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Spice crops agroforestry systems in the East Usambara Mountains, Tanzania: growth analysis

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Abstract A scarcity of cultivation land calls for more intensive and productive land use in the East Usambara Mountains in NE Tanzania. Spice crops could generate cash in higher parts of the mountains, but the present cultivation methods are depleting the valuable forest resources. The trial was established at the end of 2000 to find out how the two popular cash crops, cardamom (*Elettaria cardamomum* (L.) Maton.) and black pepper (*Piper nigrum* L.), normally grown under the natural forest, will produce in intensive agroforestry system with two multipurpose farm trees, *Grevillea robusta* A.Cunn. and nitrogen fixing *Gliricidia sepium* Jacq. Results from 6 years showed that cardamom produced better with grevillea than in natural forest; 5.5 times more in the fourth year than the average in the area. The Land Equivalent Ratios for black pepper and cardamom showed that pepper intercropped with grevillea produced 3.9 times more than in monoculture whereas cardamom intercropped with grevillea and pepper produced 2.3 times more than in monoculture. Gliricidia improved the nitrogen and organic matter content of the soil over the levels found in natural forest. Soil acidity was, however, preventing the plants from using the available mineral nutrients more effectively.

Keywords *Elettaria cardamomum* · *Gliricidia sepium* · *Grevillea robusta* · Land Equivalent Ratio · *Piper nigrum* · Growth and yield

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Introduction

Demographic pressure on public land is severe in the East Usambara Mountains in NE Tanzania. The population has steadily increased in the region, the conservation area has expanded and farmers have ended up with small, scattered fields. Cash crop cultivation in the upper parts of the mountains have been recommended for their smaller requirement for land area and potential to generate higher income (e.g., Hamilton and Bensted-Smith 1989; Stocking and Perkin 1992; Huang et al. 2002). Thus, spice-crop agroforestry could be one option for more intensive and sustainable land-use in the upper part of the mountains. However, the suitability of this option has not yet been proven.

Black pepper (*Piper nigrum* L.) and Cardamom (*Elettaria cardamomum* (L.) Maton.) are two introduced crops on the farms of the East Usambara Mountains. They are native to southern India and were introduced to the area in the 1890s by German settlers. Black pepper is one of the oldest and the world's most important spice. At the end of 1980s pepper cultivation was promoted in the East Usambaras, and now almost 60% of the farmers cultivate it as a cash crop. Black pepper generally grows supported by trees that also provide shade. The crop needs at least 3 years from planting to start production. The production of the crop increases with time and can continue up to 40–60 years, having a peak at about 15 years of age (Purseglove et al. 1981).

Cardamom, which is one of the world's most ancient spices and the third most valuable spice in the world, has already been grown for half a century under the natural forest in the area. It is mostly grown in the fragile higher parts (>850 m) of the mountains. Cardamom is a valuable source of income for about 60% of the highland farmers in the East Usambaras and its contribution to the average household income is about 30%, providing more than a half of the total cash crop income (Reyes et al. 2006). However, the heavy thinning of forest areas for cardamom cultivation is one of the main problems threatening the valuable East Usambaran forest and its many endemic species (Newmark 2000; CEPF 2005). Moreover, as the crop becomes unprofitable after about 7 years (Sah 1996), the subsequent land clearing for cultivation of annual crops have caused severe damage for the natural forests. Thus, alternative cultivation methods should be found for this high-value cash crop. As both spice crops need shade trees, and, in addition, black pepper as a vine needs a support tree, agroforestry methods appear to be a suitable option. The aim of this study was then to assess the biological feasibility of producing black pepper and cardamom in home gardens, comparing intercropping versus pure stands under different combinations with two introduced tree species, *Grevillea robusta* A. Cunn. and *Gliricidia sepium* Jacq.

Grevillea is a tree native to subtropical eastern Australia that became a very common boundary tree to claim land rights in Tanzania after the villagization program in the 1970s. In the 1980s, tree planting was promoted with free seedling distribution to the households and most farmers chose to plant grevillea (Yasu 1999), because it is fast growing, easy to propagate and it provides economically viable products such as good quality timber. It also seems to compete less with the adjacent agricultural crops when compared to other trees available for farmers, due to its deep rooting system. As it tolerates intensive pruning it provides fuelwood and fodder for households all year round and it is planted for soil improvement resulting from the shading and mulch it provides (Muchiri 2001; Harwood 1989). It reaches a maximum height of nearly 40 m and a diameter approaching 100 cm (Harwood 1989). In Kenya at the altitude of 1,400 m grevillea reaches a maximum height of about 33 m at an age of 50–60 years, while the diameter is 50–70 cm. In India it is intercropped with black pepper (Purseglove et al. 1981).

