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Potential of natural and improved fallow using indigenous trees to facilitate cacao replanting in Ghana

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Abstract Poor establishment, due to loss of soil fertility, weeds and lack of appropriate shade, is a major constraint to replanting cacao on previously used land. *Spathodea campanulata*, *Newbouldia laevis* and *Ricinodendron heudelotii* planted as monospecific improved fallow and *Terminalia ivorensis*, *T. superba* and *Antiaris toxicaria* planted as a multispecies improved fallow and a natural tree fallow were assessed for their potential to facilitate cacao replanting in a randomized complete block design experiment. Simpson and Shannon diversity indices and species richness in the natural tree fallow were 0.6, 1.6 and 20, respectively, at 4 years after trial inception. The Multispecies and the *R. heudelotii* improved fallows had better height growth, crown development and light transmission characteristics, which are desirable for cacao shade. However, these were not comparable to *S. campanulata* or the natural tree fallow in terms of improving microsite topsoil pH, % organic carbon and % total nitrogen and site capture. Since optimum fallow period is shortened by growing fast-growing trees, the height growth rate >2.0 m per annum in all the treatments except *N. laevis* indicates the suitability of these species for improved fallow. The trees species showed different and complementary characteristics and from a standpoint of biodiversity conservation and the future floristic composition of the landscape the natural tree fallow with its diversity of tree species may be recommended as a rehabilitation technique to facilitate the replanting of cacao with a diverse overhead shade.

Keywords Biodiversity conservation · Rehabilitation · Shade trees · Shade management · Site capture · Soil amelioration

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Introduction

Extensive cacao (*Theobroma cacao* L.) cultivation methods and excessive logging have played a major role in the deforestation and degradation of about eighty percent of the natural forest sites suitable for cacao cultivation in Ghana (Cleaver 1992). This implies that future expansion in the area planted to cacao would depend mostly on the rehabilitation and replanting of previously used crop and fallow lands (Ministry of Environment and Science 2002). A survey conducted in 2001/2002 ($n = 1{,}911$ farmers) showed that over 60% of new cacao plantings was undertaking in fallow compared to 30% in forest (Gockowski et al. 2004). The difficulty in re-establishing cacao on lands that had previously carried the crop has been recognized and attributed to loss of soil fertility, lack of appropriate vegetation cover for cacao shade and excessive pressure from dominant invasive weed species such as *chromolaena odorata* (Ruf and Schroth 2004). In many instances where replanting has not been successful farmers have turned to less profitable agricultural crops and fallow. Most farmers have shown concern for the level of environmental degradation resulting from this sequence of land use and have consequently shown a general willingness to ameliorate the environmental situation through technological innovations and reforestation (Boni 2006).

Improved fallow has demonstrated great biophysical potential for improving soil fertility on smallholders' farms in sub-Saharan Africa (Ajayi and Kwesiga 2003). This technology has mostly relied on the use of fast-growing monocultures of exotic leguminous tree species, which may pose a threat to local floral biodiversity as a result of their invasiveness (Sala et al. 2000). However, there is a dearth of information on the potential of native non-leguminous tree species in improved fallow to facilitate replanting of cacao in the humid West African sub-region. This study is therefore to evaluate the potential of two fallow vegetation management techniques namely natural and planted tree (improved) fallows, using native non-leguminous tree species, for soil amelioration, weed suppression and provision of shade for replanting cacao towards a more permanent shaded system on previously used lands.

