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Alley cropping of maize with calliandra and leucaena in the subhumid highlands of Kenya
Part 1. Soil-fertility changes and maize yield

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Abstract. Although N-rich leaf biomass of multipurpose trees is known to be a good source of N to crops, integrating such trees into crop production systems is a major challenge in the development of viable agroforestry systems. An approach to integrating calliandra (*Calliandra calothyrsus* Meissner) and leucaena (*Leucaena leucocephala* (Lam.) de Wit), two promising agroforestry tree species, into maize (*Zea mays* L.) production system was investigated in the subhumid highlands of central Kenya during four maize-growing seasons from 1994 to 1996. The experiment consisted of maize plots to which tree prunings obtained from hedgerows grown either *in situ* (alley cropping) or *ex situ* (biomass transfer from outside) were applied. When alley-cropped with leucaena, maize produced significantly higher yields compared to maize monoculture (both non-fertilized and fertilized) treatments, but when alley-cropped with calliandra, the yield of maize was less than that of the monocropped unfertilized control. Application of *ex situ* grown calliandra and leucaena prunings with or without fertilizer resulted in higher maize grain yield than in the nonfertilized and fertilized treatments. Yields of calliandra alley-cropped maize were 11% to 51% lower than those of nonalley-cropped treatments receiving calliandra prunings from *ex situ* grown trees; the decrease was 2% to 17% with leucaena, indicating that calliandra hedges were more competitive than leucaena hedges. The alley-cropped prunings-removed treatments produced the lowest maize yields. The study showed that, in the subhumid tropical highlands of Kenya, inclusion of calliandra hedges on cropland adversely affected maize yields. On the other hand, alley cropping with leucaena was advantageous.

Introduction

In many parts of the tropics and particularly in tropical Africa, nitrogen (N) is the most limiting nutrient to crop production. High costs of inorganic fertilizers limit their use in sufficient quantities by most smallholder farmers. This has led to increased interest in development of integrated soil fertility management systems that incorporate woody species into crop production systems where leafy biomass provide N to the annual crop (Kang et al., 1990).

The central highlands of Kenya are among the most densely populated regions in the country with more than 500 persons km^{-2}. Declining crop yields has been a major problem facing smallholder farmers in this region. The major factor contributing to reduced productivity is soil impoverishment caused by continuous cropping without addition of adequate fertilizers and manures (Kapkiyai et al., 1998). Development of improved agricultural technologies that allow for increased food production is, therefore, necessary.

With this background, a project was initiated in 1991 in Embu (one of the administrative districts in Kenya) with the aim of developing agroforestry technologies for the central highlands of Kenya. The results reported here are a part of that project. The focus of the study was to evaluate the potential contributions of selected multipurpose agroforestry tree species as components of improved integrated fertility management strategies. The tree species evaluated were *Calliandra calothyrsus* Meissner (calliandra) and *Leucaena leucocephala* (Lam.) de Wit (leucaena). These were among the species identified as most appropriate for soil improvement and crop sustainability through agroforestry research at Maseno, Kenya (Heinemann et al., 1997), which is agroecologically similar to the experimental site in Embu District.

Materials and methods

Experimental site

The experiment was conducted at the Kenya Agricultural Research Institute's (KARI) Regional Research Centre in Embu, Eastern Province, Kenya. The Centre is located in the central highlands of Kenya on the south-eastern slopes of Mt. Kenya at 0°30′ S, 37°30′ E and an altitude of 1480 m. The soils are Typic Palehumults (Humic Nitisols according to FAO-UNESCO) derived from basic volcanic rocks. They are deep, well weathered with friable clay texture with moderate to high inherent fertility (pH 5.7, total N 2.5 g kg^{-1}, extractable P 8.5 mg kg^{-1}, carbon 22 g kg^{-1}, exchangeable Ca, Mg, and K (cmol kg^{-1}) 7.2, 2.5, and 0.9 respectively, clay 38%, sand 32%, and silt 30%). Total annual rainfall is 1200–1500 mm received in two distinct raining seasons: the long rains (LR) from mid-March to June with historical average precipitation of 650 mm and the short rains (SR) from mid-October to December with an average of 450 mm. The average monthly maximum temperature is 25 °C and the minimum 14 °C. The long-term monthly average is 19.5 °C.

