits in the short-term but it will continue producing into the future without the need for chemical inputs. It also has the potential to provide significant biodiversity benefits (and already does so in some cases). We argue that this trade-off between biodiversity conservation and economic benefits is really only a trade-off in the short-term, and that a longer-term view of cocoa production allows these economic and biodiversity goals to be simultaneously met more easily.

Another important decision faced by cocoa farmers is whether to replant existing cleared areas or clear new forest for planting. Replanting existing cleared areas is preferable from a biodiversity standpoint to clearing new forested areas. However, there is often little incentive for farmers to replant in existing fields when there is forest available for clearing. This is due to issues of productivity and labor requirements. For instance, trees planted in cleared forest may yield 15% to 25% more than trees grown in an area that was replanted (Matlick, personal communication, as cited in Rice and Greenberg 2000). Furthermore, replanting requires about double the labor input as does clearing new forest (Ruf 1995, as cited in Clay 2004; Rice and Greenberg 2000). Full-sun cocoa, because it uses chemical inputs, may be more appropriate for planting in existing cleared areas that may already have some level of soil depletion. However, as mentioned above there is no guarantee that existing cleared areas will be used even when planting full-sun cocoa, if there remains forest available for planting. The trade-off between biodiversity benefits and economic benefits is very real for farmers facing the decision to replant or clear new forest.

Policy implications

Informed policy may be effective in ameliorating some of the trade-offs associated with competing goals. We make some recommendations aimed at achieving social and ecological sustainability in cocoa production and suggest that the time frame under which these goals are considered is important.

First, we suggest that outreach focusing on farm diversification may be the most effective way of optimizing ecological, economic, and social outcomes. Specifically, the diversification of crops and income may simultaneously benefit biodiversity and the economic security of small farmers. Many biodiversity and economic outcomes are linked to price fluctuations. For example, fluctuations cause cocoa to be risky for small farmers, as shown in the review of cocoa growers' behavioral patterns, and farmers often react to prices by clearing forest to plant, or abandoning fields. Over-planting of cocoa when prices are high leads to large surpluses in the future (Donald 2004). For example, Clay (2004) attributes the fall in cocoa prices in 2000–2001 to over-planting in 1976–1997 (due to high prices) which resulted in surpluses in the 1990s, causing prices to fall. Schulz et al. (1994) argue that farmers with diverse agroforestry systems are better able to weather a changing market. Incentives for increasing the diversity of crops grown or expansion of income-earning opportunities would buffer the impact of price fluctuations and the reaction of farmers to each price change. If farmers were less dependent on cocoa as their sole source of income they might be less inclined to plant during periods of high prices. Support for this comes from Alger and Caldas (1994) who find that cocoa farmers supplementing income with cattle are more likely to want to preserve remaining forest on their land. Immediate productivity could be improved by increasing labor inputs into existing crops when prices are high (see Gbetnkom 2005), which would increase income but not contribute to large surpluses in the future.

The promotion of inter-cropping may be one way to diversify the income of smallholder cocoa farmers (Clay 2004). There is evidence from a study in Panama that shaded cocoa inter-cropped with timber and plantains is likely to provide greater net income and is less risky than cocoa produced as a monocrop (Ramírez and Somarriba 2000 and Ramírez et al. 2001, as cited in Bentley et al. 2004). The ecological and biodiversity benefits of diversifying cocoa farms with economically valuable tree species are not well known (Leakey and Tchoundjeu 2001). Rolim and Chiarello (2004) suggest that in order to improve the conservation value of cocoa production systems, farmers would need to remove non-native species and allow the regeneration of native forest species. However, Ashley et al. (2006) point out that non-governmental organizations involved in the promotion of tree planting may have a history of promoting (and may continue to promote) non-native and even invasive species. Furthermore, they draw attention to challenges that may exist such as the 'reserved' species laws in some African countries that mandate government control over certain native trees and which may discourage farmers from planting or maintaining natives on their land. In such cases policy adjustments would need to be made to encourage farmers to plant native trees. In addition, research on the ecological and economic value of possible inter-crop species may help to identify the mix of species that together with cocoa would provide the greatest economic benefit to farmers while simultaneously maximizing biodiversity benefits (Leakey 1998; Rice and Greenberg 2000). In this way policy decisions could be informed on which alternative crops and income-generating activities work well to complement cocoa production in these households.

The economic security of small farmers may be improved more by encouraging diversification (Leakey 1998) than by focusing on increasing productivity in the short-term. This is because increasing the short-term productivity of cocoa may not lead to economic security of small farmers in the long-term. In particular, increasing productivity through the reduction of shade and an increase in the use of chemical inputs may ultimately decrease the economic security of small farmers. Shade provides many ecological benefits and once removed, farmers become dependent on chemical inputs that may not always be affordable to them. Improving cocoa yields does not require the use of full-sun and agrochemicals, rather increases in labor inputs such as regular pruning can reduce pests and increase yields (Clay 2004). In combination with shade, even low levels of fertilizer can lead to greater long-term production in older cocoa trees (Ahenkorah et al. 1974, as cited in Rice and Greenberg 2000). Lastly, planting cocoa under secondary forest may be preferable to primary forest in terms of combining ecological and economic benefits. Cocoa grown under secondary forest has more light than under primary forest, resulting in higher yields, while simultaneously maintaining some of the environmental and biodiversity benefits of cocoa grown under primary forest canopy (Siebert 2002).

