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MULTISTRATA AGROFORESTRY WITH BEANS, BANANAS AND *GREVILLEA ROBUSTA* IN THE HIGHLANDS OF BURUNDI

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SUMMARY

Some agronomic, economic and ecological aspects of an agroforestry system combining *Grevillea robusta* trees, bananas (*Musa* spp.) and beans (*Phaseolus vulgaris*) were studied in the subhumid highlands of Burundi. Three densities of *G. robusta*, 208, 313 and 625 trees ha^{-1} were interplanted in plots of bananas, beans and a banana–bean mixture. When *G. robusta* was interplanted with bananas, the tree had a positive effect on banana yield with maximum yield occurring at 300 trees ha^{-1}. In the presence of beans, banana yield was not influenced by the densities of the tree. Under low fertility regimes, the yields of beans interplanted with *G. robusta* were equal to or greater than those of the no-tree plots. Maximum bean yields were observed at between 283 and 295 trees ha^{-1}, representing a 25–135% yield increase above the no-tree control. When soil fertility was raised by the application of fertilizers, bean yields declined with an increasing density of *G. robusta*. Three years after planting, the growth of *G. robusta* was not affected by tree density. Mean height and mean basal diameter were 7.1 m and 13.2 cm respectively. Below ground competition between beans on the one hand, and bananas or bananas and *G. robusta* on the other, was more important than competition for light. Compared with the crops alone treatments, cumulative net present values of tree plots improved from being negative in the first year to being positive in the third year. Net present value was highest in two of three instances when the density of *G. robusta* was 625 trees ha^{-1}. A multistrata arrangement of bananas and beans with *G. robusta* is viable for the low input agriculture system of the highlands of Burundi.

INTRODUCTION

In densely populated countries such as Burundi and Rwanda where land holdings per family are very small (Guinand *et al.*, 1992), options for land-use diversification are limited. Diagnostic studies have shown that farmers produce fuelwood,

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poles, fodder or mulch on their own farms (Guinand *et al.*, 1992). Like urban architects designing flats in a densely populated town, agroforesters and farmers now consider the option of increasing productivity through a multilayered arrangement of trees and crops. Such an option was investigated by ICRAF in Burundi with *Grevillea robusta* trees grown above bananas and beans, two of the major crops in the area.

At an international workshop on *G. robusta*, the importance of this species for agroforestry in the tropical highlands was highlighted (Harwood and Booth, 1992). Although there are reports on silvicultural studies for plantations (Harwood, 1989), there are little published data on its use in agroforestry, especially in association with food crops. Of a total 244 entries in a bibliography on *G. robusta* (Harwood, 1989), only a few were about associations of *G. robusta* and arable crops. Most of the agroforestry applications reported in this bibliography were on the use of the tree as shade in coffee and tea plantations in East Africa and on the Indian subcontinent, a practice which is in decline (Owino, 1992).

In the highlands of East and central Africa, *G. robusta* is certainly one of the most common tree species found associated with crops. In central Kenya, which probably has the highest concentration of *G. robusta* trees in the highlands of East and central Africa, Thijssen *et al.* (1993) estimated 103 trees ha^{-1} of several species of which *G. robusta* was dominant in Embu, and Tyndall (1996) counted 77 *G. robusta* trees ha^{-1} of farm land in the Kirinyaga District. In Embu District, *G. robusta* accounts for nearly 50% of the most prevalent trees found on farms (K. A. Snyder, personal communication).

According to farmers, *G. robusta* does not compete with crops (Evans, 1990) and may even enhance yields. Consequently, it is found in plots of arable crops, as shade trees in coffee, on contour lines for soil conservation and on property boundaries (Spiers and Stewart, 1992; Tyndall, 1996). Branches of *G. robusta* are pruned at the beginning of the cropping season to limit shading of crops. The branches serve as fuelwood and the leaves are incorporated in the soil as a source of organic matter and nutrients, or given as fodder to livestock (Spiers and Stewart, 1992). The tree is eventually harvested as timber. Other reasons for the popularity of *G. robusta* among farmers are its ease of propagation from seed and establishment, its rapid growth (2 m a^{-1}, according to Harwood, 1989), its ability to thrive on poor soils because its proteoid roots harvest water and nutrients from low fertility soils, the absence of serious pests and diseases and its capacity to regrow after heavy pruning and pollarding (Harwood and Booth, 1992).