Both N and P had been determined to be the most limiting nutrients to crop growth in the region (FURP, 1987). As the main objective of this investigation was to evaluate N supply, all the experimental plots received basal applications of P fertilizer (50 kg P ha^{-1}) as triple super phosphate (TSP) each year at the beginning of the long rain season. The rationale for this decision was based on the fact that tree leafy-biomass incorporated into the soil contained very little P content (compared to N), which would not meet the P requirements of the associated maize crop.

The experimental site was previously cropped with maize (*Zea mays* L.)-bean (*Phaseolus vulgaris* L.) rotations for several years and then left to natural fallow for two seasons prior to this investigation beginning in June 1991. Before establishing the treatments, uniformity trials of maize (Hybrid 511) without fertilizer application during the SR 1991 and LR 1992 seasons indicated that the land was uniform in terms of soil fertility. Soil analyses (macronutrients) at the end of 1991 SR season revealed no significant differences among different blocks, confirming the uniformity of soil fertility among the blocks.

Experimental treatments

The experiment was composed of ten treatments. The test crop, maize, was grown alone or alley cropped with or without fertilizer/prunings application, as detailed below:

- Alley cropping; no fertilizer:
    1) Calliandra; prunings incorporated;
    2) Leucaena; prunings incorporated;
    3) Calliandra; prunings removed to treatment 5;
    4) Leucaena; prunings removed to treatment 6.
- Maize only; no alley cropping; prunings from outside incorporated:
    5) Calliandra prunings from 3; no fertilizer;
    6) Leucaena prunings from 4; no fertilizer;
    7) Calliandra prunings + fertilizer (25 kg N ha^{-1});
    8) Leucaena prunings + fertilizer (25 kg N ha^{-1}).
- Maize only; no alley cropping:
    9) With fertilizer (50 kg N ha^{-1});
    10) Without fertilizer.

Experimental layout

The experimental design was a randomized complete block with four replicates. The plot dimensions were 9 m × 10 m. The inter- and intra-row spacing for calliandra and leucaena trees was 4.5 m and 0.5 m, respectively. Between hedgerows, six rows of maize were grown at a spacing of 75 cm × 25 cm (two maize seeds planted per hole, but later thinned to one four weeks after planting). The trees were planted in April (LR) 1992 and the application of experimental treatments started in the LR 1993 season.

Tree and crop management

Prunings were collected from calliandra and leucaena tree hedges immediately before maize was planted. Hedges were lopped at a height of 50 cm using sharp knives. Leafy biomass and succulent stems were separated from woody stems (removed for firewood) and each weighed separately. The leafy biomass was evenly spread on the ground in the treatments designated to receive prunings (Trts 1, 2, 5, 6, 7, and 8) and soil-incorporated by hand hoes when the land was being prepared for maize planting. Leafy biomass applied in treatments 7 and 8 (that received prunings from outside the experimental plots – biomass transfer) were obtained from block plantings of calliandra and leucaena hedges established near the site. The treatments received an average biomass (dry matter basis) of 2 Mg ha^{-1} for calliandra and leucaena biomass containing approximately 60 kg ha^{-1} of N $season^{-1}$.

Root pruning was conducted at the beginning of each growing season to curb root extension into neighboring plots. Trenches, approximately 1 m deep and 0.3 m wide, were dug between plots with hedges and their adjacent plots. Roots along these trenches were cut using a sharp knife after which they were covered with soil; the sub-soil returned first followed by top soil.

Treatment 9 received the recommended level of inorganic fertilizer (50 kg N ha^{-1}) as calcium ammonium nitrate (CAN) while treatments 7 and 8 received half of the recommended dose (25 kg N ha^{-1}) (to mimic the lower levels commonly applied by most farmers in the area). Application was through top dressing in two equal doses; the first dose four weeks after maize germination and the second, four weeks later.

Sample areas of 6 m × 9 m from the middle of the plots were designated for maize harvesting. Six maize rows inside the two tree hedgerows were harvested in the alley cropping treatments, identical in size and location to the maize monocrop treatments. Harvesting was done by cutting maize plants at soil level. Maize cobs were manually separated from the stover, sun-dried, and packed in paper bags before threshing. After threshing, moisture content of the grains was determined using a moisture meter and grain weights adjusted to 12% moisture content.

