Agroforestry Systems **26**: 185–203, 1994.

Comparative performance of seventeen upperstorey tree species associated with crops in the highlands of Uganda

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Key words: agroforestry, crop yields, highlands, intercropping, MPTs, species, tree growth, Uganda

Abstract. Trials were established at three sites in Uganda to test the suitability of multipurpose trees (MPTs) as upperstorey in crop lands to provide poles, small timber and fuelwood. The three sites were Kachwekano District Farm Institute (1°16′ S, 29°57′ E, 2000 m.a.s.l.) in Kabale District, Kabanyolo University Farm (0°28′ N, 32°27′ E, 1250 m.a.s.l.) in Mpigi District and Bushenyi District Farm Institute (0°34′ S, 30°13′ E, 1610 m.a.s.l.) in Bushenyi District. The MPTs were planted in single rows at intra spacing of 2 m and each plot contained seven or nine trees. On both sides of the tree row, crops were raised. Data on crop yields were collected every season, while data on the growth of the trees were collected four times each year.

In terms of tree growth, *Grevillea robusta, Casuarina cunninghamiana* and *Alnus acuminata* performed well with height growth of 1.8–2.4 m per year at Kachwekano, while at Bushenyi *Grevillea robusta, Casuarina junghuhniana, Cupressus lusitanica* and *Cedrela serrulata* averaged 1.6–2.0 m height per year. At Kabanyolo, *Melia azedarach, Cassia siamea, Jacaranda mimosifolia, Grevillea robusta* and *Maesopsis eminii* had height increments ranging from 1.8–2.7 m annually. Crop yields were affected by the presence of the MPTs, with *Maesopsis eminii* being the most competitive (averaging 60% reduction, over five seasons). The crop rows nearest to the tree line were the most affected. Only *Alnus acuminata* seems to have had a positive effect on crop yields. The installation of a root mesh to reduce tree root competition for nutrients and water in four species increased yields in plots with MPTs by 5% (*Melia azedarach*) to 152% (*Maesopsis eminii*), but the control plot still had significantly higher bean yields, suggesting that shading could also be important. In the case of maize, suppression seems to be due mainly to root competition because after its elimination yields obtained thereafter did not differ significantly from those of the control except for the Maesopsis plots. The negative influence of the MPTs could, therefore, be minimized by periodically pruning the tree crowns and roots.

1. Introduction

The demand for timber, woodfuel, poles and other wood based products has outstripped production leading to the depletion of many indigenous forests in the highlands of East and Central Africa [Burnett, 1985; Hamilton, 1984; Malaisse and Binzangi, 1985; Thorhaug and Miller, 1986]. In addition, population increase in the region led to more forests and marginal lands being cleared for agricultural and livestock production [Allen and Barnes, 1984; Buschbacher, 1986; Kleinert, 1985; Pimentel et al., 1986]. Intensive cropping on hillslopes has resulted in increased soil erosion [Thomas, 1988] and reduced soil moisture storage which in turn has lead to low agricultural productivity.

One possible solution to reduce pressure on the indigenous forests, and to meet demands for wood products is to plant more trees in the existing farming systems [Nair, 1983; Newmann, 1983]. Trees can also provide services such as soil erosion control [Pushparajah and Elliot, 1990] and soil fertility improvement [Prinsley and Swift, 1986]. Currently, however, little information exists regarding the growth, arrangement and management of multipurpose trees (MPTs) on farms, and their compatibility with agricultural crops. To this effect, the East Africa AFRENA (Agroforestry Research Networks for Africa) programme in Uganda set up trials to compare the growth of selected upperstorey MPTs and their effect on crops. This paper reports the findings of these studies.

2. Materials and methods

2.1. *Study sites*

The site characteristics of the three study areas are given in Table 1. Makerere University Agricultural Research Institute at Kabanyolo is located 14 Km North of Kampala city. Before the experiments were established, the site had been fallow for several years and the vegetation was mainly elephants grass (*Pennisetum purpureum*) with isolated *Spathodea nilotica* and *Albizia coriara* trees. Bushenyi District Farm Institute is situated near Bushenyi town. Prior to the establishment of the experiment at this site, the vegetation was mainly *Digitaria scalarum* grass with herbs and shrubs, and a few isolated *Erythrina abyssinica* trees. Kachwekano District Farm Institute is situated 8 km outside

Table 1. The site characteristics of the three study areas in the highlands of Uganda.

	Kabanyolo	Bushenyi	Kachwekano
Latitude	0°28′ N	0°34′ S	1°16′ S
Longitude	32°27′ E	30°13′ E	29°57′ E
Altitude (m)	1250	1610	2000
Rainfall (mm)	1400	1200	1040
Temperature (°C)			
– Mean annual	22.5	21.0	14.0
– Mean maximum	27.9	25.6	23.5
– Mean minimum	15.7	13.5	10.9
Soils			
– Type	Ferralsol	Ferralsol	Ferralsol
– pH	5.4	4.7–5.4	3.9–5.2
– % C	1.3–1.9	–	2.6
– % OM	–	4.6	–
– % N	0.11–0.14	–	0.25
– P (ppm)	5.7	12.3	11.5
– CEC	6.4	–	5.1
– Slope (%)	5–10	5–25	8–56

Source: Peden et al. 1991.

of Kabale town. Steep slopes are extensive at this site (average 38% at the trial) and the surrounding area has been cleared of woody vegetation for agriculture. Prior to the establishment of the experiment, some of the land was under crops (e.g. sweet potatoes, sorghum and beans) while some was fallow.