Secondly, we suggest greater focus on determining effective economic incentives for maintaining shade in cocoa production. Premium prices for ''high quality'' cocoa grown under shade could help to promote shade production and preserve traditional cocoa varieties. Farmers in Ecuador report that the traditional shade grown cocoa variety (*nacional*) has superior flavor and lives longer than the modern full-sun varieties, but the fact that both varieties now fetch the same price is causing some of them to plant the modern varieties because of their higher yields early on (Bentley et al. 2004). Gbetnkom (2005) finds that the value added per hectare (profit per hectare) is linked to less forest clearing in a study of the causes of deforestation in Cameroon. This supports the idea that premium prices for shade grown cocoa could have positive environmental, as well as economic, effects. Rice and Greenberg (2000) suggest that farmers who grow cocoa according to specific criteria aimed at increasing biodiversity benefits could receive not only higher prices for their product but also access to credit and extensions services if environmental funds were made available for such programs.

Increases in the price of labor make full-sun cocoa cheaper to produce than shade-grown cocoa due to the higher productivity and the replacement of labor with chemical inputs. As a result Clay (2004) predicts that full-sun cocoa, if it continues to be planted in areas of Asia, will likely cause a reduction in the price of cocoa and consequently marginalize farmers using shade production especially if the price of labor increases. Farmers faced with low cocoa prices and high labor costs will be more likely to choose the production methods that minimize labor inputs, such as clearing new forest for planting. This could be remedied if the price of shade-grown cocoa could be increased through shade-grown or organic certification and fair trade programs. Fair trade has the potential to provide higher prices as well as additional benefits to small farmers. High prices can be obtained through a fair trade premium or through improving efficiency by removing middle men in the export process. For example, a fair trade company operating in Ecuador was able to pay farmers higher prices due to marketing efficiencies rather than through a premium price being paid for the fair trade label (Nelson et al. 2002).

Lastly, Clay (2004) suggests that payment for carbon sequestration could be used as an incentive to farmers for maintaining shade trees in cocoa production. Financial incentives could be in the form of tax waivers or subsidies (Alger and Caldas 1994; Donald 2004). Such incentives could also be used to encourage farmers to allow their abandoned cocoa crops to regenerate into forest rather than clearing the land for alternative uses. Saatchi et al. (2001) suggest that radar sensors could be used to monitor whether landowners receiving payment or other incentives for environmental services are complying with shade requirements.

Conclusion

''Only through additional systematic investigation will we come to know which aspects of biodiversity can co-prosper with alleviation of different aspects of poverty'' (Agrawal and Redford 2006, p.32). This is also true for understanding the trade-offs associated with the ecological, economic and social aspects of cocoa production. For example, it remains unclear to what extent shade-grown cocoa systems are capable of actually supporting interior forest species independent of nearby forest patches, and which species and other aspects of biodiversity are most likely to benefit from these systems. Additional research is also necessary for understanding which combination of native and economically valuable non-native tree species would maximize benefits to farmers while maintaining certain biodiversity benefits. Furthermore, studies on the effectiveness of various economic incentives for maintaining shade in cocoa production are important for finding sustainable solutions that benefit both farmers and biodiversity. Some further areas for future research include traditional pest control, alternative methods of boosting productivity, and broader land use patterns, and are summarized below.

Disease is a significant challenge to smallholder cocoa farmers as is illustrated by the abandonment of over 50% of all cocoa in Peru in the year 2000 largely due to moniliasis (Krauss and Soberanis 2001). Research has shown that when agrochemicals are not available farmers apply pest control measures based on traditional methods, suggesting that this is an important area for future research. Information on effective traditional methods could then be provided to farmers through extension services. The economic impact of such methods should be understood in terms of the labor requirements and success of these methods relative to the purchasing and application of chemical inputs. Another important area for future research is identifying strategies for improving productivity without causing ecological damage as occurs with the use of chemical inputs or full-sun production. For example, the number of seedpods produced on a tree is affected by the abundance of pollinators (Clay 2004), suggesting a possible alternative approach to improving tree productivity. Lastly, clearing new forest in order to expand cocoa production is deemed cheaper in terms of labor and inputs than replanting in previously used areas. Research on how cocoa can be efficiently incorporated into a cycle of crops and fallow may assist with identifying sustainable land-use practices and appropriate uses for land previously under cocoa production. Ultimately, a long-term view of cocoa production may provide an arena where both ecological sustainability and economic and social benefits to farmers can be simultaneously achieved.

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