Sampling and analyses

Soil was sampled (top 20 cm depth) before the experiment was initiated (February 1992) and after its conclusion (February 1996). Major macro-nutrients (N, P, K, Ca, and Mg), C, and pH were determined using procedures described by Anderson and Ingram (1993).

Random subsamples of prunings recovered from plots before incorporation into the soil were washed with tap water and oven dried at 65 °C for 48 h. The same procedure was applied to maize stover, cob, and grain at harvest. Plant samples were ground progressively using 2 mm followed by 0.5 mm sieve mills. The resulting powder was thoroughly mixed, packed in polythene bags and stored under dry conditions before N was determined (Parkinson and Allen, 1975).

Data were subjected to ANOVA (SAS, 1988). Means were separated by Tukey's procedure and declared different at $P < 0.05$.

Results

Soil changes

A general decline in the soil nutrient levels was observed after four years of experimentation (1992–1996), with the greatest decline occurring in the treatments that did not receive prunings (Table 1). Total soil N, however, increased in the plots that received prunings but declined in those that did not, including Trt 9 that received N fertilizer at the recommended rate.

Maize yield

There were no significant differences in maize yields among the experimental treatments during the LR season of 1993 (first season after treatment initiation). There was a crop failure during the second season (SR) of 1993 due to insufficient rainfall. Maize seedlings were attacked by chauffeur grubs (*Heteronyclus* sp.) at germination during the first season (LR) of 1994 resulting in yields that were variable (O'Neill et al., pers. comm., 1995). The results discussed in this paper are for the second season (SR) of 1994 to the first season (LR) of 1996 (Figure 1).

Figure 1 shows that maize alley-cropped with leucaena (Trt 2) produced higher mean yield than non alley-cropped (both fertilized (Trt 9) and non fertilized (complete control – Trt 10)) treatments; however, the mean yield

Table 1. Percentage change in soil properties of the experimental site at Embu, Kenya, after four years (1992–1996) of experimentation.

Trt	AC/PI/NF[a]	pH	Exchangeable cations (cmol kg^{-1})			Extractable P ($mg\ kg^{-1}$)	Total C ($g\ kg^{-1}$)	Total N ($g\ kg^{-1}$)
			Ca	Mg	K			
			% increase (+) or decrease (–)					
1	C/C/–	–2 b	–1 c	–9 b	–10 b	–3 ab	–8 c	+4 b
2	L/L/–	–2 b	0 d	–8 b	0 c	–4 a	–8 c	+8 a
3	C/–/–	–4 a	–3 bc	–14 a	–22 a	–4 a	–14 b	–2 d
4	L/–/–	–4 a	–4 b	–8 b	–20 a	–5 a	–14 b	–4 d
5	–/C/–	–2 b	–2 c	–5 c	–9 b	–6 a	–5 d	+8 a
6	–/L/–	–2 b	–3 bc	–9 b	+8 d	–5 a	–8 c	+8 a
7	–/C/25	–2 b	–1 c	–3 c	–8 b	–5 a	–6 c	+4 b
8	–/L/25	–2 b	–3 bc	–9 b	0 c	–4 a	–8 c	+1 c
9	–/–/50	–2 b	–8 a	–10 ab	–22 a	–2 b	–12 b	–4 d
10	–/–/–	–4 a	–11 a	–11 ab	–22 a	–3 ab	–18 a	–4 d

Means followed by the same letter within a column are not significantly different at $P < 0.05$.

[a] AC = alley crop tree species (C = calliandra, L = leucaena); PI = type of pruning incorporated (C = calliandra, L = leucaena); NF = nitrogen fertilizer applied (kg N ha^{-1}).

Abbreviation: Trt = treatments.