Gliricidia, native to Central America, is arguably the most widely cultivated multipurpose tree in the tropics after *Leucaena leucocephala* (Lam.) de Wit. It is the most common live fence species in Central America and in other tropical areas because of the easy rooting of large stem cuttings and its multiple uses such as forage (leaves), food (flowers), green manure, fuelwood, medicine and its properties as a rat poison. It is an important fuelwood in the sub-humid tropics due to its quick regrowth after pruning and lopping. Wood is hard, durable and termite-resistant. It is said to improve the soil through nitrogen fixing. It is used as a shade tree for perennials, and support tree for black pepper (Agroforestree Database 2006).

Materials and methods

Study site

The East Usambara Mountains are located 40 km from the coast in the northeastern corner of Tanzania in Tanga Region (longitude 38°32′ and 38°48′E, latitude 4°48′ and 5°13′S, altitude up to 1,250 m). They cover 1,300 km^2 and belong to the chain of isolated mountains called the Eastern Arc. The climate is humid tropical with a mean annual rainfall of 1,918 mm (bimodal), and a mean annual temperature of 20.6°C.

The East Usambara Mountains are covered by submontane forests that are sustained by a very tight cycling of nutrients between vegetation and soil; if this cycle is broken through forest destruction, nutrients are likely to be rapidly lost by leaching, resulting in an impoverished soil (Hamilton and Bensted-Smith 1989). The soil is generally very deep (over 150 cm), well drained and strongly acid Ferrasols. The colour varies from dark reddish brown in the topsoil to yellowish red and red brown in the subsoil, often having a clay layer in the subsoil. The experiment site is located 500 m from the border of Amani Nature Reserve, 2 km from the village of Shebomeza on a slope that includes soils classified as Haplic Acrisols in the upper section and Haplic Lixisols at the bottom. The site was cleared from natural forest for farming in 1990.

Field experiment

Cuttings of gliricidia, pot seedlings of grevillea and pepper, and tillers of cardamom (one mother tiller with a young shoot) obtained close to the experimental site were planted in November 2000 either in monoculture or in intercropping. Treatments were:

(T1) grevillea + pepper,
(T2) grevillea + pepper + cardamom,
(T3) grevillea,
(T4) cardamom,
(T5) gliricidia,
(T6) gliricidia + pepper,
(T7) gliricidia + pepper + cardamom and
(T8) pepper (supported by dead wooden poles).

A complete randomised block design was used. A total of four replications were laid out, at the top, middle and bottom of the slope, as well as one beside the forest. The direction of the slope was north (down)–south (up). The planting density for gliricidia and grevillea trees was 3 m × 3 m (about 1,100 trees/ha). Cardamom was planted between the tree rows in treatments T2 and T7 with a spacing of 2 m (2 m × 3 m, 1,666 crops/ha) and in treatment T4, which was sole crops with a spacing of 2 m × 2 m (2,500 crops/ha). Three black pepper seedlings were planted per each support tree, following a common practice to ensure the survival of at least one plant per support tree. The density for pepper was the same than for trees, 3 m × 3 m (about 1,100 crops/ha). Plot size was 16 m × 16 m.

The experiment was established at the onset the rainy season, without irrigation. No fertilizers, chemical pesticides or organic manure were applied during the experiment. No pruning, branching or thinning, except trashing of cardamom (removing old and dry leaves) once a year was carried out. Weeding was done twice a year and dead poles in the pepper monoculture were changed when required.

Growth and yield determinations

Nine sample crop plants and associated trees were systemically measured in each plot, every second month. For black pepper, height and diameter of the plant at ground level were measured; whereas for cardamom, the number of tillers, average height and average diameter of the tillers were recorded. Fresh yields of black pepper berries and cardamom seedpods were weighed per plot. The fresh weight was converted to dry weight by measuring and drying a sample of crop production. The tree measurements included tree height, diameter at ground level and at breast height (*dbh*), canopy width, and canopy height.

Dry wood biomass for grevillea was estimated as:

$$\text{Biomass} = V \times D, \text{ and } \quad V = \pi r^2 \times h \times f$$

where V = Volume (m^3), D = wood density (469 kg/m^3), h = height (m), f = form factor (0.5), r = basal area radius. The stem volume for grevillea trees was obtained as a product of height and diameter with the model: $v = h \times g \times f$, where v is volume, h height, g the basal area and f a tree form factor ($f = 0.5$). Dry wood biomass was determined as a product of volume and wood density (469 kg/m^3).

As the model for estimating the volume of gliricidia was not available and the form factor is not known due to irregular growth of gliricidia, the stem volume was derived from the regression between fresh weight and height for each sample tree. To estimate the fresh weight we weighted samples of different sized gliricidia trees in the site. The dry matter content was 0.21% in this experiment. The volume was obtained with fresh weight and wood density (750 kg/m^3). All yields were converted to per-hectare values for easier comparison. Root biomass could not be measured, as in most forestry trials, as the methods would have required considerable effort and costs.