2.2. *Experimental design and establishment*

Two upperstorey screening trials were established at Kabanyolo (November 1988 and June 1989), one at Bushenyi (April 1990) and one at Kachwekano (April 1989). Randomized complete block designs with three replications were used in all these trials. The number of treatments in each trial varied, nine in the Kabanyolo trials, twelve in Bushenyi and ten in Kachwekano. In all cases, a control plot with pure crops was established as one treatment. The list of species that had been planted at the three sites is shown in Table 2. For all trials, a plot consisted of a single row of trees planted 2 m apart, with plot lengths of 16 m, for Kabanyolo and 12 m for Bushenyi and Kachwekano trials. Plot widths were either 6 m (Kabanyolo and Kachwekano) or 8 m (Bushenyi) with 3 or 4 m on each side of the tree row, respectively. On both sides of the row of trees, crops were raised every season. During planting, each seedling at the first trial at Kabanyolo received 20 g of calcium ammonium nitrate (CAN). Seedlings that failed to establish within one month after planting were replaced but subsequent failures were left.

Table 2. The MPTs planted at the three sites in the highlands of Uganda.

Species	Sites		
	Kabanyolo	Bushenyi	Kachwekano
Alnus acuminata	+	–	+
Alnus nepalensis	+	–	+
Cassia siamea	+	–	–
Casuarina equisetifolia	+	–	+
Casuarina junghuhniana	–	+	–
Casuarina cunninghamania	–	–	+
Cedrela odorata	–	+	–
Cedrela serrulata	–	+	–
Cordia abyssinica	+	+	–
Cupressus lusitanica	+	+	+
Cupressus sempervirens	+	–	–
Erythrina abyssinica	+	–	+
Jacaranda mimosifolia	+	–	–
Grevillea robusta	+	+	+
Maesopsis eminii	+	–	–
Markhamia lutea	+	+	+
Melia azedarach	+	+	–

"+" denotes MPT planted at that particular site; "–" denotes MPT not planted at that particular site.

Associated crops were the common species in the respective areas. No crop was planted in the second trial at Kabanyolo because the area was rocky and had infertile soils, while at the Kachwekano trial no reasonable crop was harvested due also to poor soils. Planting of crops was abandoned at this site when yields continued to be too low to warrant planting. Beans were planted at a spacing of 60 × 10 cm, while maize was planted at 75 × 50 cm at Kabanyolo. The crops were weeded by hand and no fertilizer or pesticide was applied. Green mulch or prunnings from the upperstorey trees were removed from the site.

2.3. *Tree assessment and management*

Trees were assessed for survival after four months, while tree heights and root-collar diameters were measured four times each year. Trees in all the treatments were side pruned when they started to shade the crops, and at each pruning one third of the crown was removed from the bottom. All the pruned biomass was weighed and recorded, and later removed from the site. Because of its peculiar form (drooping branches), *Cordia abyssinica* was pollarded twice in addition to being side pruned.

2.4. *Crop yield assessment*

Crops were harvested row by row for each side of the tree line and a plot average obtained. In all cases, there were 10 sample rows of crops in each plot, with 5 rows on either side of the tree line. The sample area was 10 m of the 12 m or 16 m long rows, and the total grain yield per row sampled was determined by direct weighing after shelling and drying to constant weight at 100 °C. Where samples were larger than 200 g sub-samples were used for estimating the fraction of the fresh weight composed of dry matter. Yield estimates were expressed in terms of g/m^{-1} of row.

2.5. *Root mesh installation*

To determine the effect tree root competition has on crop performance, root meshes were installed in plots with Casuarina, Maesopsis, Markhamia and Melia at experiment No. 1 in Kabanyolo. This was done in the eigth (March–May, 1992) and ninth (Sept.–Oct., 1992) cropping seasons. For each species, a trench (10 cm wide, 50 cm deep and 360 cm long) was dug 50 cm away from the tree line. The mesh measuring 50 cm wide (folded once) by 360 cm long was inserted into the trench and the soil put back to cover it. This was done each season prior to the planting of the crops. Trenches were also dug (30 cm deep) around individual plots in order to eliminate roots from other MPTs entering these plots. Crop yields were then assessed and compared to those areas without the root mesh.

2.6. *Analysis of data*

Analyses of both crop and tree data were performed for the randomized complete block design using AGROBASE/4. When treatment effects were significant ($p < 0.05$, $p < 0.01$ or $p < 0.001$), means were separated by t-tests.

3. Results

3.1. *Tree survival and growth*

Survival of the MPTs at all the sites was greater than 90%, except for *Alnus nepalensis* (Kabanyolo) and *Cordia abyssinica* (Bushenyi) whose survival was only 20% and 0% respectively. The high mortality for *C. abyssinica* is attributed mainly to termite attack, while for *A. nepalensis* the altitude may have been too low. At Kabanyolo (low elevation) *Melia azedarach, Cassia siamea, Jacaranda mimosifolia, Grevillea robusta* and *Casuarina equisetifolia* attained height growths ranging from about 6 m (Grevillea) to about 9 m (Melia) within a period of 40 months (Figs. 1 and 2). These correspond to mean annual height growth rates ranging from 1.8 to 2.7 m. In terms of diameter growth, Cordia, Maesopsis, Melia, Cassia and Grevillea attained diameters ranging from about 17 cm (Grevillea, Cordia and Maesopsis) to about 23 cm (Melia) in the same period (Figs. 3 and 4). These correspond to mean annual root-collar diameter increments ranging from 5.2 cm to 7.0 cm. The slight decreases in root-collar diameters at 36 and 44 months for experiment no. 1 and no. 2 respectively, was probably caused by change in measuring instruments from tree calipher to diameter tape.