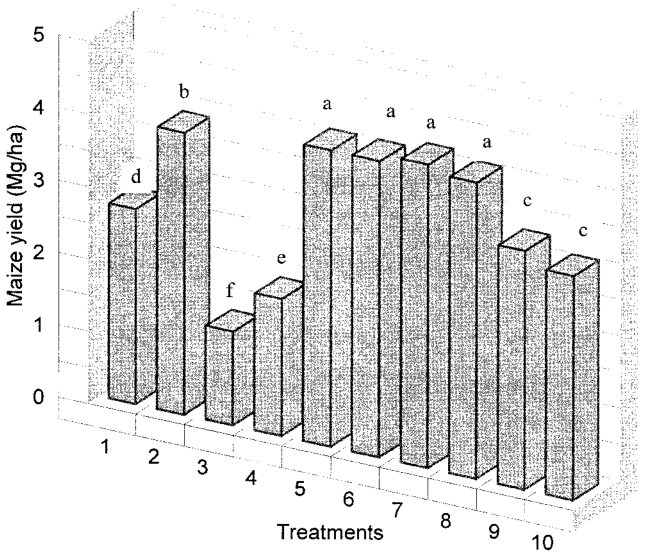

Figure 1. Mean maize grain yield (1994–96 seasons) of the various treatments at Embu, Kenya (Treatment 1 and 2 = calliandra and leucaena alley crop, prunings applied; 3 and 4 = same as 1 and 2, prunings removed; 5 and 6 = calliandra and leucaena monocrop + *ex situ* applied prunings; 7 and 8 = same as 5 and 6 + fertilizer; 9 = maize monocrop + fertilizer; 10 = complete control).

of alley-cropped calliandra (Trt 1) was less than that of the complete control. Calliandra and leucaena treatments that received *ex situ* applied prunings with or without fertilizer (Trt 5 and 6, and Trt 7 and 8) produced the highest maize grain yields. The lowest yields were obtained from the alley-cropped plots with prunings removed (Trt 3 and 4).

Competition

The rationale for establishing treatments 1 and 2 (maize alley crop, prunings applied *in situ*) and treatments 5 and 6 (maize monocrop, prunings applied ex situ – biomass transfer) was to assess the competition between tree hedges and maize by subtracting yields from treatments 1 and 2 from those of 5 and 6, respectively. The results showing yield changes from these comparisons (single degree contrasts) are presented in Table 2.

The results indicate that yields of maize alley-cropped with calliandra (Trt 1) were 11% to 51% lower than those treatments that received calliandra prunings from *ex situ* grown trees (Trt 5). Maize yields were reduced by 2% to 17% with leucaena (Trt 2 vs 6), implying that calliandra hedges were more competitive with maize than leucaena hedges. Indeed, leucaena alley-cropped treatments (Trts 2 and 4) produced 1.2 and 0.6 Mg ha^{-1} $season^{-1}$ more maize grain compared to calliandra alley-cropped treatments (Trts 1 and 3), respec-

Table 2. Yield change from contrasts comparing alley-cropped, prunings-applied treatments with the ex situ prunings-applied treatments at Embu, Kenya.

Treatments[a]	SR 94	LR 95	SR 95	LR 96
	% increase (+) or decrease (–)			
1 vs 5–	–11	–16*	–51***	–48***
2 vs 6	+14	–2	–17**	–7

Level of significance: * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

[a] Treatments: 1. Calliandra alley crop, prunings applied; 2. Leucaena alley crop, prunings applied; 5. Maize monocrop, calliandra prunings applied; 6. Maize monocrop, leucaena prunings applied.

Abbreviations: SR = short rain season; LR = long rain season.

tively (Figure 1). It is, however, noted that both calliandra and leucaena treatments that received *ex situ* prunings with or without N fertilizer (Trts 5, 6, 7, and 8) produced yields that were not significantly different from each other (Figure 1).

Maize yield on a per row basis

The lowest maize grain yield on a per row basis for those treatment plots that contained hedges (both calliandra and leucaena) were recorded for the maize rows nearest those hedges (Table 3). The southern rows, however, recorded slightly higher grain yields than the northern rows.

Implication of the experiment to a farmer in terms of decision making

The implications of this experiment in terms of farmer decision-making, nitrogen input opportunities, maize grain yield, and other possible farm returns is presented in Figure 2. The data are presented on an annual basis by com-

Table 3. Maize grain yield for rows in different distances for calliandra and leucaena hedgerows in the alley-cropped treatments at Embu, Kenya.

