

Farmers in Côte d’Ivoire value integrating tree diversity in cocoa for the provision of ecosystem services

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Abstract Côte d’Ivoire produces 40 % of the world supply of cocoa but much of the plantation area is aging and declining in productivity, while opportunities for land expansion into new forest land are quickly disappearing. Rejuvenation strategies for cocoa presently coalesce either around improved varieties and greater use of agro-chemical inputs in full sun systems or eco-certification that requires trees to be integrated with cocoa. Here, we explore the possibility of uniting

these approaches through building on current farmer practice of incorporating trees in their cocoa fields to improve cocoa productivity and diversify their livelihoods. We interviewed 355 farmers about trees integrated in their cocoa fields across four locations in the South-West of Côte d’Ivoire in 2012, stratified by whether or not farmers were eco-certified. Despite the massive deforestation, a rich diversity of trees was found in cocoa fields and an overwhelming majority of farmers (95 %) wanted more trees and/or more tree species, regardless of their certification status or ethnic origin. There was a consensus that most trees were compatible with cocoa, but farmers also traded off negative impacts of some species against their productive contribution to their livelihood. Farmers valued tree diversity on their cocoa plots and provided detailed information on how 32 tree species interacted with cocoa in terms of soil moisture retention, soil fertility improvement and pest and disease interactions but also had key gaps in knowledge about alternative hosts of mirids and mistletoe. The majority of farmers were not aware of the certification requirements for tree species and shade cover but a much higher proportion of certified farmers (76 %) had received information about shade trees than non-certified farmers (15 %), although advice only related to eight tree species. Scope for building on local knowledge and practice to sustainably increase cocoa productivity through promoting tree diversity while enhancing other ecosystem service provision was identified and the next steps required to realize this set out.

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Introduction

Côte d'Ivoire produces 40 % of the world's cocoa, an important global commodity, with an annual value of over 10 billion USD of unprocessed beans (World Cocoa Foundation 2012). The economic and political significance of cocoa is of great importance for the country; not only as a key source of foreign exchange revenue but also as a cash crop grown by 700,000 smallholders and sustaining the livelihoods of over four million people (Mission économique 2005). In the South-West of Cote d'Ivoire, over the last forty years, the growth of the cocoa sector, driven by a favorable policy environment, has attracted a large influx of migrants from neighboring countries and led to the massive destruction of large parts of the Guinea Rainforest, a global biodiversity hotspot (Clough et al. 2009; Gockowski et al. 2004). Ivorian forest cover was estimated to be 14.5 million ha in 1900, reduced to 9 million ha in 1965 and to 2.5 million ha in 1992 (Oszwald 2005). The severe impacts of widespread cocoa-led deforestation on the provision of ecosystem services, including biodiversity loss, has raised significant concern, notably amongst conservationists, about the sustainability of cocoa land use (Rice and Greenberg 2000; Schroth and Harvey 2007; Clough et al. 2009). Historically, cocoa production in Côte d'Ivoire has increased by extending the cultivated area and taking advantage of soil fertility built up under forest cover (Ruf and Zadi 1998). Today, in West Africa and particularly Côte d'Ivoire, declining yields, resulting from ageing cocoa fields with low fertility, pest and disease problems, coupled with scarcity of forest are posing severe challenges to both the farmers and the industry (Ruf 2011; Tschardt et al. 2011). Concerns over the future supply of cocoa to meet a predicted annual increase in world demand of 2–3 % has prompted the industry and governments in West Africa to support research and development activities aimed at rejuvenating ageing fields to increase their productivity (Asare 2005).

Cocoa is traditionally grown in agroforestry systems with permanent shade management resulting from thinning the original forest canopy and retaining

a diversity of trees, planting useful fruit and timber species as well as protecting valuable trees from natural regeneration. Although complex multi-strata shaded systems still prevail in Cameroon and parts of Nigeria, there has been an increasing move in West Africa towards intensification of cocoa management with shade removal and monoculture practices (Gockowski et al. 2004; Ruf 2011). In the South-West of Cote d'Ivoire, the majority of cocoa farms were established on forestland, mainly planted with unselected cocoa genetic material and a mixture of Amelonado and hybrids, temporarily established under *Musa* spp. shade and predominantly managed with low shade or no shade (Gockowski and Sonwa 2011; Sonwa et al. 2014). Agricultural extension services in Côte d'Ivoire have traditionally promoted intensive systems in full sun to maximize short-term yield (N'Goran, 1998; Asare 2005). Complete forest clearance was encouraged (Ruf and Zadi 1998) and a list of 45 forest tree species identified that should not be associated with cocoa for a number of antagonistic reasons such as pest and disease relationships, allelopathic behavior, or low shade quality because of their dense or low canopy (SATMACI 1984; FIRCA 2008). More recently, as part of the Cocoa Swollen Shoot Virus (CSSV) control strategy a new list of trees that should be excluded from cocoa fields is being disseminated to farmers (CNRA 2011), further limiting their options for tree management. Little or no scientific evidence exists as to the compatibility of most of these tree species or their host status for CSSV.

Tree removal has been synonymous with intensification practices linked to superior hybrids and external chemical inputs that result in short term increases in cocoa yield. However, in the longer term, the social and economic value of associated trees in cocoa fields has been shown to contribute to reducing household vulnerability to climatic stress, pest and diseases infestations, cocoa price fluctuations and food insecurity (Tschardt et al. 2011). Diverse shaded cocoa systems provide a range of products and environmental services, key for the sustainability of cocoa systems and local farmers' livelihoods (Duguma et al. 2001; Bisseleua et al. 2009). Trees on cocoa farms support rural communities by meeting household demand for essential products such as timber, fuel wood and fruits and by enabling the diversification of income sources with high value products that can reduce the risks associated with

relying solely on cocoa revenues (Herzog 1994; Sonwa et al. 2007, 2014; Cerda et al. 2014). From a conservation point of view, agroforestry systems involving perennial tree crops associated with a diversity of trees can be important systems when replacing tropical forest because they constitute reservoirs of biodiversity (Rice and Greenberg 2000) and hold important carbon storage potential (Somarriba et al. 2013; Saj et al. 2013). Furthermore, research into cocoa agroforestry systems has shown that trees can increase and sustain cocoa system productivity through eco-physiological, economic and environmental interactions (Clough et al. 2009). With the appropriate species and management regimes, the productivity of cocoa farms can be enhanced through amongst others; soil fertility improvement (Isaac et al. 2007), microclimatic amelioration (Tscharntke et al. 2011), reduction in pests and diseases (Schroth et al. 2000; Bos et al. 2007) and increasing resilience to climate change (Duguma et al. 2001; Franzen and Mulder 2007). Linkages between cocoa productivity and vegetation structure are still poorly understood and research on farmers' shade management strategies is important to understand how spatial distribution, tree density and species composition affect productivity (Deheuvels et al. 2012).

Despite the growing evidence that more complex multi-strata shaded cocoa systems can improve livelihood and landscape management, there is still a lack of both fundamental and applied research into cocoa agroforestry systems in West Africa. In Côte d'Ivoire in particular, efforts have focused mainly on the agronomic intensification of high yielding hybrids with a recent interest in leguminous tree species in fallow rehabilitation and cocoa replanting strategies (Asare 2006; Tscharntke et al. 2011). Challenges associated with ageing and maintenance of cocoa farms, as well as questions related to the economic and environmental sustainability of such systems, require the design of new cocoa agroforestry management strategies. Consumers worldwide have fueled an increasing demand for eco-certified cocoa through which farmers receive a premium for cultivating cocoa under a diverse layer of native shade trees and for following more environmentally-friendly practices (Franzen and Mulder 2007). New knowledge is required to understand how to manage more diverse shade systems to restore and enhance ecosystem service provision in the broader landscape. Cocoa

fields have mainly been established on forestland and trees now found associated with cocoa are influenced by a combination of factors that include; the native tree cover, farmer preferences, research recommendations and the activities of extension services (Asare 2006). How local people manage natural resources is dependent on their knowledge and on the opportunities, constraints and trade-offs that may exist around integrating trees with cocoa. The aim of this research was to improve our understanding of associated trees in cocoa systems in the South-West of Côte d'Ivoire. The main objective is to increase both productivity and sustainability of cocoa farming in the region of Soubré through improved genetic material and the promotion of good cocoa farming practices. With the aim of exploring opportunities for integrating trees that increase the delivery of ecosystem services on cocoa farms, the specific objectives of our study were to identify trends in tree species diversity in (1) eco-certified and non eco-certified cocoa farms and (2) between farmers of different ethnic origin, to compare perceptions and knowledge about general and specific tree cocoa associations.