Materials and methods

Site description

The study was conducted at the Cocoa Research Institute of Ghana (CRIG), Tafo [06°N, 00°22′W, 220 m above sea level]. The average annual rainfall over 20 years is 1461 mm. The rainfall pattern is bimodal with maxima in May–June and September–October. Variation in monthly temperature is slight. The mean monthly maximum in the hottest month (February or March) is 31–33°C; the mean monthly minimum in the coldest month (August) is 19–21°C. The mean monthly sunshine is longest in November (212.7 h) and shortest in August (92.8 h). The soils at the site (Block G) belong to the WACRI series. It is classified as Rhodi-Lixic Ferralsol (Udic; Isohyperthermic), brown to yellowish red, well drained soils developed in situ from weathered materials of hornblende granodiorite. The texture of the soil (0–8 cm depth) is sandy loam. The site has a long history of cultivation using manual weed control and without burning. In 1968 a 16.7 hectare Cacao shade × variety × fertilizer experiment was established with *Gliricidia sepium* as permanent shade. This was abandoned in 1985 due to a severe Cocoa Swollen Shoot Virus infection and the treatment method of cutting out infected trees led to a drastic reduction of cacao population in the experiment (Ahenkorah et al. 1987). The site was predominantly overgrown with panicum and imperata grasses and sward of *C. odorata*. These were manually cleared and cacao and *G. sepium* grubbed in September 1995 for the establishment of the present trial.

Trial establishment and experimental design

The trial which was to assess biophysical performance and which needed a high degree of researcher control in both design and implementation was established on-station mindful of the conditions found on smallholders' farms following Franzel et al. (2002). Selection of the test species was based on farmers' preferences for cacao shade trees (Nkyi 1990). Seedlings of *Spathodea campanulata* (T1), *Newbouldia laevis* (T2) and *Ricinodendron heudelotii* (T3) were transplanted as monospecific plots and *Terminalia superba*, *T. ivorensis* and *Antiaris toxicaria* (T4) were planted together as a multispecies plot (Mixed species). A fifth plot (T5), natural tree regeneration plot, was left unplanted. All herbaceous weeds on this plot (T5) were regularly removed to facilitate the growth of woody plants. Seedlings of *S. campanulata*, *R. heudelotii*, *Terminalia superba*, *T. ivorensis* and *N. laevis* were a year old before transplanting. Seedlings of *A. toxicaria* were collected from the wild and nursed for 3 months before transplanting. Each plot size measured 18 m × 9 m and with seedlings spaced at 3 m × 3 m to give 18 trees per plot. Plots were arranged in a randomized complete block design with three replicates.

Species description

The test species are of West African origin and their botanical descriptions and uses are indicated by Hawthorne and Gyakari (2006) and Abbiw (1990), respectively. *Terminalia ivorensis* A Chev. (Combretaceae), black afara, grows to a height of 50 m tall and DBH of 4.8 m. The wood is used for firewood and charcoal. It is also used for carpentry, joinery, building, flooring and plywood manufacture. *Terminalia superba* Engl. & Diels (Combretaceae), Afara, grows to 50 m tall. The wood is used for making furniture and musical instruments (guitars). *Antiaris toxicaria* Lesch. (Moraceae), bark cloth tree, is a pantropical forest tree up to 40 m tall. The wood is used for veneer production. The seeds, leaves and root are used in traditional medicine. From the bark a strong, coarse bark cloth is obtained. The fruit is also edible. *Spathodea campanulata* P. Beauv. (Bignoniaceae) reaches up to 25 m high. The open flowers are cup-shaped and hold rain and dew, making them attractive to many species of birds. The tree is a nesting site for many hole-building birds. The seeds are edible. The wood is used to make drums, blacksmith's bellows and paper. The bark, flowers and leaves are used in traditional medicine. *Newbouldia laevis* Seem. (Bignoniaceae), the boundary tree, reaches a height of 12 m. It is planted as a living fence to mark property boundaries and live yam stakes. The tree is considered sacred and has several medicinal uses. *Ricinodendron heudelotii* Pierre ex Pax (Euphorbiaceae) has a spreading crown and can be up to 50 m high. The wood is used to carve stools and wooden utensils. The fruits are roasted for food. Other plant parts have medicinal properties.

Woody species composition in the natural tree fallow

All woody plants in the natural tree fallow (T5) were identified and tagged from 1997 to 1999 to determine species composition, abundance and mortality.