Row[a]	SR 94	LR 95	SR 95	LR 96
	maize yield (kg 6 m row^{-1})			
0.3 N	8.5 d	8.7 b	9.2 b	7.2 b
1.1	13.0 b	12.6 a	9.7 ab	7.4 b
1.8	13.9 b	13.6 a	10.0 ab	9.7 a
1.8	16.0 a	14.2 a	11.7 a	10.4 a
1.1	14.2 b	12.8 a	10.5 ab	10.0 a
0.3 S	10.8 c	10.5 b	9.8 ab	8.8 ab

Means followed by the same letter within a column are not significantly different at $P < 0.05$.

[a] Row position denoting distance (m) from the hedgerow between two hedges in N–S direction.

bining the two growing seasons within each year and averaging the years. The advantages of leucaena (Figure 2a) over calliandra (2b) as a hedgerow intercropping species is 2.6 Mg grain ha^{-1} yr^{-1}. The returns to nitrogen fertilizer are marginal (additional maize yield obtained after applying 100 kg N ha^{-1} yr^{-1} to a maize monocrop is only 500 kg). However, the returns to addition of approximately 4 Mg of leucaena prunings ha^{-1} yr^{-1} (containing 116 kg N) offer 1.5 Mg greater maize yields than the addition of 100 kg N fertilizer.

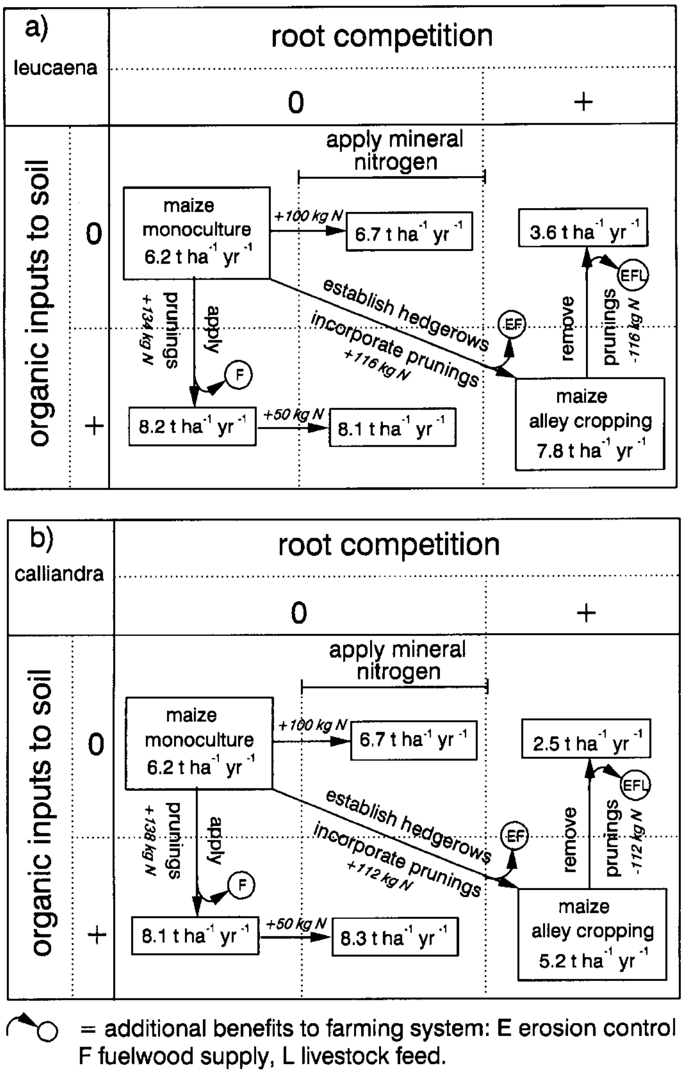

Figure 2. A comparison of nutrient inputs, maize yield (values in the boxes) and additional benefits of alley cropping management with *Leucaena leucocephala* (a) and *Calliandra calothyrsus* (b) at Embu, Kenya.