Materials and methods

Study area

The study area covered four villages and the surrounding 'campements' with different migrant communities in two departments: Gligbaedji (San Pedro), Kragui, Petit Bouaké and Buyo (Soubré) across the Bas-Sassandra region in the South-West of Côte d'Ivoire. The sites were selected because they represented a diversity of zones covered by the ICRAF/MARS Vision for Change (V4C) project and due to the presence of eco-certified cooperatives that have been active for at least 3 years. The climate is subequatorial, following a bimodal seasonal regime with two wet seasons, one from March to June and one from September to October. The annual average temperatures range from 24 to 29 °C and average annual rainfall ranges from 1,600 to 1,800 mm (Brou 2010). The soils are ferralitic and highly prone to leaching. The natural vegetation of the South-West of Côte d'Ivoire is evergreen forest belonging to the Guinea-Congo Basin massif forest. The main land uses are cocoa, oil palm and rubber. Total population

of this zone was estimated at over 940.000 inhabitants, with ~74 % living in rural areas. Once a sparsely populated forest area, the population density of the Soubré department is today significantly higher than the national average (48 inhabitant per km²), and averaged 76 inhabitant per km² (ICRAF 2011). This is mainly due to the expansion of the cocoa sector, which attracted both national and foreign migrants. Native population (mainly Bakoué, Bete and Kouzie) constitutes only about 30 % of the total population. National migrants (Baoulé, Agni, Abron, Wan, Sénoufo and Malinké) account for 45 % and foreign migrants, primarily from neighbouring Burkina Faso and Mali, account for 23 % (Assiri et al. 2009).

Data collection

A structured questionnaire was used to collect data. In the first part of the questionnaire, we collected characterization information about the farmers and their cocoa fields (number and size of fields, mode of acquisition, associated crops and tree species). The second part of the questionnaire contained open-ended questions about the general perceptions of production benefits and drawbacks linked to associated tree species in cocoa fields. A series of specific questions covering tree uses and direct tree cocoa interactions such as physical damage from branches, competition for nutrients and relationship with key cocoa pests and diseases (*Phytophthora* spp, mirids, rodents, mistletoe) were asked systematically for ten of the tree species present in cocoa fields. If the farmer had more than 10 species present in his fields, the trees evaluated by farmers were randomly selected from the list of trees species present. The majority of cocoa farmers were interviewed in their cocoa fields in order to enable an easier recollection of the trees present and their interactions with cocoa. However in cases where the farms were large or were composed of isolated plots that were not easily reachable, the list of trees was based on farmers' recollection of trees present in the cocoa fields.

Trees were recorded using local vernacular names. A visual aid folder based on the floristic guide of the Tai National Parc (OIPR and GTZ 2000) was used to facilitate the identification of trees with images and local names. A field visit was conducted by one of the authors, Dr. Gnahoua, a forest botanist, for botanical verification of as many unidentified forest tree species

as possible. The Floristic Institute of Cocody University provided additional help in species identification. Only tree species that were described by at least 20 farmers are included in the results section.

Sampling strategy

The objective was to survey the persons that make management decisions about their cocoa farms. The sample was stratified according to ethnic origin, participation in eco-certification schemes and location (Table 1). Whether or not farmers were eco-certified (Rainforest Alliance or UTZ) was a second stratification criterion. With respect to location, 90 farmers were interviewed in Kragui, 91 in Petit Bouaké, 90 in Buyo and 85 in Gilgbeaudji. A total of 21 women were included in the sample.

Data analysis

Means and standard deviations for two variables; number of associated tree species and tree density in cocoa fields were computed. Anova analysis was performed with XLSTAT 2013 (Version 4.05) with a comparison of the means according to the Newman-Keuls test at the significance level of 5 % to explore statistical differences between certification status and ethnic origin on the number and density of trees in cocoa fields.

Results

Characterization of cocoa farms

The area of cocoa in the study area was expanding rapidly from the mid 1970s to mid 1980s, almost a quarter (24.2 %) of cocoa fields in the sample were established in the 1960s, the vast majority (88 %) were

Table 1 Number of farmers interviewed in the survey in the South-West of Côte d'Ivoire according to ethnic origin and eco-certification status

Ethnic origin	Eco-certified	Non eco-certified	Total
Local	59	57	116
National migrant	66	57	123
Foreign migrant	64	52	116
Total	189	166	355

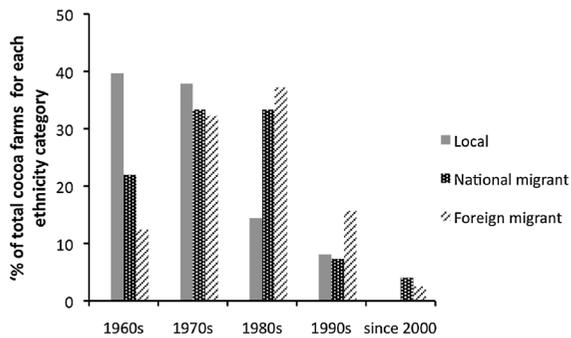


Fig. 1 Proportion of the total number of cocoa fields for each ethnicity category of farmers that were established in each of the last five decades in the South-West of Côte d'Ivoire

over 20 years old with well over half (59 %) being more than 30 years old. There was a decrease in the establishment of new cocoa fields from the mid-1980s, with only 2 % of cocoa fields in the survey having been established after 2000. Whereas most of the local farmers in the survey had established their cocoa fields by the end of the 1970s, many of the national and foreign migrants established their farms in the 1980s (Fig. 1).

Most local farmers had small cocoa fields (<5 ha) compared to national and foreign migrants, who had fields ranging between 2 and 10 ha (Fig. 2). There were no local farmers and very few migrant farmers that had cocoa fields larger than 20 ha. Field size was not significantly affected by farmers' eco-certification status. The majority of farmers cultivated a single cocoa field (76 %) whilst 19 % had two, 4 % three and 3 % had four separate cocoa fields. In terms of crops associated with cocoa, taro (*Colocasia esculenta*) was the dominant crop grown (82 %), although farmers said that it was increasingly threatened by the use of herbicides in cocoa fields. Almost a third (30 %) of farmers did not grow any food crops in their cocoa fields, while the majority (70 %) used empty spaces in the field for growing food crops. These were mainly *Musa* spp. (on 53 % of farms), yam (*Dioscorea rotundata*) (47 %) and cassava (*Manihot esculenta*) (30 %) but also included vegetables like aubergine (*Solanum melongena*), chili pepper (*Capsicum* spp.) and pineapple (*Ananas comosus*) mainly planted on field boundaries. Ten farmers also intercropped coffee in their cocoa fields.

Tree diversity in cocoa fields

The mean number of tree species found on cocoa plots was highly variable within and between certified and

non-certified farmers and ethnic origin categories and hence there were no significant difference amongst them (Table 2). Overall, there were almost ten species per farm (mean of 9.6 ± 4.6) with more naturally regenerated (6.0 ± 3.4) than planted tree species (4.0 ± 1.8).

There was a clear trend of decreasing tree density with increasing field size (Table 3). The highest tree densities were observed in the smallest cocoa fields, especially those <2 ha. Although the trend of decreasing tree density with field size was more distinct for eco-certified farms, there was no significant difference in mean tree densities between eco-certified and non eco-certified farmers. Overall, 74 tree species were botanically identified and evaluated by farmers. A further 84 vernacular tree names, in more than six local dialects, were also recorded but their botanical equivalents could not be verified, and 39 farmers, of different ethnic origins, described one or more trees without being able to give them a vernacular name.

Over 50 tree species (7 exotic and 44 native) from 27 botanical families were present on at least three cocoa farms and ranked according to their frequency of occurrence on farms (Table 4). The overwhelming majority of tree species in cocoa fields were native and naturally regenerated but the most frequently encountered species were exotic fruit trees planted by farmers and used for nutrition and income. Ten species found on cocoa farms were listed in the IUCN red list of endangered species with different conservation ratings; lower risk/least concern (5), lower risk/near threatened (2), vulnerable (2) and endangered (1).