Tyndall (1996) has demonstrated the economic profitability of planting *G. robusta* along the boundaries of maize (*Zea mays*) fields. However, the biophysical and economic implications of mixing *G. robusta* in food crops have not been documented quantitatively; neither are the optimal densities for intercropping with food crops known. Poulsen (1983) has suggested 100–200 trees ha^{-1} for optimum wood yield.

The present study was undertaken: (1) to determine the influence of *G. robusta* density on the yields of beans and bananas, (2) to quantify tree growth and potential for wood production, (3) to make a preliminary assessment of the main ecological interactions between the trees and crops, and (4) to analyse costs and benefits of the tree–crop association.

MATERIALS AND METHODS

Site

This trial was conducted in Mashitsi Research Station in Burundi (lat 3°22′S, long 34°51′E), in the bimodal rainfall highlands of East Africa at an elevation of 1600 m asl. Mean maximum and minimum temperatures are 28 °C and 10 °C respectively. The first rainy season is from late February to May followed by a four-month dry season (precipitation <50 mm per month) from late May to the end of August. The long rainy season is from September to mid-January. There is a short dry period during the second half of January. Annual rainfall averages 1200 mm. The experiment was sited on gently sloping (3% slope) Ultic Haplustox soil previously occupied by a natural *Eragrostis* spp. pasture.

Treatments and experimental design

The factorial combinations of three densities of *G. robusta*, 208 (4 m × 12 m), 313 (4 m × 8 m) and 625 (4 m × 4 m), trees ha^{-1} and three cropping systems namely banana–bean intercrop, sole banana (*Musa* spp.), and sole beans (*Phaseolus vulgaris*) resulted in nine treatments to which were added the three cropping systems without trees to obtain a total of 12 treatments. The plot size for the two highest tree densities and for the no-tree plots was 256 m^2 (16 m × 16 m) and for the lowest tree density was 448 m^2 (28 m × 16 m). A randomized block design with three blocks was used.

Management of trees

Five-month-old tree seedlings of *G. robusta*, seed for which was obtained from the Kenya Forestry Research Institute, Muguga, Kenya, were planted in March 1990. Having planted them close to the end of the rainy season, dead and damaged seedlings were replaced in October after the dry season. The lower branches of the trees were pruned in October 1991 and in February 1992 to promote the development of a single bole and to limit shading of the undersown beans. This is a common practice of many farmers. Leaves and branches were weighed separately and the leafy biomass was incorporated into the soil. After three years of growth, tree height, basal diameter (15 cm above soil level) and diameter at breast height (DBH) (130 cm above soil level) were measured.

Management of food crops

Bananas. A local cultivar of banana, Igitsiri, was planted at a density of 625 plants ha^{-1} (4 × 4 m) in November, 1990, one season after the planting of the *G. robusta*. This was to avoid high mortalities due to the dry season that would begin only a month and a half after the trees were planted. Pre-planting treatment of suckers involved removing dead leaves and roots and cutting off any rotten or diseased parts of the corm. Suckers were treated against weevils (*Cosmopolites sordidus*) and nematodes (*Pratylenchus goodeyi*) by dipping them in a suspension of Furadan (1 kg 5% Furadan and 2–3 kg clay in 10 L H_2O) and stored overnight before being planted.

Suckers 1 m in height were planted in holes 60 × 60 × 60 cm apart and fertilized with 15 kg farm yard manure and 100 g triple superphosphate. In January 1993, 10 kg (wet weight) manure, 188 g KCl and 97 g urea were applied to each stool. The recommended manure application rate is 50 kg stool^{-1} at planting and 35 kg stool^{-1} each year (S. Kabonyi, personal communication). Thinning was done regularly to maintain stools that comprised a mother pseudostem and two suckers. Thinned plants were cut into small pieces and used as mulch around the stool.