Several mathematical functions were fitted to the data to describe the growth dynamics of trees and species. Polynomials provided a good fit but the interpretation of the parameters was cumbersome. The beta function (Yin et al. 2003) on the other hand, in addition to the goodness of fit had parameters associated with biological events. The growth rate of crops and trees was estimated using a linear model of height as a function of time. All data were analysed with the "agricolae" statistical procedure for agricultural research, created by CIP within the open source R-package version 1.0–3 (De Mendiburu 2007).

Treatment comparison

Treatment differences were analysed with the Waller–Duncan *K*-ratio *t*-test. The test was selected due to its suitability for analysing large samples (3,000–5,000 units in this case).

The variables were:

- *For crops* height, ground diameter, dry yield in kg/ha in 3rd, 4th, 5th and 6th year (for black pepper only in 5th and 6th year). In addition, for cardamom, the average numbers of tillers, panicles and fruits were recorded.
- *For trees* height, ground and breast diameter, canopy height and width in two sites, canopy cover, height of the lowest branch, volume per tree, volume/ha, dry weight/ha, economic value/ha.

We compared the increase in height and diameter between treatments with a Bonferroni test.

Comparing yields with land equivalent ratio

The Land Equivalent Ratio (LER) is the ratio of the area under pure stand to the area under intercropping needed to give equal amounts of yield at the same management level. It compares the yields from intercropping with yields from the same crops in pure stands. To calculate the LER, the yield of one associated crop is divided by the yield of the same crop in pure stand and added to the same fraction for the second crop, and so on:

$$\mathrm{LER} = \mathrm{intercrop1}/\mathrm{purecrop1} + \mathrm{intercrop2}/\mathrm{purecrop2} + \mathrm{etc.}$$

If the ratio is grater than 1.0, intercropping is advantageous, while less than 1.0 indicates a disadvantage. The LER is a standardized tool for comparing different agroforestry situations and crop combinations (Mead and Willey 1980).

Light conditions

Light was measured in September 2002 every hour during three different days with a quantum sensor (Li-189, LI-COR, Lincoln, USA). It measures the photosynthetically active photon flux density (wavelength between 400 and 700 nm) in μmol $m^{-2}s^{-1}$. The light was measured by placing the sensor in the middle of the cardamom crop and for pepper at breast height (1.3 m altitude). The light intensity was compared to that measured in the open, giving a percentage relative to full light intensity above the canopy.

The light intensity, measured as photosynthetically active radiation under grevillea trees 2 years after planting, was on average 24% for pepper and 29% for cardamom, compared to the light intensity in the open. Corresponding values under gliricidia were 30–45% for pepper and for cardamom, respectively. For cardamom cultivation in the natural forest it was 30%. The light conditions under these trees were considered suitable for spice production. The ideal shade reported for most medicinal and aromatic plants in India, including cardamom and pepper is 30–50% in Karnataka (Rao et al. 2004) and about 40–60% of the light intensity in the open in the Western Ghats (Kumar et al. 1995).

Soil analysis

Soil analyses were carried out at the soil laboratory of Mlingano Agricultural Research Institute in Tanga region, Tanzania. Soil was analysed before planting the experiment in October 2000, in October 2002, and in October 2006. A total of 20 composite topsoil (0–30 cm) samples from each treatment were collected, air-dried and sieved. Measurements included the soil pH (H_2O and KCl), electrical conductivity (EC), the exchangeable magnesium (Mg), calcium (Ca), potassium (K) and sodium (Na) contents, and the cation exchange capacity (CEC) of the soil. In addition, organic carbon (C%), total nitrogen (N%) and available phosphorus (P) were determined and the base saturation ratio (BS) measured. Comparison of soil characteristics between treatments and sampling dates was done with the Bonferroni test.

Results and discussion

Growth and yield

The survival rates for plants, 1 year after planting, were 59% for pepper, 87% for cardamom, 97% for grevillea and 77% for gliricidia. The mortality of the gliricidia cuttings during the first 2 years was attributed mainly to late rains and to Mosaic virus in 2001, thus producing the drying of the cuttings before rooting. However, these survival rates were superior to reported rates of 58% for gliricidia cuttings in Sri Lanka (Gunathilake and Wasanthe 2004). It was also observed that when the support trees for pepper died, pepper plants also gradually withered.