At the Bushenyi site (mid elevation), *Grevillea robusta, Casuarina junghuhniana, Cupressus lusitanica* and *Cedrela serrulata* attained heights ranging from about 4.5 m (Cedrela) to about 5 m (Grevillea) in a period of 30 months (Fig. 5). The corresponding mean annual height increments range from 1.6 m to 2.0 m. For diameter growth, Grevillea, Cedrela and Cupressus attained root-collar growths of between 7 cm to 10 cm within the same period (Fig. 6). These correspond to mean annual root-collar diameter increments of 2.8 and 4.0 cm respectively. At the high elevation site of Kachwekano, only Greviliea, and *Casuarina cunninghamiana* attained heights in excess of 6 m in a period of 40 months (Fig. 7), giving mean annual height increments ranging from 1.8 m for Casuarina to 2.4 m for Grevillea. In terms of diameter growth, Grevillea, *Alnus acuminata, Casuarina cunninghamiana* and Cupressus attained root-collar diameters in excess of 9 cm (Fig. 8) in the same period. The mean annual root-collar diameter increments ranged from 2.7 cm for Casuarina and Cupressus, to 4.5 cm for Grevillea. There was also a slight decrease in root-collar diameters at Kachwekano and Bushenyi sites, when the trees were 30 and 28 months old respectively, possibly because measurements changed from tree calipher to diameter tape.

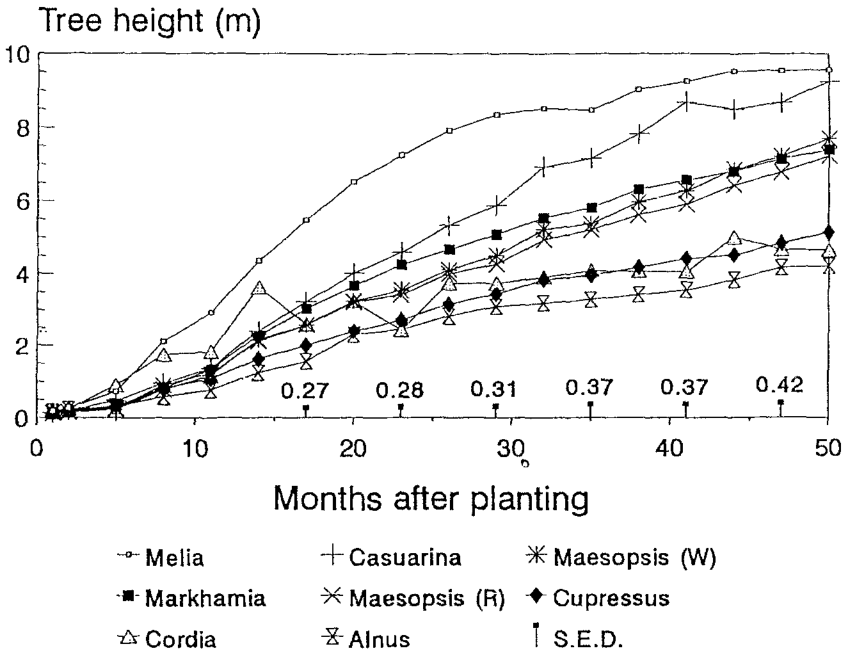

Fig. 1. Height growth of the MPTs at Kabanyolo, experiment no. 1.

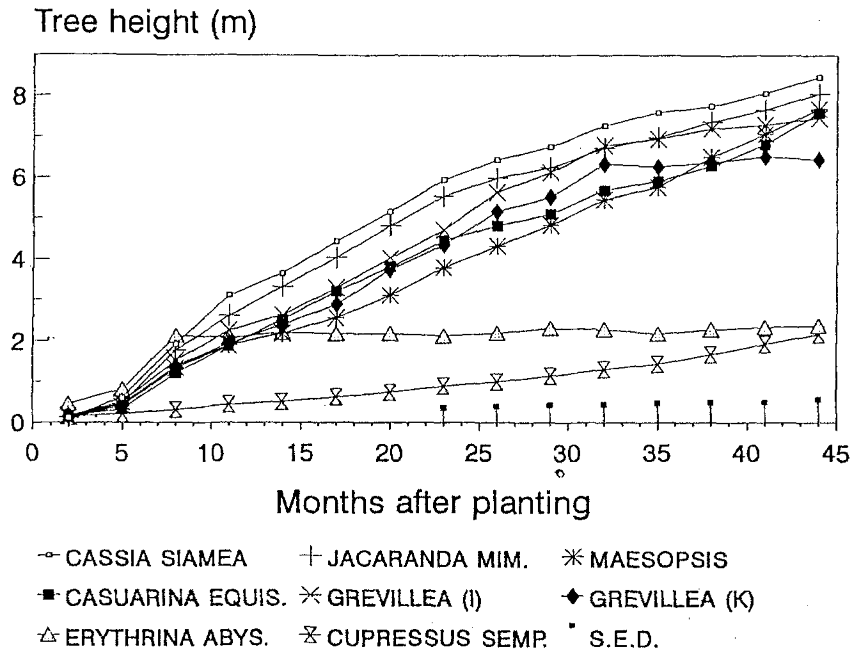

Fig. 2. Height growth of the MPTs at Kabanyolo, experiment no. 4.