Beans. Starting in November 1990, beans were undersown each season. The first bean crop failed due to bean fly attack. To minimize the effect of the beanfly infestation on plant growth, 54 kg N ha^{-1} and 140 kg P_2O_5 ha^{-1} were applied in the form of diammonium phosphate (DAP) fertilizer. Under high soil fertility status beans are able to tolerate the bean fly (T. Baert, personal communication). The fertilizer was applied when the symptoms of the attack had already been manifested and was therefore not effective. The beans were uprooted and burnt outside the experiment. At subsequent plantings, bean seeds were treated with endosulfan. Spacing was 50 × 40 cm and two plants were left per hill. Each season, except the last (March–June 1993), the bean plots, but not the others, were manured at 10 t ha^{-1} (wet weight). The last bean crop was fertilized with 112 kg N and 280 kg P_2O_5 as DAP ha^{-1} to minimize the variation within and between plots. Only the beans were fertilized because recommended nutrient inputs for pure banana are the localized applications of manure and fertilizer around the stools. The fertilization practices were in conformity with farmer practices in the region. Fertilizer (if available) and manure are applied in the planting hole when beans are sown.

Environmental interactions

Environmental interactions were investigated in the treatments with *G. robusta* at 4 m × 4 m and the crops. Light interception by the trees and the bananas was measured using a ceptometer at four positions in a plot at weekly intervals during the March–June 1993 season. In order to separate the above-ground from the below-ground interactions between the beans and the other components, nylon mesh 50 cm in depth was installed around 4 m^2 of beans in each plot. The mesh allowed water and nutrients to flow freely but prevented roots from growing through so that the beans in the area enclosed by the mesh were subject to above-ground (light) competition only.

Economic analyses

Partial budgets were drawn up to assess the benefits and costs of planting trees in the banana–bean association, as described by Akyeampong *et al.* (1995). Essentially, three years after planting, 31 men (comprising 15 charcoal makers, 10 carpenters and 6 farmers) estimated the price of *G. robusta* for poles or firewood at 167 Burundi francs (BIF) per tree (US$1 = BIF 240). For the partial budget, these values were reduced by 30% to give a cost for bulk purchases, because farmers normally sell trees in bulk. The prices of beans and bananas during the harvest period were determined in seven area markets and were each averaged over a three-year period and reduced by 20% to give farm-gate prices.

Seedlings of *G. robusta* were valued at BIF 5 each and the labour for transplanting seedlings was valued at the prevailing wage rate of BIF 120 d^{-1}. These and the reduction of crop yields caused by the trees were considered as the principal costs. Each of the three systems, *G. robusta*–bean, *G. robusta*–banana and *G. robusta*–banana–bean and its pure crop control (beans, banana and banana–bean mixture respectively) was analysed separately and an annual discount rate of 20% was used.

Data from each of the three agroforestry systems, *G. robusta*–bean, *G. robusta*–banana and *G. robusta*–banana–bean, were analysed separately because nutrient inputs were somewhat different for each of them. As appropriate, linear and quadratic regressions were used to assess the influence of increasing tree density on crop yields at each bean harvest and on the cumulative banana yield.

RESULTS

G. robusta*–bean system*

Crop yields. On an area basis, yields of the bean crops harvested in June 1991 and January 1992 were low in the presence of *G. robusta* (Fig. 1a and b) because there had been fewer bean rows in the *G. robusta* plots (the tree rows were not sown). On a per row basis, the effect of *G. robusta* on the yields of the first two bean crops was not significant. In the crop harvested in May 1992, interplanting at 208 or 313 trees ha^{-1} improved bean yields by 70% to 75% compared with the no-tree control (Fig. 1b). The following season (January 1993), lower than usual rains reduced bean yields, but the positive effect of *G. robusta* at the two lowest densities on beans remained (Fig. 1c). The coefficient of determination of the regression curves in both May 1992 and January 1993 seasons was greater than 92%. Under an improved soil fertility and moisture regime, bean yields were high in June 1993, but they declined on the tree plots compared with the control (Fig. 1c).