Black pepper

Black pepper grew best (greatest height and fastest growth rate) and had the best survival rate and vitality when intercropped with grevillea (T1 and T2: 350–360 cm; 65–70 cm/year; survival rate 72%). Grevillea has been reported to have a positive effect on the growth of some associated crops. Intercropping grevillea at a density of 300 trees/ha with banana and beans increased the crop yields by 70–75% in the highlands of Burundi (Akyeampong et al. 1999). When intercropped with gliricidia the growth of black pepper was quite slow and the survival was poor (T6 and T7: 243–249 cm; 46–49 cm/year; survival rate 45%). However, the slowest growth was observed in monoculture with dead support trees (T8: 201 cm; 40 cm/year). The difference in height was significant ($P < 0.01$); as for the diameter, only Treatment T1 (grevillea with pepper) differed ($P < 0.01$) from the other treatments in which pepper was included (Fig. 1 and Table 1).

Black pepper started berry production 5 years after planting. Polynomial growth curves showed clearly that the growth of black pepper vine declined in time of starting to produce. In the second production year, the intercropping of pepper with grevillea (T1) gave a mean of 124 kg of dry pepper/ha (with a density of about 1,100 plants/ha), which was about four times the yield obtained in the other treatments (Table 1). Pepper yields normally increase with time reaching the production peak at about 15 years after planting (Purseglove et al. 1981). Preliminary data from 2007 shows that the pepper yields in the best treatments would increase up to five fold from the level of the previous year.

Farmers in the East Usambaras grow the pepper vines one by one around suitable trees and stones near their houses. The average estimated yield per plant from 37 farmers was 0.92 kg. There are no comparative yield data per hectare from the East Usambaras. The average production of black pepper in India is 300 kg/ha, but the country's productivity figures vary a lot, ranging from 91 kg/ha in Pondicherr to 1,406 kg/ha in Karnataka. In the same country, one hectare of monocrop pepper regularly fertilized and irrigated gave an average of 600–800 kg/year, which is equal to 0.38–0.5 kg/plant (Tejwani 1994). In our case, the best mean yield per plant was 0.33 kg. Worldwide, pepper yields range from 270 kg/ha in India to 3,445 kg/ha in Thailand (Black Pepper Cultivation 2007) and 1,742 kg/ha in Vietnam (Thankamani et al. 2007). The considerable yield variations are partly explained by differences in agroecological conditions and cropping seasons.

Cardamom

Cardamom started to produce 2 years after planting. In general, as in the case of pepper, cardamom production followed the trend of plant growth (height of tillers) as good growth was correlated with high production. However, a high number of tillers were not necessarily correlated with good yield.

Cardamom intercropped with grevillea and pepper (T2) exceeded all other treatments in all aspects studied, except for the number of tillers, which was the lowest one of all treatments comprising cardamom. The growth rate of cardamom was changing from 28 to 51 cm/year depending the treatment. T2 had the highest growth and T7 the lowest. Cardamom tillers had the maximum height in the time of maximum production about 3.5 years after planting.

In the 3rd year (the first production year) the yield of cardamom in T2 was 3 times higher than in other treatments, and in the two following years, it was double. In the 4th year (the 2nd production year) the dry weight yield of cardamom produced by treatment T2 averaged 560 kg/ha (370–710 kg/ha). The yield and the number of panicles were correlated ($P < 0.01$). Good growth of the tillers for both height and diameter, and a high number of panicles had a positive effect on production (Table 1). Cardamom

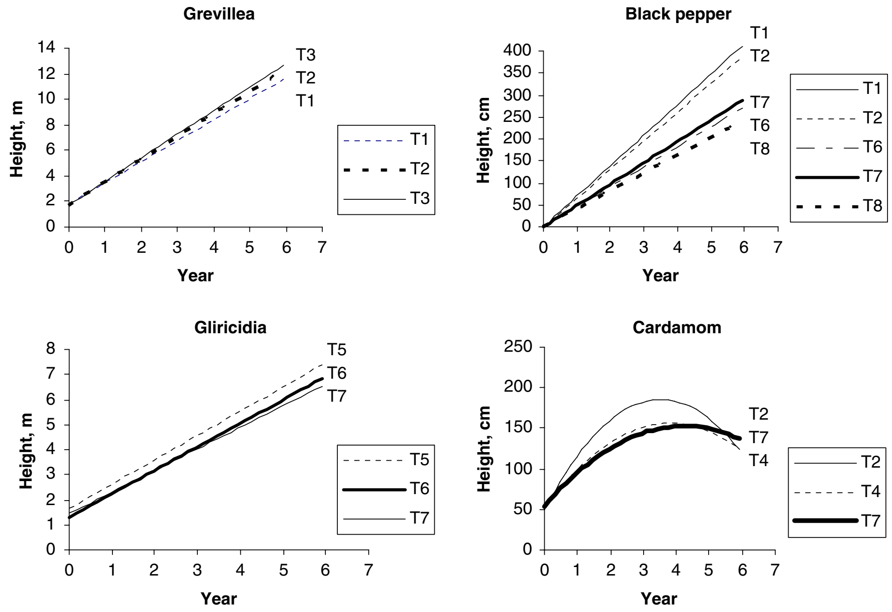

Fig. 1 *Regression lines* describing the growth of *Grevillea robusta*, *Gliricidia sepium*, *Piper nigrum,* and growth curves for *Elettaria cardamomum.* Treatments: *T1* Grevillea + pepper, *T2* Grevillea + pepper + cardamom, *T3* Grevillea, *T4* Cardamom, *T5* Gliricidia, *T6* Gliricidia + pepper, *T7* Gliricidia + pepper + cardamom, *T8* Pepper