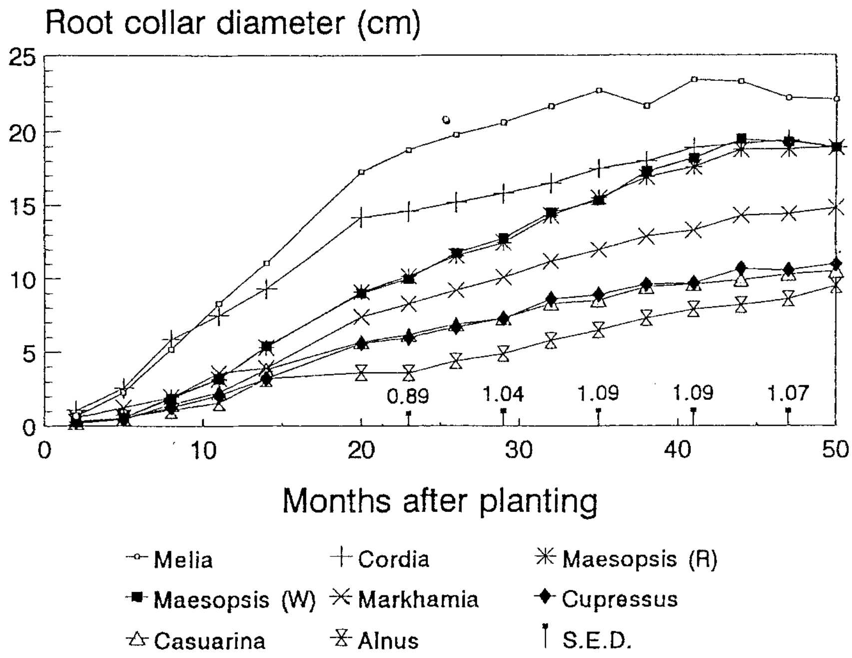

Fig. 3. Diameter growth (root-collar) of the MPTs at Kabanyolo, experiment no. 1.

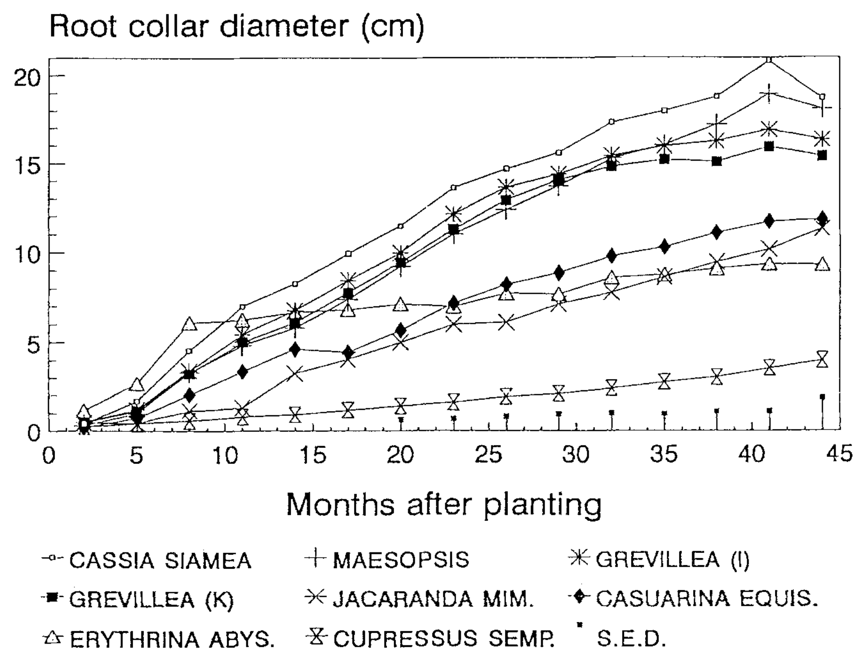

Fig. 4. Diameter growth (root-collar) of the MPTs at Kabanyolo, experiment no. 4.

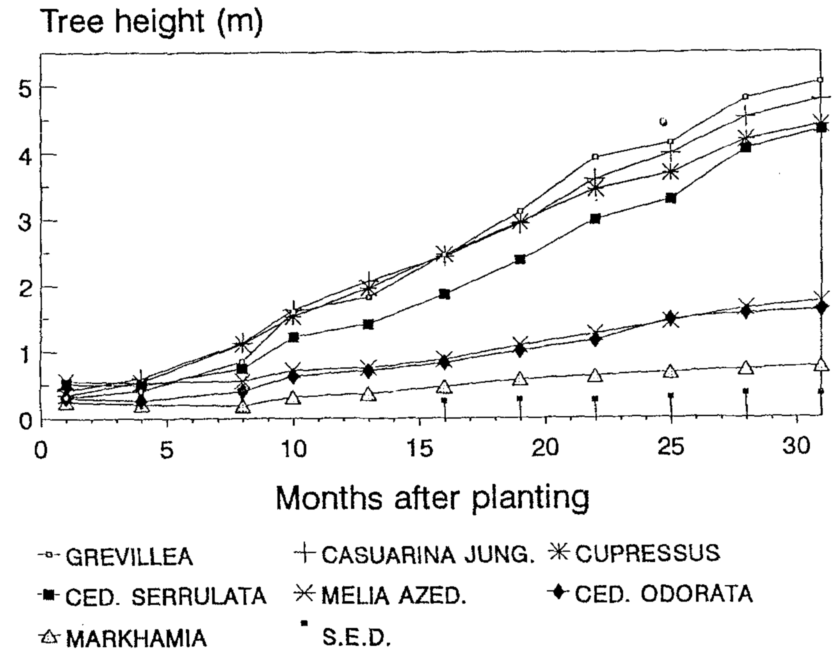

Fig. 5. Height growth of the MPTs at Bushenyi.