Tree growth. Three years after planting, density did not influence height (mean, 7.5 m), basal diameter (mean, 13.7 cm) nor DBH (mean, 9.5 cm) (Table 1). The quantities of biomass pruned per tree at 20 months after planting was 0.6 kg leaf and 0.7 kg wood $tree^{-1}$ and at 24 months after planting were 1.2 kg leaf and 1.1 kg wood $tree^{-1}$.

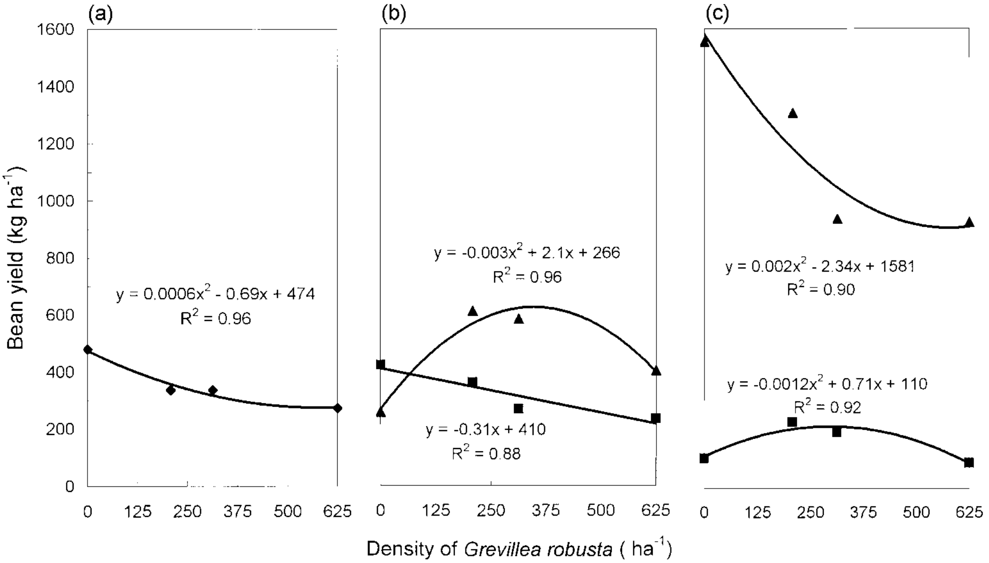

Fig. 1. Regressions of bean yields versus density of *Grevillea robusta* in a *G. robusta*–bean (*Phaseolus vulgaris*) system at Mashitsi Research Station in Burundi. Harvest of (a) June 1991 (◆), (b) January (■) and May (▲) 1992 and (c) January (■) and June (▲) 1993.

Table 1. Height, basal diameter and diameter at breast height (DBH) of *Grevillea robusta* intercropped with beans (*Phaseolus vulgaris*), bananas (*Musa* spp.) or beans and bananas, three years after planting at Mashitsi Research Station, Burundi.

	Density of *G. robusta* (trees ha^{-1})			
	208	313	625	L.s.d.
	G. robusta–*beans*			
Height (m)	7.4	7.6	7.6	0.4
Basal diameter (cm)	13.5	14.1	13.5	0.7
DBH (cm)	9.2	10.0	9.4	0.5
	G. robusta–*bananas*			
Height (m)	6.8	6.9	6.8	0.6
Basal diameter (cm)	12.7	12.5	12.6	1.0
DBH (cm)	8.7	8.5	8.0	1.0
	G. robusta–*beans–bananas*			
Height (m)	6.8	6.9	6.8	0.4
Basal diameter (cm)	13.7	12.8	13.4	1.0
DBH (cm)	9.2	8.8	9.1	0.8