Farmers' perceptions about tree species grown with cocoa

An overwhelming majority of cocoa farmers (338 out of 355) expressed a generally favorable opinion about integrating trees in their cocoa fields. The most important benefits of trees mentioned by farmers were related to ecosystem services including protection of cocoa trees from heat stress, especially in the dry season, and soil fertility improvement, both mentioned by over half the farmers (Table 5). The value of trees for 'bringing rain', increasing soil moisture availability and controlling soil erosion, was mentioned by over 20 % of farmers. The most important drawbacks of trees in cocoa plots were that they could cause physical damage to cocoa, mentioned by almost a third of

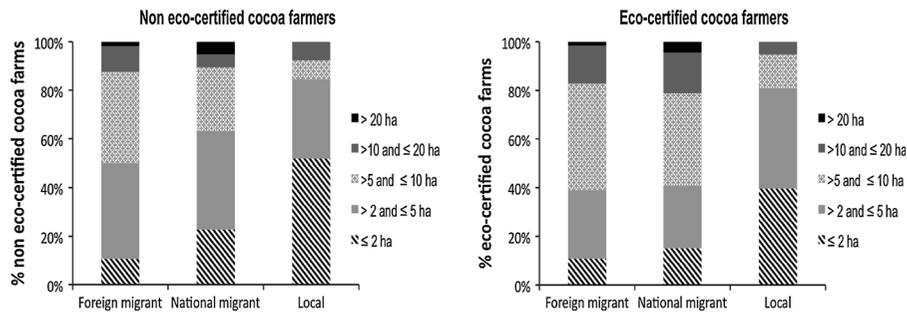


Fig. 2 Percentages of eco-certified and non eco-certified cocoa farms in different size categories according to ethnic origin of farmers in the South-West of Côte d'Ivoire

Table 2 Means and standard deviations of numbers of tree species (planted and naturally regenerated) in cocoa fields, according to eco-certification status and ethnic origin in the South-West of Côte d'Ivoire

Type of farmer	Total number of tree species	Number of naturally regenerating species	Number of planted species
Eco-certified	10.0 ± 4.6	5.8 ± 3.3	4.2 ± 1.9
Local	9.6 ± 4.9	5.9 ± 3.5	3.7 ± 1.7
National migrant	10.3 ± 4.6	6.1 ± 3.3	4.2 ± 1.9
Foreign migrant	10.0 ± 4.4	5.5 ± 3.1	4.6 ± 2.0
Non eco-certified	9.2 ± 4.6	5.3 ± 3.6	3.9 ± 1.6
Local	8.3 ± 4.6	5.0 ± 3.6	3.3 ± 1.7
National migrant	10.1 ± 4.7	5.8 ± 3.6	4.3 ± 1.5
Foreign migrant	9.0 ± 4.4	5.0 ± 3.6	4.0 ± 1.5
Grand Average	9.6 ± 4.6	6.0 ± 3.4	4.0 ± 1.8

No significant differences ($p < 0.05$) were observed between means within the same column

farmers, and that they attracted rodents (mentioned by almost a quarter of farmers). Other drawbacks such as competing with cocoa for nutrients, increasing the incidence of black pod disease (*Phytophthora* spp.) and shade decreasing cocoa production, were mentioned by <10 % of farmers. Overall, farmers mentioned benefits of trees much more frequently than drawbacks.

Farmers were aware of a diverse set of tree species that were grown with cocoa, this included 26 tree species, which 20 or more farmers were able to evaluate in detail. There was a general consensus amongst farmers that most of the tree species present in cocoa fields were compatible with cocoa (Fig. 3) and the vast majority of them (>90 %) considered *Artocarpus altilis*, *Terminalia superba*, *T. ivorensis*, *Spathodea campanulata* and *Ricinodendron heudelotii* compatible with cocoa. Twelve species were described as incompatible with cocoa by 25 % or more farmers, with oil palm (*Elaeis guineensis*) and mango (*Mangifera indica*) being the most frequently mentioned (42 and 40 % of farmers, respectively).

The species-specific benefits that farmers described from trees included products and services such as

providing high quality shade and soil fertilization while drawbacks were related to attracting pests and diseases and competition for nutrients and water (Table 6).

Some tree species were clearly identified as negative for specific issues such as attracting small rodents, competing for nutrients and hosting parasitic plants (Fig. 4).

For example, *Elaeis guineensis* was perceived by 82 % of farmers as attracting rodents, *Psidium guajava* by 100 % of farmers for nutrient competition and *Cola nitida* by 76 % of farmers for being an alternative host for parasitical plants (*Tapinanthus* spp.). On the other hand, very few trees were perceived as a threat in terms of doing physical damage from branches falling on cocoa. The two trees most associated with physical damage were *Ceiba pentandra* and *Triplochiton scleroxylon* mentioned by almost two-thirds of farmers (62 and 60 %, respectively). Farmers did not perceive the large majority of tree species grown with cocoa as attracting mirids (*Sahlbergella* sp. and *Distantiella* sp.). Trees commonly identified as hosts of mirids were *C. nitida* and *M. indica* with 38 and

Table 3 Mean values and standard deviations of tree density in cocoa fields based on interviews with farmers according to eco-certification status, ethnic origin and size of cocoa field in the South-West of Côte d'Ivoire

Farm size type of farmer	≤2 ha	>2 and ≤5 ha	>5 and ≤10 ha	>10 and ≤20 ha	>20 ha
Eco-certified	14.8 ± 12.3a	8.8 ± 6.7b	5.9 ± 4.8c	4.0 ± 2.4c	3.1 ± 2.1c
Local	14.0 ± 12.2a	7.6 ± 4.5b	3.9 ± 1.6c	2.6 ± 1.5c	–
National migrant	21.0 ± 13.2a	10.6 ± 10.0ab	6.7 ± 5.6b	4.4 ± 2.7b	3.5 ± 2.4b
Foreign migrant	8.2 ± 5.0a	8.7 ± 4.6a	5.8 ± 4.5ab	3.9 ± 2.1b	2.1 ± 0.0b
Non eco-certified	17.1 ± 17.5a	8.1 ± 5.9ab	4.7 ± 4.1ab	2.2 ± 1.7b	4.6 ± 2.5ab
Local	14.9 ± 15.7a	5.4 ± 2.8b	4.8 ± 3.2b	1.6 ± 0.8c	–
National migrant	20.4 ± 21.7a	10.4 ± 7.3ab	5.2 ± 4.7b	3.8 ± 2.6b	4.4 ± 2.8b
Foreign migrant	19.7 ± 13.3a	7.9 ± 5.2ab	4.4 ± 3.7b	1.8 ± 0.9c	5.3 ± 0.0b
Grand average	16.0 ± 15.4	8.5 ± 6.3	5.4 ± 4.6	3.4 ± 2.3	3.9 ± 2.4

Mean values with the same letter within the same row are not significantly different ($p < 0.05$)

30 %, respectively. Similarly, most trees were not perceived by farmers as causing the spread of black pod disease (*Phytophthora* spp.) with only *C. nitida* frequently being reported by 38 % of farmers.

Access to advice on integrating trees in cocoa fields

Among the 189 eco-certified farmers interviewed, 150 farmers were affiliated to cooperatives engaged in the Rainforest Alliance eco-certification scheme and 46 were engaged in eco-certification with UTZ Certified in the Buyo area. There was a large difference between the numbers of eco-certified farmers (76.1 %) and non eco-certified farmers (15.7 %) that had received advice on growing trees in cocoa fields. Advice focused on the benefits of trees for soil fertility improvements and general benefits of shade (Table 7).

Cocoa farmers' knowledge of tree density required for eco-certification varied from 7 to 70 trees ha⁻¹ (Table 8) with half of the farmers mentioning 18 trees ha⁻¹. Almost a third of eco-certified farmers were unaware of the number of trees required. Farmers' knowledge of the number of different tree species required for eco-certification also varied widely (from 1 to 18) with almost a third of farmers opting for three or less and almost half of the eco-certified farmers simply stating that they did not know the number of species required.