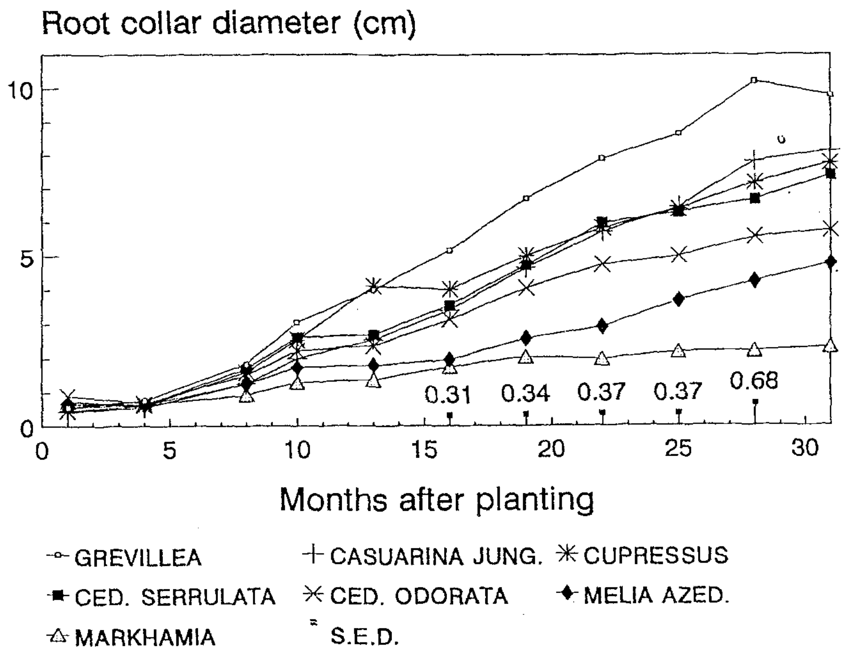

Fig. 6. Diameter growth (root-collar) of the MPTs at Bushenyi.

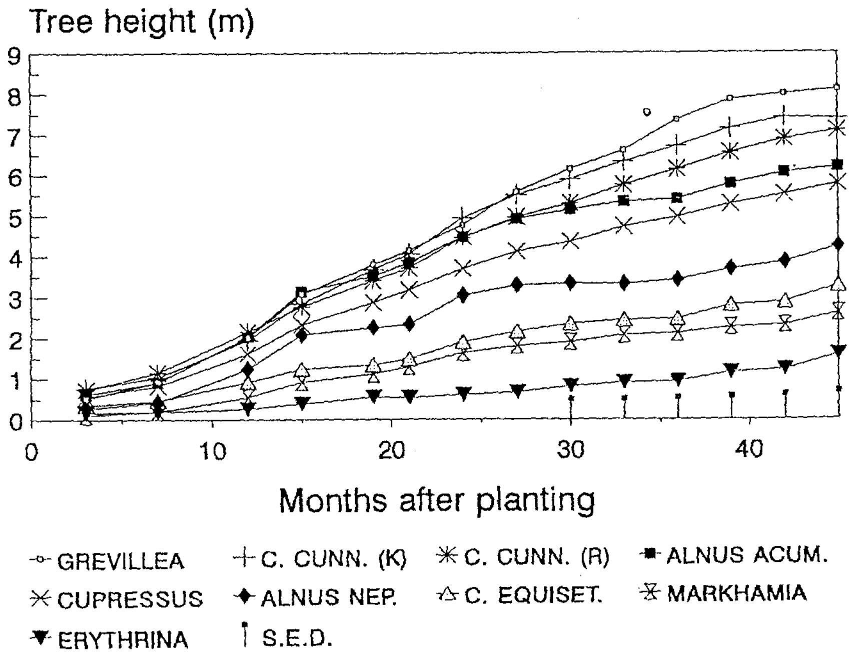

Fig. 7. Height growth of the MPTs at Kachwekano.

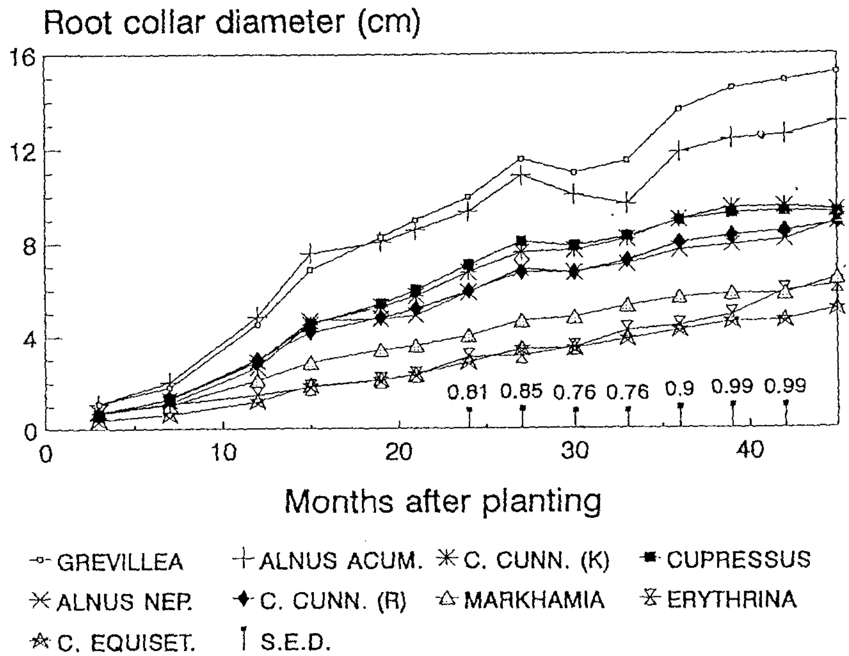

Fig. 8. Diameter growth (root-collar) of the MPTs at Kachwekano.

The species that had been planted at more than one site (*A. acuminata, A. nepalensis, C. equisetifolia, C. lusitanica, E. abyssinica, G. robusta, M. lutea* and *M. azedarach*) showed remarkably different growth patterns (Table 3). High growth rates were recorded for Melia and Markhamia at Kabanyolo (low elevation) but the two species performed poorly at Bushenyi (mid elevation) and so did Markhamia at Kachwekano (high elevation). *Alnus acuminata* and *A. nepalensis* both showed poor growth at Kabanyolo but *A. acuminata* performed well at Kachwekano, while *A. nepalensis* still performed poorly at this site. *Casuarina equisetifolia* performed well at Kabanyolo but poorly at Kachwekano, meanwhile *E. abyssinica* performed initially well at Kabanyolo but later performed poorly at both sites. On the other hand, Grevillea and *Cupressus lusitanica* to some extent, performed well at all the three sites.

Table 3. Growth performance of the MPTs planted at three sites, twenty-two months after planting.