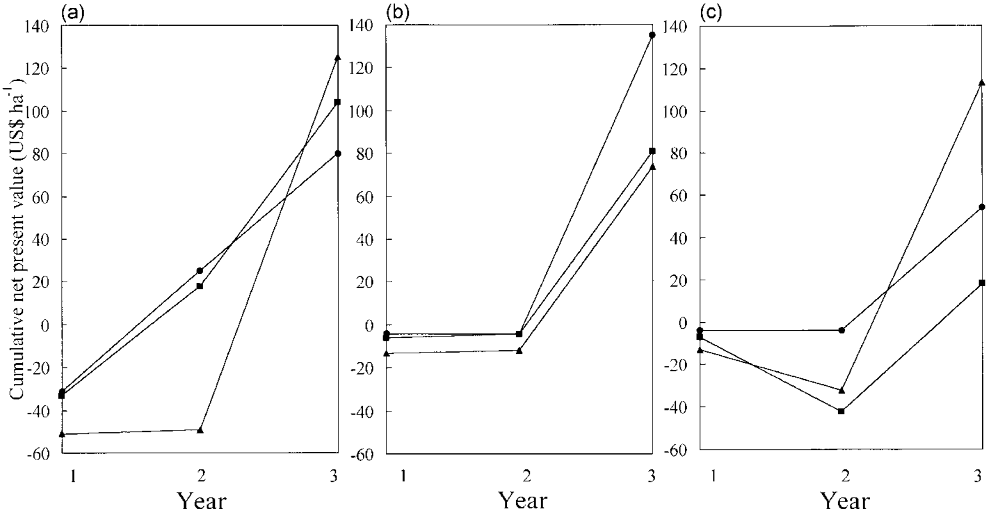

Fig. 2. Cumulative net present values versus time for (a) the *Grevillea robusta*–beans (*Phaseolus vulgaris*), (b) the *G. robusta*–banana (*Musa* spp.) and (c) the *G. robusta*–banana–bean intercropping systems. *G. robusta* was planted at 208 (—●—), 313 (—■—) and 625 (—▲—) trees ha^{-1} at Mashitsi Research Station in Burundi.

Economic analyses. In the *G. robusta*–bean system, net present values (NPV) in the first year were negative compared with the sole bean treatment because of the cost of planting the trees (Fig. 2a). The cumulative NPV of the plots with 208 and 313 trees ha^{-1} were positive in the second year but that of the treatment with 625 trees ha^{-1} remained negative. By the third year, when the trees were marketable, NPV were the reverse of what they had been in the first two years, with the highest tree density plots having the highest cumulative returns.

G. robusta–*banana system*

Crop yields. The yields of bananas growing with *G. robusta* but without beans showed a quadratic response to tree density ($R^2 = 0.88$) with the maximum banana yield occurring at 320 trees ha^{-1} (Fig. 3).

Tree growth. Tree density did not influence tree growth. Average height, basal diameter and DBH were 6.8 m, 12.6 cm and 8.4 cm respectively (Table 1). Mean leaf and wood prunings were both 0.4 kg tree^{-1} at 20 months after planting and were 0.9 and 0.8 kg tree^{-1} at 24 months after planting.

Economic analyses. When banana and *G. robusta* were intercropped, NPV in the first two years were negative (Fig. 2b). In the third year, cumulative NPV was positive for all treatments compared with the sole banana plots. NPV was highest where trees were at 208 ha^{-1} and lowest where trees were at 625 ha^{-1}.