tillers grew best with grevillea and pepper (T2) and also the survival rate (92%) and plant vigour were the best in this treatment. Cardamom tillers reached their maximum height at 3.6–3.9 years, depending on the treatment. This was the only species reaching the asymptotic growth within the time span of the experiment (Fig. 1). The tillers grew shorter after that, probably due to increasing shade and competition. The highest growth of tillers correlated with the best production time. The intercropping with grevillea and black pepper (T2) gave cardamom an early high growth rate compared with the other treatments.

The following equations describe the relationship between cardamom height and time after planting, in years:

T2: Height (cm) = 110.1702 Year − 15.5077 Year ^{2}; Year < 7; $R^2 = 96.5\%$, max h 195.67 cm in 3.55 years.

T4: Height (cm) = 88.9520 Year − 11.8893 Year ^{2}; Year < 7; $R^2 = 94.2\%$, max h 166.36 cm in 3.74 years.

T7: Height (cm) = 82.6874 Year − 10.5093 Year ^{2}; Year < 7; $R^2 = 95.1\%$, max h 162.64 cm in 3.93 years.

The beta function curves of cardamom showed clearly the stagnation of the growth in the end of dry season and that there was less rain than normally during the short rains of the year 2003. The dry weight yield of cardamom 4 years after planting (in its second production year; 563 kg/ha) in T2 could be considered as an optimum without manure application and improved planting material. Generally cardamom in forest cultivation in the East Usambaras produces the highest yield in the fourth year after planting, about 125 kg/ha, with annual averages over 10 years of about 80 kg/ha (Masayanyika 1995). The average yield in India is about 150 kg/ha/year (Korikanthimanth 2001) but with improved varieties and good management cardamom can produce higher yields. In Karnataka, cardamom was intercropped in paired row system (2,315 plants/ha) between rows of Robusta coffee (*Coffea robusta* L.), yielding 1,400 kg/ha 4 years after planting, averaging 672 kg/ha in seven cropping seasons. In this case organic and commercial fertilizers and irrigation were applied, and plant protection measures implemented (Korikanthimanth et al. 1998). The second best treatment in the present experiment was the monoculture of cardamom (T4). The results were, however, biased by the high production of one plot (more than 570 kg/year) out of four replications, the average production in the three other plots was 160,60 and 24 kg/ha (Table 1).

Grevillea

Grevillea did not differ among treatments in height and canopy height (Table 1). The average annual

Table 1 Performance of grevillea, gliricidia, pepper and cardamom in year 6 from establishment and pepper and cardamom yields in years 3–6

Variable	*Grevillea robusta*				*Gliricidia sepium*			
	Mean	Treatment			Mean	Treatment		
		T1	T2	T3		T5	T6	T7
Growth rate (cm/a)	175	164.1	177.0	183.9	92.3	97.1	93.6	86.1
Height (cm)	1,120	1050^{a}	1147^{a}	1164^{a}	654	726^{a}	644^{b}	614^{b}
Ground diameter (cm)	10.4	9.5^{b}	10.5^{ab}	11.2^{a}	8	9.8^{a}	8.2^{b}	6.7^{c}
DBH (cm)	7	6.2^{b}	7.1^{ab}	7.9^{a}	4.7	5.8^{a}	4.6^{b}	4.0^{c}
Canopy height (cm)	922	854^{a}	939^{a}	976^{a}	614	690^{a}	604^{b}	571^{b}
H lowest branch (cm)	198	196^{a}	208^{a}	188^{a}	39.8	35.2^{a}	29.7^{a}	42.8^{a}
Canopy width (cm)	290	297^{ab}	266^{b}	307^{a}	330	393^{a}	356^{a}	265^{b}
Canopy cover (m^2)	4.5	4.6^{ab}	4.2^{b}	4.7^{a}	5.1	6.1^{a}	5.5^{a}	4.2^{b}
Dry weight (1,000 kg/ha)	13.7	9.8^{b}	13.8^{ab}	17.7^{a}	14.2	15.7^{a}	14.0^{b}	13.3^{b}
Volume (m^3/tree)	0.03	0.019^{b}	0.027^{ab}	0.034^{a}	0.017	0.019^{a}	0.017^{b}	0.016^{b}
Volume (m^3/ha)	29.2	21.0^{b}	29.5^{ab}	37.7^{a}	18.9	21.0^{a}	18.6^{b}	17.8^{b}