Only a small proportion of eco-certified farmers had received advice about specific tree species to grow with cocoa, with *Terminalia* spp. overwhelmingly promoted (Table 9).

Overall, farmers expressed the desire to plant 52 different tree species in their cocoa fields. Amongst the twenty species most desired (Table 10), almost a third of farmers had a preference for five species that included native shade trees (*Terminalia* spp., *Ricodendron heudelotii*, *Ceiba pentandra*) and two exotic fruit trees (*P. americana* and *C. sinensis*). There was no difference in preferences between ethnic categories except for *C. nitida* which was favored by foreign migrants. *Terminalia superba* was the tree most desired by eco-certified farmers when compared to non eco-certified farmers.

Discussion

Characterization of cocoa farms

The times of establishment of cocoa plots by farmers of different ethnicity to the East to West progression of the cocoa pioneer front in the 1970s and 1980s, with an increasing number of migrants benefiting from soil fertility built up under forest, opportunities arising from the bridge constructed over the Sassandra river and a policy environment in the country that favored cocoa cultivation (Léonard and Ibo 1994). The majority of cocoa fields in the project area were between 20 and 30 years old. A recent survey of cocoa farms showed that over 50 % of cocoa farmers in the Soubré region have been using unselected material, only 8 % using Amelonado varieties, and the average yield quoted for the region was 560 kg/ha without any information on variability provided (Assiri et al.

Table 4 Diversity of tree species found in cocoa fields, ranked according to frequency and with information on their origin and main local uses as discussed with farmers in the South-West of Côte d'Ivoire

Scientific name	Family name	Frequency of occurrence on farms (%)	Origin		Uses		Charcoal						
			Planted	Natural regeneration	Food	Medicine		Income	Fodder	Timber	Firewood		
<i>Persea americana</i> (e)	Lauraceae	87	*	*	Fruit	*	*	*	*	*	*	*	*
<i>Citrus sinensis</i> (e)	Rutaceae	82	*	*	Fruit	*	*	*	*	*	*	*	*
<i>Cola nitida</i> (n)	Sterculiaceae	74	*	*	Nut	*	*	*	*	*	*	*	*
<i>Mangifera indica</i> (e)	Anacardiaceae	67	*	*	Fruit	*	*	*	*	*	*	*	*
<i>Ceiba pentandra</i> (n)	Bombacaceae	59	*	*	Leaf	*	*	*	*	*	*	*	*
<i>Ficus exasperata</i> (n)	Moraceae	46	*	*		*	*	*	*	*	*	*	*
<i>Ricnodendron heudelotii</i> (n)	Euphorbiaceae	45	o	*	Seed	*	*	*	*	*	*	*	*
<i>Cocos nucifera</i> (e)	Arecaceae	31	*	*	Fruit	*	*	*	*	*	*	*	*
<i>Milicia excelsa</i> ^a (n)	Moraceae	30	o	*		*	*	*	*	*	*	*	*
<i>Bombax buonopozense</i> (n)	Bombacaceae	28	*	*	Flower	*	*	*	*	*	*	*	*
<i>Elaeis guineensis</i> (n)	Arecaceae	28	*	*	Seed	*	*	*	*	*	*	*	*
<i>Alstonia boonei</i> (n)	Apocynaceae	27	*	*		*	*	*	*	*	*	*	*
<i>Pycnanthus angolensis</i> (n)	Myristicaceae	23	*	*		*	*	*	*	*	*	*	*
<i>Spathodea campanulata</i> (n)	Bignoniaceae	21	*	*		*	*	*	*	*	*	*	*
<i>Holarrhena floribunda</i> (n)	Apocynaceae	20	*	*		*	*	*	*	*	*	*	*
<i>Terminalia superba</i> (n)	Combretaceae	18	o	*		*	*	*	*	*	*	*	*
<i>Terminalia ivorensis</i> ^b (n)	Combretaceae	18	o	*		*	*	*	*	*	*	*	*
<i>Spondias mombin</i> (n)	Anacardiaceae	16	*	*	Fruit	*	*	*	*	*	*	*	*
<i>Citrus reticulata</i> (e)	Rutaceae	15	*	*	Fruit	*	*	*	*	*	*	*	*
<i>Psidium guajava</i> (e)	Myrtaceae	15	*	*	Fruit	*	*	*	*	*	*	*	*
<i>Albizia</i> spp. (n)	Mimosaceae	14	*	*		*	*	*	*	*	*	*	*
<i>Triplochiton scleroxylon</i> ^c (n)	Sterculiaceae	14	*	*		*	*	*	*	*	*	*	*
<i>Entandrophragma utile</i> ^b (n)	Meliaceae	11	*	*		*	*	*	*	*	*	*	*
<i>Piptadeniastrum africanum</i> (n)	Mimosaceae	10	*	*		*	*	*	*	*	*	*	*
<i>Sterculia tragacantha</i> (n)	Sterculiaceae	8	*	*		*	*	*	*	*	*	*	*
<i>Citrus maxima</i> (e)	Rutaceae	8	*	*	Fruit	*	*	*	*	*	*	*	*
<i>Artocarpus altitilis</i> (e)	Moraceae	7	*	*	Fruit	*	*	*	*	*	*	*	*
<i>Pterygota macrocarpa</i> ^b (n)	Sterculiaceae	6	*	*		*	*	*	*	*	*	*	*
<i>Nauclea diderrichii</i> ^b (n)	Rubiaceae	5	*	*		*	*	*	*	*	*	*	*
<i>Ficus sur</i> (n)	Moraceae	5	*	*		*	*	*	*	*	*	*	*

Table 4 continued

Scientific name	Family name	Frequency of occurrence on farms (%)	Origin		Uses								
			Planted	Natural regeneration	Food	Medicine	Income	Fodder	Timber	Firewood	Charcoal		
<i>Celtis zenkeri</i> (n)	Celtidaceae	5	*										*
<i>Musanga cecropioides</i> (n)	Cecropiaceae	5	*										
<i>Dacryodes klaineana</i> (n)	Bursaceae	4	*			*			*				*
<i>Morinda lucida</i> (n)	Rubiaceae	4	*			*			*				
<i>Nesogordonia papaverifera</i> ^b (n)	Sterculiaceae	4	*										
<i>Vernonia</i> sp. (n)	Asteraceae	2	*			*							
<i>Irvingia gabonensis</i> ^c (n)	Irvingiaceae	2	*					Fruit	*				
<i>Raphia hookeri</i> (n)	Areaceae	2	*										
<i>Erythrophileum ivorense</i> (n)	Caesalpinaceae	2	*										
<i>Tieghemella heckelii</i> ^d (n)	Sapotaceae	1	*					Seed	*				
<i>Monodora myristica</i> (n)	Annonaceae	1	*						*				
<i>Coula edulis</i> (n)	Oliaceae	1	*					Seed					
<i>Antiaris toxicaria</i> (n)	Moraceae	1	*						*				
<i>Anthocleista djalonenis</i> (n)	Loganiaceae	1	*						*				
<i>Beilschmiedia mannii</i> (n)	Lauraceae	1	*										
<i>Cordia millenii</i> ^e (n)	Boraginaceae	1	*										
<i>Funtumia elastica</i> (n)	Apocynaceae	1	*										
<i>Parkia bicolor</i> (n)	Mimosaceae	1	*					Seed					
<i>Rauvolfia vomitoria</i> (n)	Apocynaceae	1	*						*				

Species with superscript letter are listed in IUCN red list of endangered species as

^a Lower Risk/near threatened

^b Vulnerable A1cd

^c Lower Risk/least concern

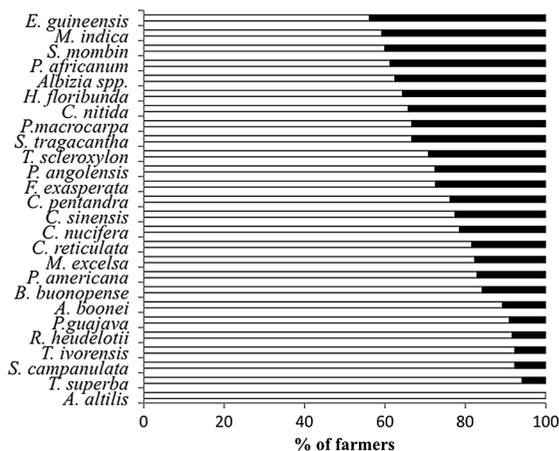
^d Endangered A1cd

^eSpecies recently planted by a few eco-certified farmers

n exotic species, *n* native species

Table 5 Main production benefits and drawbacks of integrating trees with cocoa reported by eco-certified and non eco-certified farmers in the South-West of Côte d'Ivoire