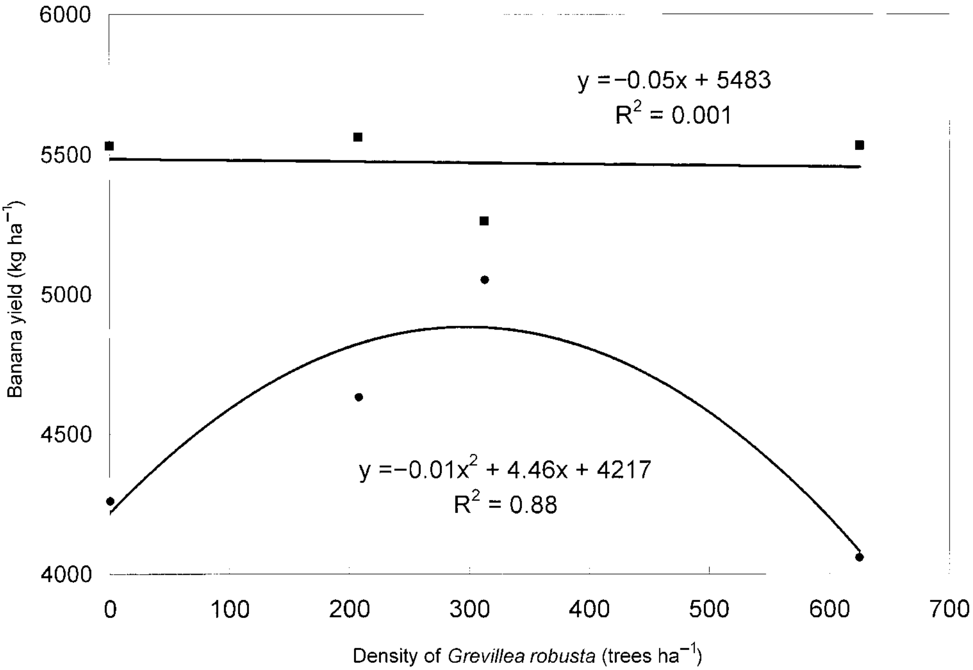

Fig. 3. Regressions of cumulative yields of banana (*Musa* spp.) and density of *Grevillea robusta* at Mashitsi Research Station in Burundi. Banana alone (●) and banana–beans (*Phaseolus vulgaris*) (■).

G. robusta*–banana–bean system*

Crop yields. In this complex system, there was no relationship between the yields of banana and the density of *G. robusta* (Fig. 3). However, bean yields, in general, declined with increased density of *G. robusta* (Fig. 4). The exception was observed in the crop harvested in May 1992, where bean yields at the intermediate densities were higher than that of no-tree control plots, as was seen in the *G. robusta*–bean system (Fig. 1). However, the reason for the low yields on the tree plots, where crops were harvested in June 1991 and January 1992, was that the beans were not sown in the tree lines. Row by row comparisons revealed no significant differences between tree and non-tree plots.

Tree growth. The growth of *G. robusta* in this system was not affected by tree density. After three years of growth, average height was 6.8 m, and mean basal diameter and mean DBH were 13.3 cm and 9.0 cm respectively (Table 1). Leafy and woody prunings averaging 0.5 kg and 0.6 kg tree^{-1} respectively were harvested at 20 months after planting. At 24 months after planting, leaf and wood prunings of 1.1 and 0.8 kg tree^{-1} respectively were obtained.

Economic analyses. Compared with the no-tree control of bananas and beans, NPV of the treatments were negative in the first two years; those of the plots with the two highest tree densities actually declined from year 1 to year 2 (Fig. 2c).

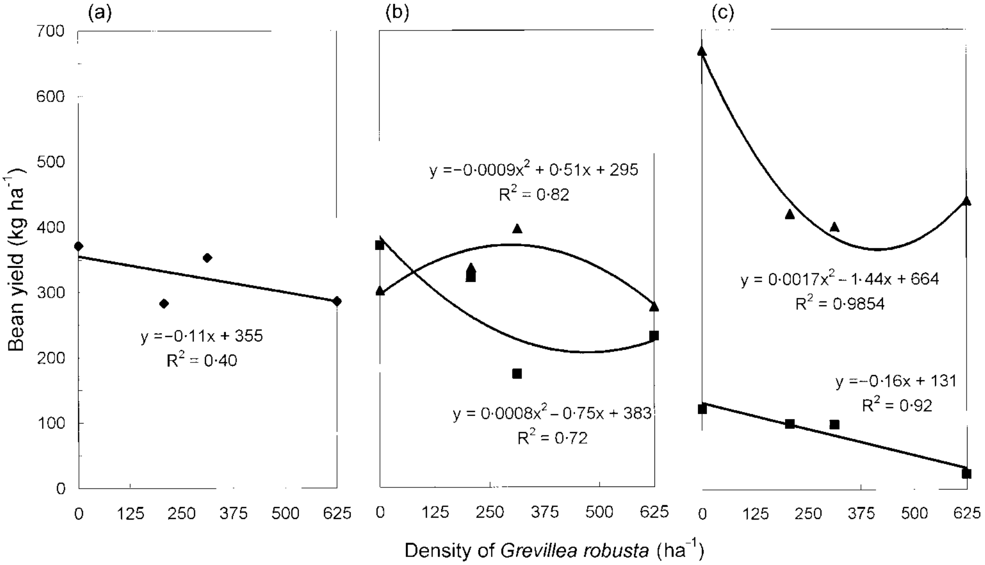

Fig. 4. Regressions of bean yields versus density of *Grevillea robusta* in the *G. robusta*–banana (*Musa* spp.)–bean (*Phaseolus vulgaris*) system at Mashitsi Research Station in Burundi. Harvest of (a) June 1991 (◆), (b) January (■) and May (▲) 1992 and (c) January (■) and June (▲) 1993.