Species	Mean annual height growth (m $year^{-1}$)			
	Kabanyolo (1,250 m)	Bushenyi (1,610 m)	Kachwekano (2,100 m)	S.E.D. of means
Alnus acuminata	1.1	*	2.1	0.50
Alnus nepalensis	0.7	*	1.3	0.30
Casuarina equisetifolia	2.6	*	0.8	0.85
Cupressus lusitanica	1.5	1.9	1.7	0.12
Erythrina abyssinica[a]	2.9	*	0.3	1.30
Grevillea robusta	2.6	2.2	2.3	0.12
Markhamia lutea	2.0	0.3	0.7	0.61
Melia azedarach	2.8	0.7	*	1.60

"*" denotes MPT not planted at that particular site; [a] Species heavily infested by pests.

3.2. *Crop yields*

The crop data reported here concentrate mainly on the Kabanyolo trial that was established in November 1988. Data for the second trial at this site and the Kachwekano trial are not reported here because the harvests were very poor due to poor soils, while data for the Bushenyi trial are not reported because the trees are still young to have any significant effect on the crops. The performance of beans under the different MPTs at Kabanyolo is shown in Tables 4a and 4b. During the first cropping season (Sept.–Nov. 1988), the MPTs did not significantly influence bean yields (Table 4a). This is presumably because the MPTs were still too young to have any influence on the crop. In the second season (April–May 1989) however, Cordia significantly reduced ($p < 0.05$) the yield of beans. The bean yields for this season were very low due to poor rains during the season. The plots containing the other MPTs gave yields which did not differ significantly from the control. Cordia and Melia significantly reduced ($p < 0.001$) bean yields in the third season (Sept.–Nov.

Table 4a. Mean bean yields (gm^{-1} of row) per plot by season interplanted with MPTs at Kabanyolo.

Species	Seasons						Mean
	1 (Sept.– Nov. '88)	2 (April– May '89)	3 (Sept.– Nov. '89)	6 (April– May '91)	7 (Sept.– Nov. '91)	9 (Sept.– Nov. '92)	
A. acuminata	75	0.7	41	38	34	21	35
Control	75	0.4	28	29	32	18	30
C. lusitanica	81	0.5	32	24	26	10	29
C. equisetifolia	76	0.4	28	21	31	9	28
M. lutea	92	0.5	31	17	25	5	28
M. azedarach	80	0.4	13	19	28	10	25
C. abyssinica	85	0.3	13	13	25	5	24
M. eminii (K)	85	0.5	27	13	22	5	25
M. eminii (W)	78	0.4	25	8	20	4	23
Mean	81	0.5	26	20	27	10	
S.E.D.	8.6	0.12	4.1	5.6	3.7	2.3	

Table 4b. Mean bean yields (gm^{-1} of row) at different distances from the tree line across seasons for the MPTs at Kabanyolo.

Species	Distance (cm) from the tree line					Mean
	60	120	180	240	300	
A. acuminata	30	33	32	30	29	31
Control	25	25	27	26	27	26
C. equisetifolia	17	18	21	20	24	20
C. lusitanica	11	15	21	25	29	20
M. azedarach	17	19	19	20	21	19
M. lutea	13	14	15	18	17	16
C. abyssinica	14	14	14	14	17	15
M. eminii (Kakamega)	8	10	12	16	19	13
M. eminii (Wundaji)	6	9	11	12	16	11
Mean	16	18	19	20	22	19
S.E.D.	3.1	3.4	3.3	3.4	4.1	3.2

1989), while Alnus significantly increased the yields. Crop yields from plots containing the other MPTs did not differ significantly from the control. In the sixth season (April–May 1991), Alnus, Cupressus, Casuarina and Melia plots gave yields which did not differ significantly ($p < 0.001$) from the control. However, Maesopsis and Markhamia plots in addition to the Cordia plot also gave significantly lower yields compared to the control. A similar pattern was repeated during the seventh (Sept.–Nov. 1991) and ninth (Sept.–Nov. 1992) seasons. At this stage, Maesopsis appeared to be the most competitive MPT, while initially it was Cordia (2nd, 3rd and 6th seasons) and Melia (3rd and 6th seasons) which seemed to be the most competitive. When the yield of beans was considered on row by row basis, Alnus, Cordia, Markhamia and Melia affected yields uniformly, irrespective of the distance of the crop row from the tree line (Table 4b). However, for Casuarina, Cupressus and Maesopsis, the yields from rows nearest the tree line were more affected than those further away.

The yield of maize when intercropped with the MPTs at Kabanyolo is shown in Tables 5a and 5b. During the fourth season (April–May 1990) Alnus, Markhamia, Casuarina and Cupressus plots gave yields which did not differ

Table 5a. Mean maize yields (gm^{-1} of row) per plot by season interplanted with MPTs at Kabanyolo.

Species	Seasons			Mean
	4 (April–May '90)	5 (Sept.–Nov. '90)	8 (April–May '92)	
A. acuminata	225	293	317	278
Control	180	268	251	233
C. equisetifolia	166	228	244	213
M. lutea	187	212	207	202
C. lusitanica	159	209	208	192
M. azedarach	95	154	221	157
C. abyssinica	16	186	191	131
M. eminii (K.)	119	115	130	121
M. eminii (W.)	100	103	104	102
Mean	139	196	208	
S.E.D.	24.7	25.8	20.5	

Table 5b. Mean maize yields (gm^{-1} of row) at different distances from the tree line across seasons for the MPTs at Kabanyolo.