Benefits	Total farmers (%)	Eco-certified (%)	Non eco-certified (%)	Drawbacks	Total farmers (%)	Eco-certified (%)	Non eco-certified (%)
Protect cocoa against heat stress	70.1	72.3	68.7	Physical damage	32.7	34.6	30.7
Increase soil fertility	52.7	57.4	47.6	Rodents increase	23.9	26.1	21.7
'Bring rain'	28.2	30.3	25.9	Nutrient competition	6.8	7.4	6.0
Increase soil moisture	23.7	25.5	21.7	Pod rot increase	6.8	8.5	4.8
Control erosion	21.7	26.6	24.1	Shading decreases yield	4.5	3.2	6.0
Increase cocoa production	9.9	9.6	10.2	Increase parasitic plant	3.7	2.7	4.8
Protect cocoa from wind	5.1	3.7	6.6	Excessive humidity	3.1	5.3	0.6
No benefits	4	4	5	Mortality of neighbouring cocoa	2.8	3.2	2.4
Provide shade for farmer to rest under	3.7	2.7	4.8	No problems identified	2.5	1.1	4.2
Increase cocoa resistance pests and diseases	2.0	1.6	2.4	Decrease in yields	2.5	2.1	3.0
No answer provided	0	0	0	No answer provided	43	43.1	42.2

**Fig. 3** General compatibility of tree species associated with cocoa as perceived by farmers in the South-West of Côte d'Ivoire (white square box: compatible; black square box: incompatible)

2009). Research in Ghana has shown that the economic lifespan of intensively managed hybrid cocoa ranges from around 18 to 29 years (Obiri et al. 2007), indicating that much of the cocoa in the study area is nearing the end of its productive life. In contrast, a recent study has shown that by constantly eliminating low yielding, damaged or diseased trees, farmers in complex cocoa agroforestry systems in Cameroon can extend the productive life of their

plantation up to over 40 years (Jagoret et al. 2011, 2014). The reduction in number of new cocoa farms established since 1985 coincides with forestland becoming scarce at the same time as world cocoa prices were declining (Ruf and Zadi 1998). The farm size distribution confirms that cocoa has remained a predominantly smallholder enterprise in the country, with most farms <10 ha and almost a quarter <2 ha. In general, local farmers had smaller plots than migrant farmers who generally acquired larger areas to make the migration worthwhile.

Tree diversity in cocoa fields

Farmers described a rich diversity of tree species on their cocoa farms, including 74 species that could be botanically identified, 63 of which were native. A further 84 vernacular tree names in six different dialects were recorded, but were not botanically identified and hence may contain some overlap amongst themselves and with the 74 identified species. Consequently, the likelihood is that farmers recognized well over 100 different species that were growing in their cocoa fields. The difficulty and limitations of identifying species from vernacular names, inherent in ethno-botany (Wilkie and Saridan 1999), was further complicated in the present context by the linguistic diversity in the survey area, and, by the sparse knowledge about native flora

Table 6 Summary of farmers' perceptions of key benefits and drawbacks associated with the five most compatible and the five least compatible tree species grown with cocoa in the South-West of Côte d'Ivoire

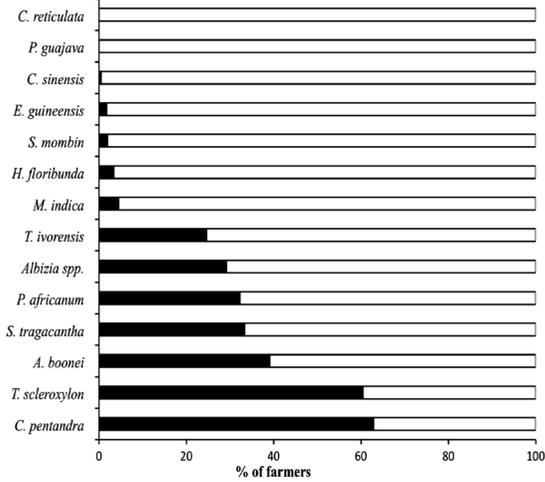
Tree name	Benefits	Drawbacks
<i>Terminalia superba</i>	Good shade quality, increases soil moisture, soil fertility improvement, timber	Attracts rodents, unclear timber value,
<i>Terminalia ivorensis</i>	Good shade quality, soil fertility improvement, timber	Attracts rodents, unclear timber value
<i>Ricinodendron heudelotii</i>	Nutrition, income and cultural value, increases soil humidity, good shade quality, soil fertility improvement	Attracts rodents
<i>Spathodea campanulata</i>	Increases soil moisture, soil fertility improvement because of fast decomposing litter	Attracts rodents and mistletoe
<i>Albizia</i> spp.	Good firewood species	Competitive for nutrients and water, attracts rodents, causes physical damage
<i>Piptadeniastrum africanum</i>	Timber	Competitive for nutrients and water, physical damage, attracts rodents, negative shade
<i>Spondias mombin</i>	Soil fertility improvement and good shade quality	Attracts mistletoe and rodents, few uses
<i>Mangifera indica</i>	Nutrition, income	Competitive for nutrients, dense shade, attracts mirids and rodents
<i>Eleais guineensis</i>	Nutrition, cultural value, income	Low quality shade and cumbersome crown, attracts rodents, competitive for water and nutrients

amongst some migrant farmers, recently arrived from very different agroecological conditions in their home regions. This is an important result that underlines the challenges of communicating and sharing knowledge about trees associated with cocoa amongst farmers, extension workers and scientists. The tree species richness found on cocoa farms in the study area was significantly higher than those shown by previous inventories in the central region of Côte d'Ivoire, where 25 tree species were recorded (Herzog 1994). The results were also higher than those shown by a study in the Ondo State in Nigeria, with 45 species (Oke and Odebiyi 2007) and by an inventory of mature cocoa farms in the Ashanti region of Ghana that recorded 66 species (Anglaaere et al. 2011). On the other hand, it was lower than the richness described in studies of traditional agroforestry systems in Cameroon where 206 tree species were inventoried (Sonwa et al. 2007) and cocoa agroforests in central Cameroon where 165 tree species were inventoried (Nomo et al. 2008). The survey results indicate that, despite the significant deforestation trends and the promotion of full-sun cocoa, the cocoa farms in the South-West of Côte d'Ivoire represent a refuge for a large number of native tree species. These include ten species on the IUCN red list of threatened species conservation status that include one endangered, five vulnerable, two near threatened and two at lower risks.

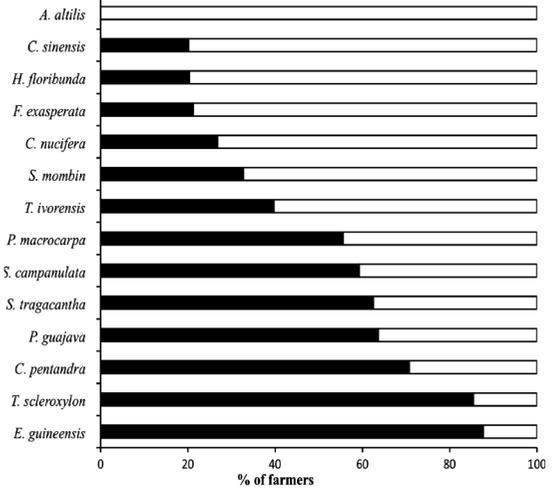
More information on the abundance of these rare species would be required to assess the extent to which cocoa farms represent effective refugia.