Cumulative NPV in the third year was positive for all treatments and was highest where trees were at 625 and lowest where trees were at 313 ha^{-1}.

Environmental interactions

The amount of light intercepted by *G. robusta* trees growing alone over the beans was 10–60% (Table 2). The associated decrease in bean yield was 45% of the no-tree control (Table 3). With a root mesh the decrease was only 26% (due to light competition), indicating that root competition explained 19% of the yield decrease.

Bananas and beans intercepted only 9–35% light (Table 2). The associated reduction in bean yield was 28%, but only 5% with a root mesh between bananas

Table 2. Light interception (% total photosynthetically active radiation) by *Grevillea robusta* (625 trees ha^{-1}), beans (*Phaseolus vulgaris*) and banana (*Musa* spp.) during the sixth cropping season at Mashitsi Research Station in Burundi.

Weeks after sowing beans	Trees–banana–beans	Trees–beans	Banana–beans	Beans	S.e.d.
4	15.9	10.5	8.8	3.4	4.1
5	52.5	19.1	27.1	8.4	13.5
6	46.5	29.4	16.2	4.4	17.5
7	40.1	47.3	22.5	3.1	14.9
8	60.0	46.9	35.2	6.4	11.6
9	57.1	60.8	32.2	3.1	23.3

Table 3. Bean yields (g m^{-2}) within and outside the root-restraining nylon mesh during the sixth cropping season of *Grevillea robusta*, beans (*Phaseolus vulgaris*) and bananas (*Musa* spp.) at the Mashitsi Research Station in Burundi.

	G. robusta absent		*G. robusta* present		
	Beans	Banana–beans	Beans	Banana–beans	Mean
Within mesh	155	147	114	114	133
Outside mesh	183	132	100	43	115
Mean	169	140	107	79	
Mean	154		93		
S.e.d. between means					
Position relative to nylon mesh		6			
Tree		24			
Banana		24			
Tree × banana		34			
Tree × position		25			
Banana × position		25			
Tree × banana × position		35			

and beans (Table 3). Therefore, light competition from the bananas explained 5% of the bean yield decrease and root competition 23%.

When *G. robusta* and bananas grew together over the beans, they intercepted 16–60% light (Table 2). Bean yields were then reduced by 77%, but by only 27% when a root mesh was installed (Table 3).

DISCUSSION

A three-year multistrata system comprising *G. robusta*, beans and bananas is to be recommended economically. After three years, the highest tree density gave the greatest economic benefits because the value of the trees more than compensated for any loss in crop yields. In a country where annual per caput income is less than US$200, farmers could obtain an additional US$20–140 from the multistrata systems. Having trees close to the homestead saves women and children time and effort used in searching for fuelwood (K. A. Snyder, personal communication) and reduces pressure on forests.

This study is relevant for the highlands of East and central Africa. Banana intercropped with trees is the dominant system in Uganda and is found to varying degrees in Kenya. Tree–banana–bean systems are widely practised in Burundi, Rwanda and Tanzania. Growing beans under trees is common throughout the region.

The fact that banana and bean yields were not always depressed by *G. robusta* confirms the claims of many Burundian and Kenyan farmers that *G. robusta* does not compete with food crops (Guinand *et al.*, 1992; Spiers and Stewart, 1992). Bananas being shallow-rooted feed from a different zone from the deep-rooted *G. robusta* (Mwihomeke, 1992). These results are similar to those of Akyeampong *et al.*

(1995) who reported that *G. robusta* interplanted at 312.5 tree ha^{-1} did not affect the yield of bananas during the first three years after planting. Shading by *G. robusta* was not a problem either because bananas have a certain degree of shade tolerance although shade delays fruit maturation (Torquebiau and Akyeampong, 1994).