Growth data collection

Tree height (canopy height) and stem diameter at breast height (DBH) were measured annually for 5 years from 1997 to 2001. DBH was measured using a diameter tape and height was measured using an Optical Reading Clinometer PM-5 (Suunto Precision Instruments). Measurements of crown diameter, depth and volume were made using the clinometer and tape and following the methods described by Philip (1994). The number of trees and their diameters (DBH) were recorded and used to determine tree basal cover following Philip (1994).

Tree leaf litter fall pattern, quantity and decomposition

Five litter traps of 1.0 m^2, from which litter was collected monthly from September 1999 to August 2001, were randomly located on the soil surface at permanent positions in each plot. Upon collection, the litter was sorted for leaf litter. The leaf litter was washed and air-dried before weighing. Sub samples from the air-dried leaf litter from each treatment plot were collected and oven-dried at 80°C for 48 h to account for moisture (oven dry weight). The equivalent of 2.0 g oven-dry weight from the air-dried sample was placed in plastic mesh litterbags measuring 20 cm × 15 cm with a mesh size of 1 mm for leaf litter decomposition studies using the litterbag method. For each treatment, 60 bags per plot per replication were randomly placed in the plots. Five bags per plot per replication were retrieved at monthly intervals for 12 months and the loss rate of leaf litter biomass was monitored. At each sampling time, soil and other debris adhering on bag surfaces were carefully removed by gently rinsing with tap water over a fine soil sieve. Cleaned leaf samples for each treatment plot per replication were bulked. Bulked samples were oven dried at 80°C for 48 h and weighed.

Tree stand light transmission characteristics

Light transmission through the crown of trees in the various treatment plots was assessed monthly from January 2000 to December 2002 using a light meter (LUXMETER HD 8366, Wagtech International Ltd. Berkshire, UK). Measurements were carried out at 4 week intervals under clear sky conditions around midday (1200 h GMT) when the vertical projection of the crown on the ground is concentrated around the base of the tree. Measurements were done in four quadrants around four trees at a distance of 0.5 m from the base of each tree. Light transmission was calculated as the ratio between sunlight intensity under tree crown and direct sunlight intensity in the open expressed in percent.

Effect of trees on microsite soil characteristics

Soil samples were taken at random from four locations at depths of 0–15 cm and 15–30 cm from the five treatment plots each with three replications at yearly intervals from 1995 to 2003. Similarly, soil samples were taken from two other experimental control plots namely; a cultivated control plot (young cocoa of the same age as the present trial) and an uncultivated control plot (adjacent treeless uncultivated plot with weeds cut back at regular intervals). For each treatment and control plot, the four samples collected from the same depth were bulked for soil analysis. Undisturbed cylindrical soil cores were also taken at random at a depth of 0–20 cm at four locations in all the plots for the determination of soil bulk density. This was done following the core method procedure described by McIntyre and Loveday (1974). Soil pH, organic carbon and total nitrogen of subsamples of soils collected were determined for each year that the samples were collected following the methods described by Andersen and Ingram (1993).

Data analysis

Woody species diversity was analyzed for three separate years using the Simpson and Shannon diversity indices. Rényi diversity profiles were used to order patterns of species richness and evenness for the three separate diversity data obtained from the natural tree fallow plots (T5) following Kindt and Coe (2005). Other data sets were analyzed using ANOVA-General Linear Model in MINITAB. Means were separated using either Fisher's pairwise comparisons or Standard Error of the Difference between Means (SED) obtained from the Tukey Simultaneous Test (Pairwise Comparisons) using the MINITAB release 12 statistical software. The single exponential decay model (Olson 1963) provided an adequate fit to the data on leaf litter biomass remaining at each sampling date based on the graphical analysis of the residuals plotted against the fitted values and the R^2 values. This was used to calculate the decomposition rate constant k. The decomposition half-life of leaf litter was calculated as $-\ln(0.5)/k = 0.693/k$ (Olson 1963).