While the diversity of native tree richness interests conservationists, the most frequent tree species were exotic fruit trees used for nutrition and income that had been planted by farmers. This trend is common across other Western and Central African regions where many farmers manage trees in cocoa plantations for the nutritional benefit they provide to the household as well as a range of other productive and service roles (Herzog 1994; Leakey and Tchoundjeu 2001; Asare 2005; Koko et al. 2013; Sonwa et al. 2014). Sixty percent of Ivorian farmers in the Bas-Sassandra region planted fruit trees in their cocoa plots, a situation slightly above the Ivorian average but similar to cocoa farms studies in Ghana and Nigeria (Gockowski et al. 2004). Cocoa fields appeared to be the only significant farm niche where fruit trees were planted and managed by farmers in the study area. Homesteads were generally kept free of trees because the land was used primarily for cocoa drying. Fallows were rare, cropland scarce and trees rarely associated with other local land uses such as food crops, paddies, rubber or oil palm. There were no significant differences between farmers of different ethnic origin, eco-certification status or the age of their plantations, in terms of the

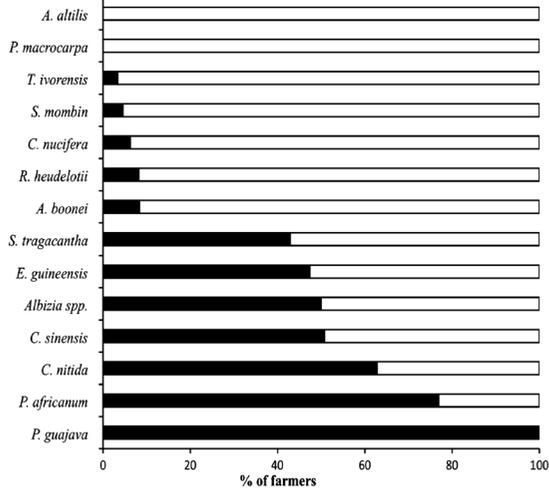
(a) causes physical damage



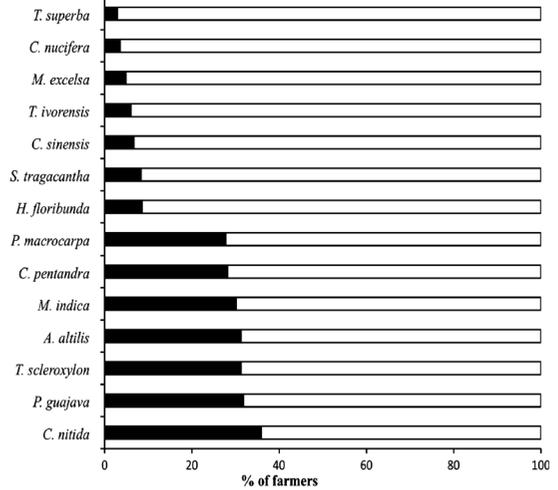
(b) attracts rodents



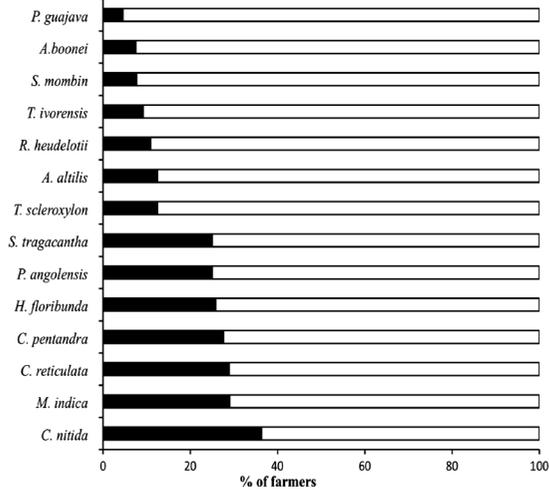
(c) competitiveness for nutrients



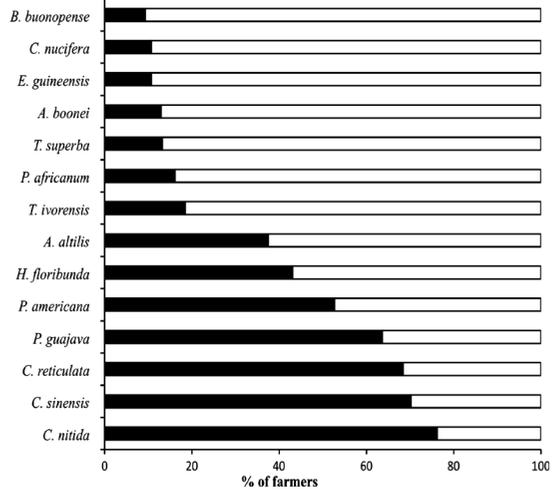
(d) favouring Phytophthora spp



(e) alternative host of mirids



(f) alternative host of miseltoe



◀ **Fig. 4** Status of tree species associated with cocoa perceived by farmers in the South-West of Côte d'Ivoire with respect to: **a** Physical damage by branches, **b** attractiveness to rodents, **c** competitiveness for nutrients, **d** favouring *Phytophthora* spp., **e** alternative host of mirids, and **f** alternative host of mistletoe (*Tapinanthus* spp). Data shown only for the seven most and seven least susceptible species (*white square box*: no; *black square box*: yes)

Table 7 Number of farmers who have received different types of advice about shade tree associations in cocoa fields according to eco-certification status in the South-West of Côte d'Ivoire

Nature of advice	Eco-certified	Non eco-certified
Soil fertility improvement	50	2
Shade is beneficial	45	3
Specific trees recommended	45	2
Increase cocoa productivity	17	1
Soil moisture retention	12	2

Table 8 Number of eco-certified and non-eco-certified farmers in the South-West of Côte d'Ivoire who stated that they had received advice on planting tree species in their cocoa fields

Scientific name	Eco-certified	Non eco-certified	Total
<i>Terminalia superba</i>	38	0	38
<i>Terminalia ivorensis</i>	17	0	17
<i>Gliricidia sepium</i>	4	1	5
<i>Ricnodendron heudelotii</i>	4	1	5
<i>Spondias mombin</i>	3	0	3
<i>Milicia excelsa</i>	0	2	2
<i>Entandrophragma utile</i>	1	0	1
<i>Ceiba pentandra</i>	0	1	1
Total	67	5	72

number of species found on cocoa plots but the variation was large within each of these categories as found in other studies in Cameroon (Nomo et al. 2008). The mean number of species found per plot was 9.6 with a higher proportion of native naturally regenerating species (6) than of planted species (4) which is higher than the 5.4 species previously recorded in Côte d'Ivoire (Herzog 1994) but lower than farms studied in Central Cameroon where means of 21 tree species ha⁻¹ (Sonwa et al. 2007) and 25 tree species ha⁻¹ were recorded (Jagoret et al. 2011).

Similar to previous results reported by N'Goran (1998), there was a significant variability in the densities of non-cocoa trees in cocoa fields, although our study did not show density consistently varying with age of the field. In the research area, tree density ranged from 2 to 21 trees ha⁻¹ much lower than those recorded in cocoa agroforestry systems in Cameroon which averaged around 120 trees ha⁻¹ (Jagoret et al. 2011). Low tree densities are explained partly by the historical promotion of full-sun cocoa systems but are also by the fact that migrant cocoa farmers secure land ownership through the conversion of forest land to agricultural use (Ruf and Zadi 1998; Asare 2005). Densities varied according to the field size, with small fields having the highest densities and a clear decreasing trend in tree density as field size increased. This is consistent with cocoa fields being almost the only farm niche where trees are grown and managed for the household. Farmers with smaller land sizes would intercrop trees more densely in order to meet their needs. The present results were based on farmers' recall and it is possible that there could be systematic bias of recall with farm size. There was no significant difference in tree density between certified and non-certified farmers because most certified farmers had only recently engaged in eco-certification schemes at the time of the survey and had not taken steps to align with the shade tree requirements of between 12 to 18 trees ha⁻¹ and the long term goal of providing 40 % shade cover (SAN (Sustainable Agricultural Network) 2009).