The reduction in yields for the second and third crops of beans on the plots with *G. robusta*, as has been explained above, was due to lower bean densities. Whereas the beans on the tree plots competed with the trees for the unused fertilizer that had been applied to the first bean crop because of crop failure, the beans without competition on the no-trees control plots grew well resulting in high yields. This same phenomenon explains the significantly lower bean yields during the sixth cropping season in the tree plots with a high application of fertilizer. It seems, therefore, that under low soil fertility, the presence of *G. robusta* at about 300 tree ha^{-1} enhances bean and banana yield significantly. The trees may have provided a favourable micro-environment for the crop, while the organic matter from the incorporated leaves may have improved the physical and chemical characteristics of the soil. This beneficial effect of the tree is not always apparent when soil fertility is high.

In the root mesh study, the 27% reduction in bean yield due to above-ground competition from the bananas and *G. robusta* together was no different from that which was observed with *G. robusta* only (26%), indicating that competition is the same whether *G. robusta* is alone or mixed with bananas. This could be explained by some interactions occurring between the trees and bananas. One possible explanation is the competition between them, another is the overlap of the leaves of *G. robusta* and bananas. Thus, the shade of the two species growing together was less than the sum of the shade of the two species growing separately. If light competition from trees and bananas growing separately were additive, it would reach 32% when the two species were mixed, but the experiment shows that it reached only 27%, indicating that the amount of foliage is lower by about 5%. The measurement of light intercepted by the trees and the bananas separately in the tree–banana mixture might improve understanding of the mechanisms involved.

Root competition in the tree–banana mixture is, however, more than expected from the trees and bananas grown separately. It reached 50% instead of 42% (19% + 23%). Manure application to the bananas may also explain this difference, since the beans were probably able to use part of these nutrients. To alleviate below-ground competition, Neumann (1983) recommended deep hoeing to destroy surface tree roots before sowing the crop. While it may be conducive to bean growth, deep hoeing may be detrimental to bananas or other perennials associated with the trees.

The possibility of progressive thinning to alleviate competition and preserve crop yields, which is the main aim of the farmer, makes this a very low risk technology. If fuelwood production is the farmer's objective as was the case in central Kenya (Tyndall, 1996), a three-year rotation could be practised on a 1-ha farm. This would involve removing one-third of the trees from the plots with 625 trees ha^{-1} (where competition was most intense) and would provide a 5-person Burundian household with its fuelwood needs (Kamangaza, 1991).

Bean yields were lower in the *G. robusta*–banana–bean system than in the *G. robusta*–bean system. The reduction in bean yields caused by the bananas was due mainly to below-ground competition. This was expected as both bananas and beans are shallow-rooted. The yield decrease due to above-ground competition was very low (5%) and correlated well with light response studies of beans in other parts of the East African Highlands which showed that a 27% decrease in light does not affect beans, and that a further decrease in light to 42% of total photosynthetically active radiation (PAR) decreases dry grain yield of beans by 27% compared with the control not subjected to a decrease in PAR (Torquebiau and Akyeampong, 1994).

It is difficult to obtain data in the literature with which to compare the performance of *G. robusta* in an agroforestry system. The mean height growth rate (2.4 m a^{-1}) obtained in this trial was higher than the range (1.52–2.1 m a^{-1}) reported for young *G. robusta* (<six years old) in various silvicultural configurations and in different environments (Abebe, 1992; Neumann, 1983; Harwood and Booth, 1992; Kalinganire and Hall, 1993) probably because of the nutrient inputs into the agroforestry system.

In conclusion, it has been shown that crop yields can be maintained or even increased, and fuelwood and eventually timber can be obtained by interplanting *G. robusta* in low-input banana–bean production systems in the highlands of East and central Africa.

It must be emphasized that competition from the trees was expected to increase as they grew bigger and that both biophysical and economic factors could change over time. Data collection was halted when the authors had to leave the Gitega area of Burundi because of a deteriorating security situation following the 1993 attempted military *coup d'etat*.

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