Results

Species identity, diversity and succession in the natural tree fallow

Rényi diversity profiles ordered changes in species diversity from 1997 to 1999 with 1997 having the highest diversity and 1999 the lowest (Fig. 1). *Solanum eriathum* was the most dominant species (61.0% abundance) in the natural tree fallow in 1999. The disappearance of six species from the natural tree fallow in 1999 resulted in significant reduction in species richness as indicated by both the Shannon and Simpson diversity indices (Table 1). Of the 20 tree species identified in the natural tree fallow in 1999 (Table 1), 13 are commonly occurring or preferred shade trees in cocoa farms in Ghana (Nkyi 1990). *Khaya ivorensis* (class 1), *T. superba*, *T. ivorensis* (class 2), *Pycnanthus angolensis* and *Antiaris toxicaria* (class 3) are valuable timber species in the designated class categories (Fig. 1; Table 1).

Growth performance

The growth rate of trees in terms of height was fastest in the Mixed species stand and *R. heudelotii* achieving average growth rates >3.0 m year^{-1}. Average growth rate was slowest in *N. laevis* at 1.0 m year^{-1}. Canopy cover or site capture as indicated by tree basal cover was significantly highest in the natural

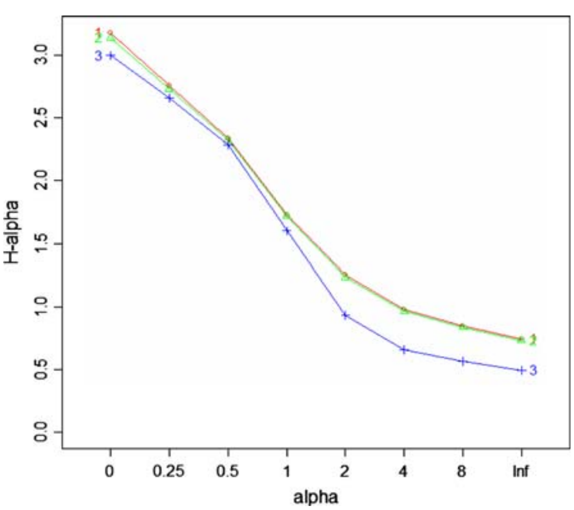

Fig. 1 Rényi diversity profiles of the natural fallow for 1997 (1), 1998 (2) and 1999 (3) dataset at CRIG Tafo, Ghana

Table 1 Species richness and composition of woody component of naturally regenerated fallow at CRIG Tafo

Species	1997 abundance	Proportion (%)	1998 abundance	Proportion (%)	1999 abundance	Proportion (%)
Pioneer species						
Solanum eriathum	271	47.54	241	48.10	155	61.02
Solanum torvum	49	8.59	35	6.99	–	–
Terminalia ivorensis	83	14.56	73	14.57	10	3.94
Rauvolfia vomitoria	99	17.36	90	17.96	27	10.63
Alchornea cordiflora	10	1.75	10	2.00	9	3.54
Lantana camara	1	0.18	1	0.20	1	0.40
Ficus capensis	1	0.18	1	0.20	2	0.79
Ficus exasperata	4	0.70	4	0.80	16	6.30
Spathodea campanulata	4	0.70	3	0.60	2	0.79
Mallotus oppositifolus	10	1.75	9	1.80	6	2.36
Trema orientalis	2	0.35	2	0.40	–	–
Bridelia stenocarpa	4	0.70	4	0.80	5	1.97
Capsicum annum	3	0.53	3	0.60	–	–
Elaeis guineensis	2	0.35	2	0.40	–	–
Unidentified species	2	0.35	2	0.40	–	–
Unidentified species	2	0.35	1	0.20	3	1.18
Ricinodendron heudelotii	1	0.18	1	0.20	1	0.40
Voaganga toxicaria	1	0.18	1	0.20	1	0.40
Terminalia superba	–	–	–	–	1	0.40
Psydrax subcordata	–	–	–	–	1	0.40
Non-pioneer species						
Khaya ivorensis	6	1.05	6	1.20	6	2.36
Funtumia elastica	2	0.35	2	0.40	3	1.18
Albizia zygia	1	0.18	1	0.20	3	1.18
Antiaris toxicaria	7	0.23	5	1.00	1	0.40
Cnestic ferruginea	1	0.18	–	–	–	–
Pycnanthus angolensis	4	0.70	4	0.80	1	
Total	570		501		254	
Species diversity indices						
Simpson diversity	0.714		0.709		0.601	
Shannon diversity	1.73		1.72		1.60	
Species richness	24		23		20	

tree fallow on account of the relatively high number of woody plants present and least in *N. laevis* ($P < 0.01$; Table 2).