Variable	Pepper						Cardamom			
	Mean	Treatment					Mean	Treatment		
		T1	T2	T6	T7	T8		T2	T4	T7
Growth rate (cm/a)	53.9	69.5	65.2	45.6	48.6	40.5	31.1	50.5	33.8	28.3
Height (cm)	287	360^{a}	351^{a}	249^{b}	243^{b}	201^{c}	133	135^{a}	131^{a}	133^{a}
Ground diameter (cm)	1.26	1.50^{a}	1.26^{b}	1.17^{b}	1.20^{b}	1.10^{b}	1.55	1.67^{a}	1.51^{ab}	1.46^{b}
Yield (dry), year 3 (kg/ha)	0	0	0	0	0	0	74	143^{a}	52^{ab}	25^{b}
Yield (dry), year 4 (kg/ha)	0	0	0	0	0	0	314	563^{a}	216^{b}	163^{b}
Yield (dry), year 5 (kg/ha)	32	78^{a}	22^{b}	17^{b}	11^{b}	31^{ab}	309	436^{a}	279^{a}	213^{a}
Yield (dry), year 6 (kg/ha)	51	124^{a}	32^{b}	42^{b}	25^{b}	32^{b}	85	135^{a}	59^{a}	62^{a}
Number of tillers							23.4	20.6^{b}	21.2^{b}	28.2^{a}
Number of panicles							58	104^{a}	22^{b}	49^{ab}
Number of fruits							1,160	2457^{a}	278^{b}	748^{ab}

Different superscripts represent statistical differences between treatments ($P < 0.05$)

Treatments: *T1* Grevillea + pepper, *T2* Grevillea + pepper + cardamom, *T3* Grevillea, *T4* Cardamom, *T5* Gliricidia, *T6* Gliricidia + pepper, *T7* Gliricidia + pepper + cardamom, *T8* Pepper

growth rate was 1.75 m, whereas tree heights after 5 years of growth were over 10 m. In those cases of observed differences between treatments, grevillea in monoculture (T3) had the highest values, followed by T2 (grevillea with two crops). The mean annual volume increment varied from 3 to 11 m^3/ha. The curves from beta-analysis showed that grevillea had exponentially high growth rates in each treatment during the two-first years being about 3 m per year (315–325 cm/a).

Research conducted in Kenya has indicated that the most rapid volume growth occurs between the ages of 5 and 20 years, when the mean annual volume increment is about 10–18 m^3/ha in plantations and on farms (Muchiri 2001) and it can produce more when it is regularly pruned after the age of 5–7 years. Grevillea was a suitable black pepper support tree as its rough bark allowed the vine to climb and attach well to the trunk. The data suggest that intercropping did not significantly affect the growth of grevillea for the first 6 years. This good performance in intercropping, concurs with its success as the most popular farm tree in the East Usambara Mountains. Harwood (1989) claimed that grevillea does not perform well in wide-scale monoculture plantations. However, in the present experiment grevillea performed similarly in all cases. In 6 years only 40% of the trees in the trial exceeded the breast height diameter of 11 cm, which is the limit for firewood becoming a timber tree when its value would double.

Gliricidia

Gliricidia in monoculture (T5) had the highest values in all variables studied ($P < 0.05$) compared to the two intercropping situations. Differences between T6 (gliricidia with pepper) and T7 (gliricidia with pepper + cardamom) were limited to a few variables with a tendency of T6 to have higher values than T7 (Table 1; Fig. 1).

The maximum growth of gliricidia after 6 years was 6–7 m. The growth of gliricidia was very modest in the trial, with a rate of height growth that varied from 86 to 97 cm/year being highest in monoculture and lowest when mix cropping with 3 species. This could be an effect of the altitude of the experimental site (1,000 m a.s.l.). Although the ecological altitude limit of gliricidia is claimed to be 1,200 m a.s.l. (Agroforestree Database 2006) this species is not common at more than 850 m a.s.l. in the East Usambaras. It is normal for gliricidia that the height varies much due to its irregular stem form; for instance from 2 to 15 m in Sierra Leone (Amara and Kamara 1998). The wood production of gliricidia in Guatemala was found to be from 5 to 6.8 kg/tree at 36 months (NRI-note 2005). In the present trial the dry weight at the same age was only about 2–3 kg/tree, and after 6 years it was, on average, 12.8 kg/tree.

Comparing yields with land equivalent ratio

Intercropping was highly advantageous for pepper and cardamom. Pepper intercropped with grevillea produced 3.9 times more than in monoculture and cardamom intercropped with grevillea and pepper yielded 2.3 times more than in monoculture (Table 2).