Species	Distance (cm) from the tree line				Mean
	75	150	225	300	
A. acuminata	295	267	263	287	278
Control	240	236	226	231	233
C. equisetifolia	173	193	210	231	204
M. lutea	190	193	180	217	195
C. lusitanica	141	189	213	225	192
M. azedarach	147	142	143	167	150
C. abyssinica	83	130	140	172	131
M. eminii (K)	49	80	145	212	121
M. eminii (W)	42	58	115	178	98
Mean	151	166	183	214	178
S.E.D.	25.9	17.2	23.4	26.8	19.7

significantly from the control plot. In the fifth season, only Alnus and Casuarina gave yields which did not significantly differ from the control with other species significantly reducing maize yields. In the eigth season, Alnus significantly ($p < 0.001$) increased maize yields, while the Casuarina plots gave yields which did not differ significantly from the control. All the other MPTs significantly reduced maize yields. As in the case of beans, Alnus, Markhamia and Melia trees affected the yield of maize uniformly across all the five rows form the tree line (Table 5b). For the other species, the yield of maize for rows nearest the tree line were more affected than those further away.

3.3. *Effect of the root mesh*

The results of the analysis of data for areas with and without the root mesh are shown in Tables 6 and 7. Without the root mesh, the bean yields for the four MPTs differed significantly for row 1 and 2 ($p < 0.01$) and for rows 3, 4 and 5 ($p < 0.05$) (Table 6). The overall plot means also differed significantly ($p < 0.05$) between the four MPTs. In all cases, the Melia and Casuarina plots consistently gave higher yields than the plots with Maesopsis and Markhamia. The introduction of the root mesh, however, eliminated the differences in bean yield for the rows and the plots between the MPTs (Table 6). The presence of the root mesh increased yields for Maesopsis (152%), Markhamia (75%) and Casuarina (16%). A comparison of plot means

Table 6. Mean dry weight of beans (gm^{-1} of row) in areas with and without root mesh for some MPTs at experiment no. 1, Kabanyolo.

Row number	Species					S.E.D.	CV (%)
	Casuarina	*Maesopsis*	*Markhamia*	*Melia*	Control		
No root mesh							
1	4.04	0.48	2.87	9.90	20.39	1.60	45.3
2	6.75	1.18	2.72	9.60	15.36	1.54	37.3
3	12.02	3.07	5.37	10.13	20.13	2.37	38.0
4	12.79	4.77	4.90	10.08	16.83	2.36	35.6
5	12.06	8.23	4.80	9.21	15.95	2.38	34.0
Mean	9.51	3.55	4.13	9.79	17.73	2.87	30.3
Root mesh							
1	9.04	2.91	5.12	7.12	20.39	3.82	42.3
2	10.43	6.05	4.35	9.65	15.36	4.10	36.9
3	11.06	9.79	6.93	7.16	20.13	2.91	38.0
4	12.30	12.06	9.95	6.73	16.83	3.01	35.9
5	12.22	13.84	9.72	11.51	15.95	2.50	34.0
Mean	11.01	8.93	7.21	8.44	17.73	2.30	32.2
S.E.D.	0.91	1.45	0.79	0.54			

(for the root mesh data) of the four MPTs with that of the control plot still showed significantly lower values for the MPTs, indicating that bean suppression may not be due to root competition alone, but could also be due to shading.

As in the case of the beans, the maize yields for the four MPTs differed significantly ($p < 0.001$) for the rows and the plot means (Table 7). These differences are mainly due to the lower values for Maesopsis rows and plot mean. The introduction of the root mesh again eliminated these differences between maize yields for the four MPTs. The presence of the root mesh increased yields for the Maesopsis plot (102%), Markhamia plot (36%), Casuarina plot (13%) and the Melia plot (5%), A comparison of plot means (for the root mesh data) of the four MPTs with that of the control plot showed no significant differences. This suggests that root competition was the main cause of maize yield suppression.

From the above results, it can be deduced that at Kabanyolo, Alnus generally had a positive influence on the yields of both maize and beans. But it is also worth noting that in terms of growth, it was the worst performing MPT at this site (Figs. 1 and 3). Casuarina, Markhamia and Cupressus seem to have affected the maize crop less than did Cordia, Melia and Maesopsis. Meanwhile, Casuarina, Melia and Cupressus seem to have affected the bean crop less than did Cordia, Markhamia and Maesopsis. Melia seems to affect maize more than beans, while Markhamia seems to affect the beans more than the maize. For both crops, however, Maesopsis was the most competitive MPT.

Table 7. Mean dry weight of maize (gm^{-1} of row) in areas with and without root mesh for some MPTs at Experiment no. 1, Kabanyolo.

Row number	Species					S.E.D.	CV (%)
	Casuarina	*Maesopsis*	*Markhamia*	*Melia*	Control		
No root mesh							
1	265	115	217	237	244	20.70	12.3
2	226	79	239	210	237	17.39	10.7
3	278	116	165	163	246	40.95	24.6
4	235	121	190	173	255	37.53	21.5
Mean	244	104	207	221	251	21.91	12.9
Root mesh							
1	216	145	215	150	244	46.13	29.29
2	262	217	304	237	237	49.30	23.67
3	359	203	296	282	246	70.27	30.20
4	218	271	315	258	255	60.26	27.8
Mean	275	209	283	232	251	32.96	16.2
S.E.D.	15.60	23.02	19.86	16.91			

Table 8. Regression analysis relating crown diameters[a] of the MPTs to crop yields[b] at Kabanyolo.

Crop		Regression equation	R^2
Maize	Row 1	Y = 343.3 – 0.755X	0.61
	2	Y = 332.9 – 0.654X	0.71
	3	Y = 293.7 – 0.431X	0.45
	4	Y = 269.7 – 0.216X	0.15
	Mean	Y = 341.9 – 0.552X	0.51
Beans	1	Y = 25.8 – 0.032X	0.27
	2	Y = 29.0 – 0.036X	0.32
	3	Y = 30.7 – 0.036X	0.41
	4	Y = 30.4 – 0.032X	0.35
	5	Y = 29.2 – 0.022X	0.19
	Mean	Y = 17.4 – 0.026X	0.30

[a] = Data used was of December 1992 for beans and June 1992 for Maize; [b] = Data used was of September–November, 1992 season for beans and April–May, 1992 for maize.