Leaf litter fall and decomposition

Leaf litter fall was significantly higher ($P < 0.001$) in *S. campanulata* (812 g m^{-2} year^{-1}) and the natural fallow (699.5 g m^{-2} year^{-1}) than the Mixed species stand (588 g m^{-2} year^{-1}), *R. heudelotii* (378 g m^{-2} year^{-1}) and *N. laevis* (168 g m^{-2} year^{-1}) (Fig. 2). The seasonality of leaf litter fall was bimodal for all the species except *N. laevis* which is evergreen. *S. campanulata*, the Mixed species stand and the natural tree fallow retained on average more than 50% of their foliage throughout the year (Fig. 3). Leaf litter

Table 2 Growth of trees at 5 year after establishment and leaf litter decomposition at CRIG Tafo

Treatments (trt)	DBH (cm)	Tree basal cover (m^2 ha^{-1})	Tree height (m)	Crown depth (m)	Crown diameter (m)	Crown volume (m^3)	Leaf litter decomposition half-life
S. campanulata	16.8a	24.6a	12.8a	6.2a	5.0a	40.6a	5.24a
N. laevis	10.5b	9.6b	6.5b	4.1b	3.2b	11.0b	9.22b
R. heudelotii	16.1c	22.6c	15.3c	9.2c	8.4c	169.9c	9.97c
Mixed species	11.2d	10.9d	15.5c	9.3c	8.8c	188.5d	8.38d
Natural fallow	7.9e	25.6e	12.6a*	6.8d*	5.4a*	51.9e*	7.58e
Pooled SD	0.089	0.363	0.195	0.195	0.261	0.504	0.262
Critical value**	2.228	2.228	2.228	2.228	2.228	2.228	2.228

* For trees of DBH $\geq$ 10 cm

Means in a column with different letters are significantly different at $P < 0.01$

** Fisher's pairwise comparisons

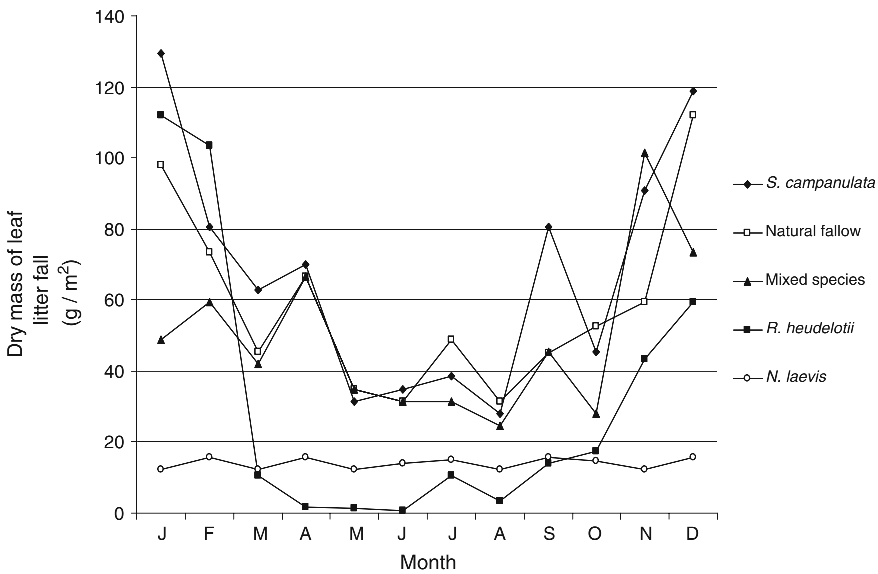

Fig. 2 Leaf litterfall in improved and natural fallow at CRIG Tafo, Ghana

decomposition half-life was significantly fastest in *S. campanulata* at 5.24 months ($P < 0.01$; Table 2).