The LER for Treatment T1 (grevillea with pepper) was 4.5, which means that 4.5 times more land would be needed to produce the combined yields of the two crops in pure stands. Likewise, LER ratio for T2 (grevillea with pepper and cardamom) was 4.1. Treatments with gliricidia, T6 (gliricidia with pepper) and T7 (gliricidia with pepper and cardamom) resulted in higher than double yields (LER 2.22 and 2.68) as compared to monocrop systems. In intercropping, the timber yield was always lower, and the yield of the spice crop was higher, meaning that the biological efficiency of intercropping depends on the effects of the system on the yield of the crop. The high LER values, showed a very clear benefit from intercropping black pepper and cardamom with grevillea or gliricidia.

The LER is defined as a ratio, and large values can be obtained because of high yields in intercropping but also because of small yields in corresponding monocrops (Mead and Willey 1980). However, the LER is criticized because often the whole stand density is higher in intercropping than in monocrop systems (Vandermeer 1989). In our case the densities of tree species and black pepper in intercropping were the same as the individual densities in monocrop systems, but for cardamom the density was higher in the monocrop system. Still the yield of cardamom in monoculture was the lowest one when compared to other systems. It is also discussed whether the optimal monoculture yield should be chosen as a base of comparison (Vandermeer 1989), in this case mean yields have been chosen in monoculture and in intercrop systems. Jolliffe (1997) reported that, on average, mixtures are 12% more productive than pure stands, based on 202 direct observations, or 13% more productive, based on 604 estimates using yield-density relationships.

Soil fertility

Soils at the experimental site were determined as having low fertility in year 2000 when the field experiments were started. All soil characteristics improved from year 2002 onwards, except for the pH and Ca (Table 3). Many soil characteristics (pH KCl, available P, K, Mg, B.S.% and CEC) showed a decreasing trend from year 2000 to year 2002 and rose again until 2006. The organic carbon and nitrogen contents increased steadily.

Gliricidia improved soil conditions more than did the other plants in the trial. There was a difference ($P < 0.05$) between intercropping with gliricidia and the other treatments without gliricidia in terms of N, C, C/N, and Ca. Total soil nitrogen increased in the

Table 2 Wood biomass, spice yields (kg/ha) and the land equivalent ratio in different agroforestry components

Yield					LER				
	T1	T2	T6	T7	Monoculture				
	GR + BP	GR + BP + C	GS + BP	GS + BP + C	(M)	T1/M	T2/M	T6/M	T7/M
Grevillea	9,827	13,816			17,684	0.56	0.78		
Gliricidia			13,968	13,321	15,736			0.89	0.85
Pepper	123.57	31.91	42.12	24.68	31.54	3.92	1.01	1.34	0.78
Cardamom		135.11		61.76	58.98		2.29		1.05
LER						4.47	4.08	2.22	2.68

Table 3 Comparison of changes in soil characteristics between 2000 and 2006 with Bonferroni test

Variable	Means			Ratio treatment in 2006/treatment in 2000							
	2000	2002	2006	T1	T2	T3	T4	T5	T6	T7	T8
pH H2O 1:2.5	5.90	4.91	4.69	−0.4	−0.6	−0.25	−0.75	−0.6	−1.4	−0.8	−0.25
pH KCl 1:2.5	4.30	3.88	4.18	0.25	0.1	0.2	0.15	0.2	−0.3	0.05	0.15
Org C%	2.59	3.58	3.65	−0.24	0.165	−0.39	0.49	−0.365	2.325*	1.865*	0.03
N%	0.16	0.27	0.29	0.015	−0.045	0.01	−0.005	0.065*	0.26*	0.175*	0.01
C/N	16.00	13.50	12.69	−1	2.5	−2.5	1	−4.58*	−5.5*	−1.5	−1
Av. P mg/kg	2.05	1.25	5.54	2.8	3.595	4.205	4.66	2.92	3.665	4.245	5.29
Na Me/100 g	0.21	0.09	0.10	−0.02	−0.015	0.005	−0.05	−0.035	−0.16	−0.105	0.04
K Me/100 g	1.28	0.03	0.08	−0.58	−0.57	0.055	−0.59	−0.56	−1.18	−0.635	0.04
Ca Me/100 g	3.73	1.51	1.39	−0.42	−0.71	−0.65	−2.13*	−0.49	−2.7*	−2.76*	−0.69
Mg Me/100 g	2.33	0.29	0.31	−0.95	−0.96	0.16	−1.34	−1.04	−2.24	−2.01	0.01
EC Ms/cm	0.04	0.07	0.16	0.065	0.085	0.065	0.125	0.115	0.175	0.12	0.07
B·S.%	64.30	37.25	50.94	6	2	19.5*	0	1.5	−15.5	−8	16*
CEC Me/100 g	11.70	4.78	9.45	0.78	1.345	2.17	−1.415	1.335	−2.82	1.75	3.635

An asterisk denotes significant change ($P < 0.05$) from 2000 to 2006 when comparing each plot separately

presence of gliricidia from low (0.16) to medium (0.42) levels (Fig. 2). The values of organic C and N were superior to those in the natural forest.