Perceptions about integrating trees in cocoa fields

The prevailing view within the cocoa industry is that cocoa farmers in Ghana and Côte d'Ivoire will progressively reduce and ultimately eliminate shade in their cocoa fields and, in keeping with this, full sun cocoa is the industry standard (Ruf 2011). In Western Ghana, 90 % of farmers were reported to be eliminating trees to reduce shade, largely as a result of their perception that new cocoa hybrids were intolerant of shade (Ruf et al. 2006). In marked contrast to this, we found that 95 % of farmers in the Western part of Côte d'Ivoire valued the presence of trees associated with cocoa for both products and environmental services, regardless of their origin or certification status. Most of the cocoa in the Western part of Côte d'Ivoire is not of hybrid origin (Gockowski and Sonwa 2011) and this

could explain why farmers have a positive attitude towards integrating trees with cocoa. The most frequently planted trees in cocoa fields in Western

Table 9 Cocoa farmers' knowledge about the number of trees and species per hectare required for eco-certification in the South-West of Côte d'Ivoire

Number of trees/ha	Eco-certified farmers (%)	Number of species/ha	Eco-certified farmers (%)
70	2.1	18	0.5
25	2.6	15	0.5
20	6.3	12	2.1
18	50.8	10	1.1
15	1.1	7	3.2
12	2.1	6	0.5
10	1.1	4	2.6
7	3.7	3	9.5
Does not know	31.7	2	18.5
		1	12.2
		Does not know	48.7

Côte d'Ivoire reported here were fruit trees, used for both household nutrition and income. In addition to products derived from trees, farmers also expressed the importance of the environmental services that they provide. The major environmental benefit perceived by 70 % of farmers was to protect cocoa trees from heat stress in the dry season. Over the last 20 years, there has been increasing report of climate change in southern Côte d'Ivoire, with trends towards reduced rainfall and increased length of the dry season (Brou 2010). Farmers said that drier climatic conditions were the major driver for wanting shade in their fields, especially to protect cocoa trees from water stress in the dry months of January and February. This corroborates the view that changing climatic conditions, with an increase in the length of the dry season, is increasingly affecting cocoa productivity, and requires the design of new strategies, using shade trees to buffer cocoa from water and heat stress in the dry season (N'Goran 1998). Soil fertility improvement was the second most frequently mentioned benefit of incorporating trees in cocoa fields, expressed by more than

Table 10 Percentages of farmers who desired different tree species for cocoa association according to ethnic origin and eco-certification status in the South-West of Côte d'Ivoire (data shown for the twenty trees most desired)

Tree species	National migrants (%)	Foreign migrants (%)	Local (%)	Eco-certified (%)	Non eco-certified (%)	Number of farmers
<i>Terminalia superba</i>	50	32	38	52	27	143
<i>Ricinodendron heudelotii</i>	46	32	35	39	37	134
<i>Persea americana</i>	40	43	28	38	36	131
<i>Citrus sinensis</i>	33	41	27	32	36	119
<i>Ceiba pentandra</i>	40	38	19	37	27	115
<i>Terminalia ivoriensis</i>	36	26	28	35	23	106
<i>Milicia excelsa</i>	28	16	17	22	19	73
<i>Mangifera indica</i>	20	22	19	19	21	71
<i>Cola nitida</i>	15	30	13	15	23	68
<i>Gliricidia sepium</i>	0	19	9	20	10	54
<i>Bombax buonopozense</i>	15	16	3	13	10	41
<i>Ficus exasperata</i>	11	9	6	9	9	32
<i>Cocos nucifera</i>	8	12	5	10	7	30
<i>Alstonia boonei</i>	8	10	3	11	3	26
<i>Citrus reticulata</i>	6	3	10	4	9	23
<i>Spondias mombin</i>	9	7	3	10	3	23
<i>Spathodea campunolata</i>	12	2	4	6	7	22
<i>Triplochiton scleroxylon</i>	6	4	9	6	7	22
<i>Entandrophragma utile</i>	6	3	3	4	5	15
<i>Eleaïs guineensis</i>	4	3	4	5	2	14

50 % of farmers. The soil conditions prevailing in Soubré make cocoa fields particularly prone to early senescence with attendant low yield and even cocoa mortality (Ruf and Zadi 1998; Koko et al. 2009). Replanting has become increasingly difficult on land not recently cleared from forest (Ruf and Konan 2001). In the absence of new forestland to clear, there is an increasing reliance on the use of chemical fertilizers to maintain yield, which many farmers cannot afford (Assiri et al. 2009). While exotic leguminous trees have recently been promoted in the context of soil fertility improvement, notably in the regional Sustainable Tree Crops Program (Asare 2005), there is little information on the suitability of different tree species to improve both nutrient cycling and soil fertility in different contexts. Trees associated with cocoa systems have been shown to be important for improving soil quality and provide a high level of soil-related ecological services (Rousseau et al. 2012). Research on tree phenology, leaf decomposition rates and N-mineralization from litter of a broad range of tree species, is required to develop guidelines for farmers on which species to use to improve soil health (Barrios et al. 2012). Soil moisture conservation and erosion control were also important services that farmers associated with trees. Only a few farmers linked shade trees with prolonging the life span of cocoa, although this has been frequently observed by scientists (Ruf and Zadi 1998; Obiri et al. 2007). Farmers also did not mention weed suppression as a benefit derived from trees, and this could be due, even with full sun cocoa, to the fact that cocoa density is high and hence shade from the cocoa itself is sufficient to suppress weeds (Assiri et al. 2009).

Farmers mentioned drawbacks of integrating trees with cocoa much less frequently than benefits. The most frequently cited drawback mentioned by about a third of farmers, was physical damage to cocoa or people caused by falling branches, but this was only a drawback with seven species (discussed further below). The second most frequent drawback, mentioned by more than a quarter of the farmers, was attracting rodents and fewer than 10 % mentioned other drawbacks, including favoring an increase in incidence of black pod disease and competition for nutrients. This is broadly consistent with a recent study of cocoa farmer perceptions in Ghana that reported negative ecological interactions, principally attracting squirrels and increasing incidence of black pod

disease, as the reason for almost a quarter of farmers (23 %) removing shade trees from their cocoa fields (Ruf 2011). The incidence of black pod disease was linked to high humidity, especially in areas of heavy rainfall. The lack of tree ownership by farmers and destructive practices associated with timber extraction was an obstacle to managing timber trees on cocoa farms. The exclusion of farmers from the timber market is an important constraint to managing timber trees on cocoa farms in Ghana and Côte d'Ivoire (Anglaere et al. 2011; Ruf 2011) and this was often the reason why farmers were felling or burning high value timber trees in their cocoa plots (Ruf et al. 2006).

Consensus on compatibility of tree species with cocoa

In Côte d'Ivoire, despite the long-term promotion of full sun cocoa systems and the lack of information about compatible tree species for cocoa from the research and extension services, farmers shared common perceptions about the suitability of trees species for integrating with cocoa. Overall, most farmers considered most of the trees commonly found on farms to be compatible with cocoa but some species were considered more compatible than others. Amongst the most compatible species was *A. altilis* but this species was only present in one of the study locations (Kragui). *Terminalia ivorensis*, *T. superba*, *S. campanulata* and *R. heudelotii* were also generally mentioned as highly compatible with cocoa and have been previously identified as suitable for integrating with cocoa in Ghana (Asare 2005). They were valued by farmers for the quality of shade, soil fertility improvement and in the case of *S. campanulata* and *R. heudelotii* for their positive role in increasing soil moisture availability, especially in the dry season. The role of *S. campanulata* in increasing soil moisture has been previously recorded in Ghana (Anim-Kwapong and Osei-Bonsu 2009). *Ricinus dendron heudelotii* is also known to root deeply, likely to reduce competition for water with cocoa, and because of the high market potential of its kernels, has been identified as a promising tree species for domestication in West Africa (Tchoundjeu and Atangana 2007). The least compatible tree species were oil palm (*E. guineensis*) and mango (*M. indica*) although mentioned by only 40 % of farmers, suggesting the large divergence in responses probably arose from the different extent to

which farmers were considering trade-offs when responding. In the case of oil palm, there was common knowledge that it provides a nesting environment for rodents and is competitive for nutrients and water but its cultural importance for nutrition explains why some farmers maintain oil palm in their cocoa fields despite its drawbacks. In the case of mango, present on 67 % of cocoa fields, the importance for nutrition and income means that farmers tolerate individual trees in their fields, despite the trade-offs with cocoa production.