Shade characteristics

The natural tree fallow transmitted the least amount of light (<10%) for most parts of the year (April–October) on account of the high tree density, tree basal cover and the leaf-shed pattern of the tree species involved (Figs. 3, 4). The amount of light transmitted through the crown of trees in the Mixed species stand is of interest with particular regard to the four peaks of light transmitted in the year, which averaged 30%. Though the three species in the Mixed species stand are deciduous, flowering and leaf abscission occurred at different times therefore the stand was never devoid of foliage at any time of the year hence the relatively low % light transmitted compared to *S. campanulata* and *R. heudelotii* which completely shed their foliage between November and February. Table 2 show significant ($P < 0.01$) differences in the crown characteristics of the tree species tested. These differences would have implications for the quality of shade provided by the different trees when planted as shade for cacao.

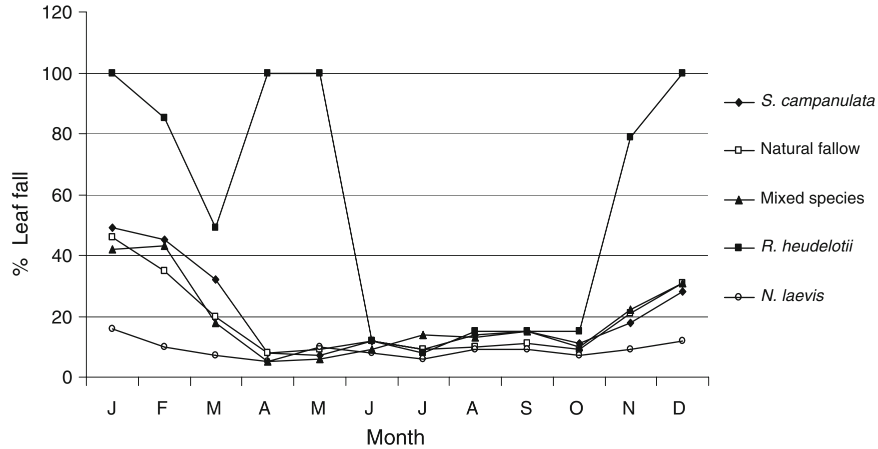

Fig. 3 Leaf shed pattern in improved and natural fallow at CRIG Tafo, Ghana

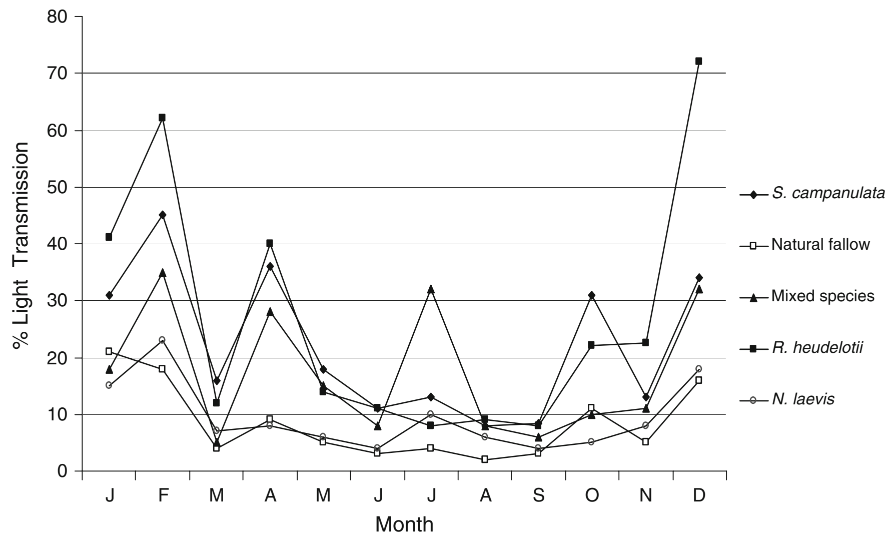

Fig. 4 Light transmitted beneath canopy of improved and natural fallow at CRIG Tafo, Ghana