These improvements resulted even in the absence of the use of gliricidia leaves as green manure. It has been reported that the foliage of gliricidia contains about 4% of nitrogen and is therefore an excellent source of green manure (Gunathilake and Wasanthe 2004). There is therefore a potential to enhance the soil organic matter with gliricidia branches and leaves: 1 t dry weight of leaves has been estimated to be equivalent to 27 kg N (Patil 1989). Field observations in Malawi indicated that gliricidia produced more foliage biomass than any of the other ten species studied (Sitaubi 1990).

Soils remained very acidic (pH 4.0–5.2) in all plots. Lower pH values were recorded in the plots with crop monocultures (T4 and T8). Pepper varieties differ with respect to the range in soil pH, but they normally grow best in soils with a pH near neutral (Sivaraman et al. 1999). The soil was very acidic due to leaching of cations during high rainfall leaving iron and aluminium oxides in the soil. These oxides tend to bind the phosphorous thus rendering it non-available for the plants. The available P rose on average from 2 to 5.5 ranging from 4.05 to 7.02 mg/kg. Notwithstanding this improvement the levels were still below critical ones.

Magnesium (0.16–0.44 me/100 g) and potassium (0.05–0.13 me/100 g) remained very low even though improvements were observed in the plots. The soil potassium should be maintained at a high level especially when cultivating cardamom, which in India has been found to have a very high potassium

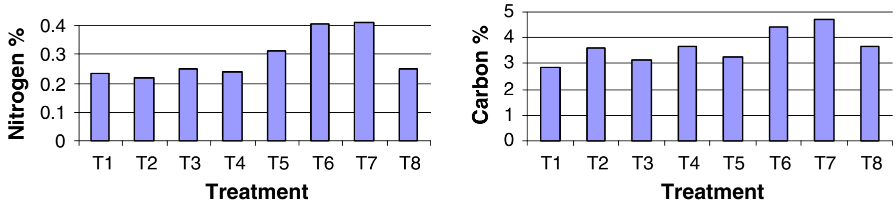

Fig. 2 Soil nitrogen and organic carbon content (%) at year 6 in agroforestry systems treatments in East Usambaras, Tanzania. Treatments: *T1* Grevillea + pepper, *T2* Grevillea + pepper + cardamom, *T3* Grevillea, *T4* Cardamom, *T5* Gliricidia, *T6* Gliricidia + pepper, *T7* Gliricidia + pepper + cardamom, *T8* Pepper

requirement. Cardamom growing in a soil well supplied with a potassium buffering power yielded two fold compared to yields in soils without buffer capacity (Nair et al. 1997).

Exchangeable calcium (0.04–2.28 mg/kg) and sodium (0.06–0.15 me/100 g) levels were low. Conductivity results (0.09–0.26 mS/cm) showed that the salinity in the experimental soils was low. That was a positive result since high levels of salts in the soil inhibit the growth of many crops. CEC (6.5–14.4 me/100 g) was low and BS (46–56%) was moderate (Table 3).

Conclusions and recommendations

Our results suggest that in the East Usambaras there clearly are some viable intercropping and cultivation possibilities for spice crops in agroforestry systems as black pepper yields were four times higher with grevillea whereas cardamom yielded more when intercropped with grevillea and pepper. Land Equivalent Ratios show that intercropping of pepper and cardamom is advantageous, especially in the case of grevillea as associated tree. A comparison of other response variables also shows the superiority of intercropping. The performance of gliricidia was very modest, which could be attributed to the high altitude of the experimental site to this variety and to the lack of pruning. However, gliricidia proved its ability to improve the organic matter content and total nitrogen of the soil to levels that exceeded those found in the natural forest.

The soil analysis showed that the intercropping of trees and spice crops can improve some soil characteristics, but addition of organic manure might be needed to maintain the soil productive in the long term, as it was noticed that 5 years after the establishment the production of cardamom started to decline. With fertilizers it could probably be maintained at a profitable level for a longer time. Recent preliminary data from the area support this finding. To reduce soil acidity it is recommended to mix rock phosphate with organic manure. Certainly there would be other suitable varieties for growing in the East Usambaras. This could include pepper varieties that could be harvested at a younger age. There is a considerable potential to increase the yields with better planting material, as evidenced by the two fold increase in cardamom yield and five fold increase in pepper yield obtained in India with improved material (Korikanthimanth et al. 1998).

We recommend the inclusion of economic analysis in further long-term work on the system.

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