Species-specific knowledge

Farmers were aware that different tree species displayed different attributes that affected their compatibility with cocoa and their uses. For example, farmers said that *C. pentandra*, the tree most commonly identified as causing physical damage to cocoa or people from falling branches, was particularly problematic in this respect when old. As the most frequent forest tree relic found on cocoa farms, many trees were old, very tall and so difficult to prune. In terms of other species that cause damage, *T. scleroxylon* is a self-pruning tree from which branches can be expected to fall and *Alstonia boonei* and *S. tracagantha* are known to have brittle branches that break easily (Palla 2005; Orwa et al. 2009). It is clear that the issue of trees causing damage to cocoa is limited to a few species. The development and implementation of appropriate species-specific management guidelines could minimize risk of damage which may also be accepted by farmers as justifiable because of the economic value of the timber (Ryan et al. 2009).

Trees attracting rodents was relevant to a broader range of species but the most problematic tree was oil palm because the morphological characteristics of its fronds made it suitable for squirrels to nest in them. Other trees that particularly attracted rodents were *C. pentandra* and *T. scleroxylon*. Farmers explained that these trees frequently loose branches and limbs that open cavities that become ideal habitat for squirrels. Although cocoa pod damage by squirrels causes yield loss, farmers frequently mentioned that they hunted squirrels, which made a useful contribution to family nutrition. Given that the original forest fauna has largely disappeared, many farmers, especially national migrants, said that squirrels had become an important source of animal protein in the family diet.

Only seven, mainly fruit tree species were commonly identified as competitive for nutrients with cocoa. The most competitive species was unanimously *P. guajava*, followed by *Piptadeniastrum africanum* a leguminous timber species and fruit trees such as *C. nitida* and *C. sinensis*. Surprisingly, *Albizia* spp., although leguminous and known to improve soil, was considered to be competitive by almost half of the farmers.

Phytophthora megakarya is increasingly important in West Africa (Holmes et al. 2003), and has a variety of alternate host plants, notably native forest trees (Opoku et al. 2002). Ivorian farmers linked seven tree species with increased incidence of black pod disease, including *C. nitida*, *P. guajava*, *T. scleroxylon*, *A. altilis*, *M. indica* and *C. pentandra*. Opoku et al. (2002) have provided evidence of *P. megakarya* parasitism on *Sterculia tracagantha* and *R. heudelotii* but they found no visual evidence of higher infestation levels on cocoa plants nearer the host trees and concluded that it was unlikely that the presence of the identified host trees would have any significant influence on the levels of black pod disease on cocoa. In our survey, 8 % of farmers identified *S. tracagantha* and 10 % identified *R. heudelotii* as increasing black pod disease. Such effects may arise from the level and quality of shade affecting humidity rather than the host status of the tree (Schroth et al. 2000).

Scientific evidence has also shown that species taxonomically related to cocoa, i.e. members of the Sterculiaceae family, can share pests and diseases with cocoa. This is notably the case for mirids, one of the most important cocoa pests in West Africa (Schroth et al. 2000). Most farmers (79 %) in our survey identified *C. nitida* as an alternative host for mirids, concurring with technical information available (SATMACI 1984; Schroth et al. 2000), but this was the only member of the Sterculiaceae that they identified in this context. *Sterculia tracagantha* and *Pterygota macrocarpa*, for example, were not identified as alternate hosts for mirids and neither were most species of the Bombacaceae family, that have also been mentioned as possible alternate hosts (SATMACI 1984; Schroth et al. 2000). One exception was *Bombax buonopense* mentioned by only 10 % of farmers. No farmers mentioned *C. pentandra* in this regard despite its prevalence in the area. On the other hand, 75 % of farmers identified *Citrus* species as alternative hosts of mirids, concurring with previous information (Padi and Owusu 2003).

Mistletoes (*Tapinanthus* spp.) are important parasitic plants affecting cocoa causing loss of cocoa tree vigor and yield decline, with heavy attacks sometimes causing cocoa mortality (Padi and Owusu 2003). Our results show that farmers identified fruit trees such as *C. nitida*, *M. indica* and *C. reticulata* as alternative hosts in addition to forest tree species such as *C. pentandra*, *Holarrhena floribunda*, *Pycnanthus angolensis* and *T. scleroxylon*, corroborating previous results showing these species to be alternative hosts of *Tapinanthus* spp. in Ghana (Phillips 1977). This knowledge was not evenly distributed amongst farmers. Despite the increasing threat of the CSSV in Côte d'Ivoire, only a few farmers were aware of the virus and the host status of tree species in their cocoa plots.

Certification and advice about integrating trees with cocoa

Engagement with eco-certified cooperatives was clearly an important source of advice about shade trees for protecting cocoa in the dry season. Only a minority (15 %) of non certified farmers had received advice about cocoa shade trees compared to 76 % of certified farmers, still showing that almost a quarter of eco-certified farmers had not received any advice on trees. Eco-certification schemes principally operating through the Sustainable Agriculture Network (SAN) have put forward shade management criteria and indicators for cocoa farms as part of good cocoa management practices. In Côte d'Ivoire, farmers are required to maintain or plant 12 native species ha⁻¹ and 40 % canopy cover (SAN (Sustainable Agricultural Network) 2009). Our results show that both the number of tree species and the shade density in cocoa fields were well below certification requirements, even amongst certified farmers, consistent with the recent onset of certification in the area. Perhaps of greater concern was the large variation in knowledge amongst eco-certified farmers about both the number of trees and species required. Farmers only recalled eight species being recommended as shade trees for cocoa, dominated by *Terminalia* spp., despite the existence of an official list of 19 recommended species (SAN (Sustainable Agricultural Network) 2009). Although advice was concentrated on a limited list of species and had a clear influence on preferences shared by eco-certified farmers, overall, both eco-certified and non eco-certified farmers expressed a desire to use a

broader diversity of trees to meet their needs for products and services.

Conclusion

Despite the cocoa frontier expanding at the expense of forest cover, and full sun cocoa being the predominant form of cultivation promoted over the last half century in Cote d'Ivoire, cocoa farms still contain a reservoir of forest tree species, including some of high conservation value. Farmers overwhelmingly want to have more trees on their farms, both to sustain their cocoa production and to diversify their livelihood, particularly in relation to their food security, as shown by the important presence of fruit trees in cocoa fields. Whether certified or not, farmers valued a variety of tree species in their cocoa fields because they believed that they protected cocoa from water stress in the dry season and improved soil fertility. Farmers were interested in integrating a diversity of tree species on their farms to meet their needs and had detailed knowledge about how different species affect a range of ecosystem services responsible for sustainable cocoa productivity, regardless of their ethnic origin or certification status. In addition there were notable knowledge gaps, particularly relating to trees as alternate hosts to pests and diseases such as *Phytophthora* spp. and CSSV. Assessing local knowledge about integrating trees with cocoa in the country remains a challenge because of the linguistic diversity of the ethnic groups involved and their diverse places of recent origin. Eliciting local knowledge would be the key next step in developing approaches to promoting tree diversity in cocoa. This would allow identification of gaps in knowledge that research and extension should address and help to refine current understanding of field, farm and landscape niches for different tree species. In the past, research recommendations for cocoa production in the region have often served as a barrier to farmer innovation instead of building on local knowledge and preferences and led at best to the promotion of a few key species rather than increasing tree diversity (Asare 2005). The importance of knowledge transfer between farmers and scientists to improve shade-tree management and to implement certification schemes for cocoa has been identified (Tscharntke et al. 2011) and has been instrumental in promoting diversity in coffee agroforestry (Soto-Pinto

et al. 2007; Cerdan et al. 2012). It is unlikely that the conservation value of trees in cocoa systems will be maintained without some deliberate action, since as time goes on, the regeneration of forest species diversity is likely to decline (Robiglio and Sinclair 2011) and farmers will tend to preserve a limited set of species that most immediately meet their needs (Vaast et al. 2005; Harvey et al. 2011). The cocoa landscapes in the South-West of Côte d'Ivoire appear to be at a turning point. Their productivity is declining along with their conservation value. Both issues can be addressed by promoting appropriate tree diversity with good management practices, supported by a favorable policy environment, that includes security of land and tree tenure for farmers, certification schemes and better integration of producers in value chains to ensure higher economic returns to cocoa and other tree products. Integrated research embracing local knowledge, cocoa agronomy and ecosystem service provision is urgently required to achieve production and conservation objectives simultaneously.

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