Effect of trees on microsite soil characteristics

Data for topsoil (0–15 cm) samples collected in 1997 and 2003 only are presented in Table 3. There were significant differences among the trees species in terms of their effect on soil pH, %C, total N% and bulk density with *S. campanulata* showing a relatively strong soil ameliorative capability with regards to its effect on %C, % total N and bulk density when compared to *N. laevis* and the Mixed species stand in particular. The natural tree fallow was significantly ($P < 0.001$) better in increasing soil pH over time compared to the other treatments. The difference between the planted fallow and natural fallow on one hand and the two control treatments on the other was highly significant ($P < 0.001$) (Table 3).

Discussion

Almost all of the woody species in the natural tree fallow were established from seeds that were either present in the soil seed bank or dispersed from mother trees in the immediate landscape. Species richness was low compared to a value of 35 for trees ≥20 cm DBH in a 0.25 ha sample plot in a closed canopy natural forest but similar to that of coppice-regenerated trees of height ≥1.3 m on a replanted young cacao farm developed on fallow (Anim-Kwapong and Teklehaimanot 1995). The low diversity of tree species in the natural fallow is mainly due to the system of cacao cultivation where farmers initially undertake selective clearing of the original forest vegetation to provide permanent shade

Table 3 Effect of trees and time on microsite soil properties at CRIG Tafo

Treatments (trt)	pH			Organic C (%)			Total N (%)			Bulk density (g cm^{-3})		
	1997	2003	trt mean	1997	2003	trt mean	1997	2003	trt mean	1997	2003	trt mean
S. campanulata	5.93	6.21	6.07	1.38	1.89	1.64	0.153	0.203	0.178	1.31	1.23	1.27
N. laevis	5.65	6.13	5.89	1.23	1.65	1.44	0.130	0.163	0.147	1.32	1.30	1.31
R. heudelotii	5.88	6.19	6.04	1.21	1.90	1.55	0.150	0.190	0.170	1.33	1.27	1.30
Mixed species	5.76	6.14	5.95	1.34	1.65	1.50	0.137	0.187	0.162	1.35	1.26	1.31
Natural fallow	6.01	6.36	6.19	1.29	1.69	1.49	0.147	0.203	0.175	1.35	1.24	1.29
Uncultivated control	5.64	6.08	5.86	1.17	1.43	1.30	0.130	0.170	0.150	1.32	1.37	1.35
Cultivated control	5.58	5.40	5.49	1.20	1.04	1.12	0.120	0.120	0.120	1.34	1.42	1.38
Mean for year	5.78	6.07		1.26	1.61		0.138	0.177		1.33	1.30	
Trt (SED 28df)	0.03			0.023			0.005			0.012		
Year (SED 28df)	0.29			0.012			0.003			0.006		
Trt × Year (SED 28df)	0.04			0.033			0.007			0.017		

for cacao. Subsequent weed control measures and shade regulation keeps species richness at the farm level low. These have implications for the floristic composition of communities that develops after cacao (Horn 1976). Furthermore, in early successional stages, the site might be dominated by early successional species and usually have fewer plant species representative of mature forest. It is important to note however that the small plot size and number of sample plots used for the study might have also contributed to the low species diversity and richness (Kindt and Coe 2005).

The growth rates of *T. ivorensis* and *T. superba* in this study are comparable to those reported on the species by Butterfield (1996) and Norgrove and Hauser (2002). In cacao, rapid growth of shade trees to provide quick soil cover and reduce weed infestation is an important criterion for the selection of shade trees. Mobbs and Cannell (1995) indicated that optimum fallow period is shortened by growing fast-growing trees. In this regard, the growth rate of trees in the Mixed species stand and *R. heudelotii* are noteworthy. The natural tree fallow with its superior canopy cover or site capture is also noteworthy. This could be an effective means of suppressing noxious shade intolerant weeds and help reduce cost when replanting cacao (Beer et al. 1998).