4. Discussion

The varying growth performance of species across sites as shown by these results can be attributed to species adaptation mainly to temperature and to some extent soils and rainfall. *Alnus acuminata* for example, grew better at high elevation (Kachwekano) than at the lower elevation (Kabanyolo) while *Casuarina equisetifolia* grew better at low elevation than at the high. Other species like *Grevillea robusta* and *Cupressus lusitanica* tended to grow fairly well at both elevations. These patterns of species adaptations to sites have also been established elsewhere [Forestry Research Centre, 1986].

Several workers have found that trees when interplanted with crops tend to suppress the growth and yield of the associated crops. This suppression has been attributed to either light competition due to shading [Kang et al., 1981; Kessler, 1992; Kleninert, 1985; Sae-Lee et al., 1992] or competition from the tree roots for water and nutrients [Prajapati et al., 1971; Rao et al., 1990; Singh et al., 1989; Zohar, 1985]. In some cases, however, both shading and root competition have been found to affect the performance of the interplanted crops [Kater et al., 1992; Verinumbe and Okali, 1985; Yamoah, 1991]. The results from this study tend to confirm these findings. The relatively fast growing trees with broad and dense canopies (Maesopsis, Cordia) or tall canopies (Markhamia, Melia) appear to be more competitive than those that are slow growing (Alnus) or with narrow and less compact canopies (Casuarina). In this study, crop yields were found to be significantly ($p < 0.001$) negatively correlated with crown size, with R^2 values ranging from 0.15 to 0.71 (Table 8). The lower productivity of crops grown in associated with MPTs which have broad and dense canopies has been attributed to shading [Mathew et al., 1992]. This affects the photosynthetic efficiency of the companion crop since the biomass production of the understorey crop is a function of the photosynthetically active radiation (PAR) falling on the ground surface [Hazra and Tripathi, 1986]. Trees such as Maesopsis and Cordia which form broad and dense canopies reduce solar radiation to the understorey crop, although this was not measured in this study. In contrast, trees such as Alnus and Casuarina with narrow and less compact canopies seem to facilitate light penetration to the understorey crop as evidenced by high crop yields in their plots.

Similarly, MPTs like Maesopsis and Markhamia which have significantly high amounts of fine feeder roots at the top 30 cm of the soil seem to be more competitive than those that have low amounts such as Alnus [Okorio, For. Ecol. Manage, in preparation]. Since the crops also have most of their roots in this zone [Incerti and O'Leary, 1990], competition for water and nutrients between the MPT and the crop is bound to occur [Campbell, 1989; Gillespie, 1989]. This leads to decreased crop yields as shown by these results and by reports elsewhere [Prajapati et al., 1971; Rao et al., 1990; Singh et al., 1989; Verinumbe and Okali, 1985; Zohar, 1985]. The crop yield data obtained after the installation of the root mesh seems to indicate that root competition and shading jointly contributed to the poor performance of beans, while root competition appears to have been the main contributing factor in the poor performance of maize.

It has also been found that the suppressive effect of the MPT depends on the interplanted crop. *Morus alba* has been found to affect rice more than wheat, while *Grewia optiva* affects wheat more than rice [Khybri et al., 1992] and *Sesbania sesban* affects maize more than pole bean [Yamoah, 1991]. *Leuceana leucocephala* hedgerows also affects pigeon pea more than sorghum [Rao et al., 1990] and rubber trees (*Hevea brasiliensis*) affects pine apple and bananas more than the cereals (rice and corn) and legumes (soya bean, mugbean and peanut) [Laosuwan et al., 1988]. Similarly in this study, *Melia azedarach* affected maize more than the beans, while *Markhamia lutea* suppressed the beans more than the maize.

Overall, it can be stated that Maesopsis was the most competitive MPT for both crops for the reasons already stated above. Alnus, on the other hand, was the only MPT which appeared to have had a positive effect on the performance of beans and maize. Similarly at Kachwekano, where the species had been planted as a hedgerow to control erosion, increases in bean yields (an average 49%) were observed [Peden et al., 1993]. This could probably be attributed to the ability of the species to improve soils through nitrogen fixation [Lane, 1988] in addition to its less compact crown and slow growth rate at this site. The species was found nodulating profusely at this site [Okorio, Plant Soil, in preparation], and the analysis of soils taken from beneath the MPTs indicate that the Alnus trees had significantly increased soil organic matter, nitrogen, calcium and pottassium [Okorio, Plant Soil, in preparation].

5. Conclusions

It is evident from these and other results that MPTs in most cases tend to negatively affect the growth and consequently the yield of crops grown in association with them. This implies that to successfully grow the two together without seriously affecting crop yields, crown and root pruning (i.e. tree management) ought to be done every season prior to the planting of the crops. This reduces competition between the two components for light, nutrients and water. The other factor to be considered in the design and management of the upperstorey tree plantings is the shade tolerance of the understorey crops. A combination of a fast growing tree and a shade tolerant crop leads to increased biomass productivity and hence a better utilization of the site resources. The only MPT which appears to have had a positive effect on crop performance in this study was *Alnus acuminata*. It therefore, seems necessary to design more detailed studies on the species across sites to confirm this finding and try to understand the processes involved in this positive interaction between the MPT and the crops.

Acknowledgements

The AFRENA Uganda Agroforestry programme is jointly being implemented by the Government of Uganda and by the International Centre for Research in Agroforestry (ICRAF). Funding is provided by the United States Agency for International Development (USAID) through its local mission in Kampala and the USAID office in Washington. The authors thank Dr C. Ong and Dr E. Torquebiau of ICRAF head office who assisted in the acquisition and installation of the root mesh, and all those who directly or indirectly made this study possible. Secretarial services rendered by Evelyn M. Tarushoke are appreciated.

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