In the present studies *S. campanulata* was comparatively better than the other treatments in improving microsite topsoil % organic carbon and % total nitrogen values overtime. This report supports studies in Cameroun that indicated differential effects of trees on soil properties (Ngobo and Weise 2003). The natural fallow was as effective as or even better than some of the planted tree (improved) fallow species in improving topsoil pH, % organic carbon, % total nitrogen and bulk density over time. This supports the report on the soil ameliorative capacity of natural fallow in humid West Africa (Hullugalle 1992). Furthermore, it adds to the list of studies which show that non-legumes are capable of improving microsite soil fertility (Deans et al. 2003; Fisher 1995). The organic matter contents of soils are very important in relation to growth and yield of cacao (Omotosho 1975). Generally, both the natural fallow and improved fallow raised the topsoil organic carbon appreciably to levels satisfactory for the growth of young cacao (Omotosho 1975).

Trees in the Mixed species stand and *R. heudelotii* which had umbrella-like crown shape (strongly whorled horizontal branches/boughs) can be planted at low densities in cacao farms, therefore making more space available for cacao whilst providing effective shade following Kuuluvainen and Pukkala (1987). The tree architecture of Terminalia species and the associated fast growth rate of the species make them particularly suitable as shade for cacao. In managing the tree species as shade for cacao, the problem of deciduousness in the Terminalia species, *A. toxicaria* and *R. heudelotii* can be circumvented by taking advantage of the temporal differences in their leaf fall pattern and light transmission characteristics. These species can be planted together in an appropriate spatial pattern to optimize their shading effect all year round. In this regard, the Mixed species or the natural tree fallow with its diversity of tree species with different leaf shedding pattern and light transmission characteristics may be considered as better options compared to the monospecific tree plots in the rehabilitation of land for replanting cacao in a shaded system.

Conclusions and implications

The study shows that within a reasonable time after removing moribund cacao and associated vegetation and using appropriate management, a diverse community of tree species can develop in situ. Despite the low species richness, the number of preferred cacao shade trees regenerated naturally in the present trial is adequate for managing a multi-species shaded cacao system. This might not be obtained in circumstances where farmers start to replant immediately after clearing old cacao using habitual methods which includes slash and burn and removal of all vegetation cover to facilitate initial food crop production which also serves as temporary shade for young cacao. Where permanent shade is not provided through planting and no measure is taken to control capsids (*Sahlbergella singularis* Hagl and *Distantiella theobroma* (Dist) (Heteroptera:Miridae)) attack, young replanted cacao may suffer severe moisture stress during the dry season and capsid damage leading to high seedling mortality after the temporary shade has been phased out. Repeated attempts at replanting could deplete the soil seed bank of tree floral diversity and also aggravate environmental degradation.

It is evident that trees have different and complementary characteristics which could be combined to provide ideal shade for cacao. From a standpoint of biodiversity conservation and the future floristic composition of the landscape, a natural tree fallow with its diversity of tree species may be recommended as a rehabilitation technique for replanting cacao towards a shaded system. Site rehabilitation and restoration based on natural tree regeneration depends on the microsite condition, seed bank, seed rain, mother trees and living stumps of the desired species (Gomez-Pompa and Burley 1991). Where conditions are not favorable, a multispecies improved fallow with desirable shade trees may be established or compensatory (enrichment) planting can be carried out.

Farmer management of the environment is critical to sustainable cacao production, therefore, with the erosion of traditional land acquisition methods following the individualization of land rights (Quisumbing et al. 2001) and the appropriate legislative framework (Timber Resources Management Act (Amendment), 2002 (Act 617) and legislative instrument 1721) in place to protect tree ownership, the need to disseminate appropriate tree planting and nurturing technologies to assist farmers manage shade for sustainable cacao production would be crucial to the long-term goal of environmental sustainability. Long-term investments in tree planting and nurturing could also strengthen individual land rights were they are weak (Quisumbing et al. 2001).

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