Discussion

The amounts of prunings applied into the soil (averaging 4 Mg ha^{-1} yr^{-1} and containing approximately 120 kg N ha^{-1}) did not contribute sufficient amounts of nutrients to compensate wholly for those removed through harvest (N removal by crop harvest in the plots that received prunings ranged from 150 kg to 269 kg ha^{-1} year^{-1}; Mugendi et al., 1999, in press). These results agree with those reported by others (Kang, 1993; Nair, 1993) where a smaller decline was observed in soil fertility parameters in the plots that had prunings applied compared to those that did not. The findings, however, do not agree with reports from the humid tropics where application of prunings to the soil resulted in increased soil organic matter and higher N, P, K, Ca, and Mg (Kang et al., 1990; Tian et al., 1993). Whereas hedgerow tree species in the humid tropics produce approximately 8 to 10 Mg ha^{-1} yr^{-1} of biomass (Young, 1997), those in the subhumid tropics of Kenya produce only half of that amount. Low biomass production of hedgerow tree species in alley cropping systems is one major drawback that limits the potential of prunings to improve fertility and productivity of soils (Young, 1997; Nair, 1993).

Maize yield decrease in the treatments that contained tree hedges *in situ* was most likely the result of below-ground competition between the maize crop and tree roots. Competition for light was minimal because hedges were maintained at a low height (50 cm) during a growing season. The competitiveness of calliandra tree hedges compared with leucaena's may be explained by the root morphology of the two species. Calliandra trees develop strong superficial root system in addition to the tap root (NAS, 1983). Jama et al. (1998) demonstrated that calliandra had the greatest root density in the top 15 cm of soil when compared to four other multipurpose tree species (*Eucalyptus grandis*, *Sesbania sesban*, *Markhamia lutea*, and *Grevillea robusta*) evaluated in an oxisol in the subhumid highlands of western Kenya. On the other hand, leucaena is reported to have a strong tap root system that develops few lateral roots which also grow downward following emergence (NAS, 1977). After an initial, moderately rapid establishment phase with some horizontal roots in the top soil, most of leucaena's later root development tends to be confined in the lower levels of the soil (Van Noordwijk et al., 1996). Govindarajan et al. (1996) observed a lower leucaena root density in the 0 to 12.5 cm soil depth compared to maize roots in an alfisol in semiarid Machakos, Kenya. However, at soil depth below 75 cm, the root density of leucaena increased over that of maize. The superiority of leucaena alley-cropped treatments over those of calliandra may, therefore, be attributed to calliandra roots being more competitive with maize than leucaena. It is noteworthy that, when prunings from both species were applied *ex situ* (Trt 5 and 6), the maize yields obtained were not significantly different from each other (Figure 1). The negative effects of calliandra compared to leucaena do not, therefore, appear to be related to the quality of pruning inputs, but rather, result from more intense below-ground competition with maize crop.

The maize yield decline nearer the hedges (Table 3) could be attributed to greater root competition due to higher densities of fine roots nearer the hedgerows as was reported by Yamoah et al. (1986) and Smucker et al. (1995). The decline that was consistently higher on the northern part of the hedge as compared to the southern side could be attributed to the gentle slope (5%) that runs in a N–S direction. Similar observations were made by Smucker et al. (1995) who attributed the observed differences to the downward movement of water and nutrients due to sloping terrain benefiting the crop at the lower level immediately above the hedge.

Despite the promising results shown by alley cropping technology (with leucaena) in the central highlands of Kenya, issues surrounding labor requirements need to be resolved before a wide adoption by farmers can be expected. Alley cropping technology is labor-intensive (required additional 90 man-days of labor ha-1 to prune and to spread the prunings on the ground) with much of the demand for labor occurring during the raining season when conflicting labor requirements are greatest (Nair, 1993). Additional labor for persons already fully occupied at peak labor seasons is considered more costly than when additional demands come during slack periods, and the cost of production increases considerably if additional labor must be hired. Although the additional labor costs may be offset by increased yields, its availability and costs serve as a disincentive to the adoption of the technology (Kang et al., 1990). Hernandez et al. (1995) reported that an additional 30 days of labor were required to prune *Erythrina poeppigiana* when alley cropped with maize and beans in Costa Rica and that labor costs were better invested as N fertilizers. On the other hand, Fujisaka et al. (1995) described a process of farmers adapting contour hedgerows to their specific needs in the Philippines that included developing labor-saving methods and incorporating hedgerow species that offer direct cash returns.

The implications of this study in terms of farmer decision-making as presented in Figure 2 is that, farmers may opt to establish hedgerows, monocrop maize or apply chemical fertilizers. If a farmer chooses to establish hedgerows, then he can manage them in different ways in order to obtain direct (maize grain) or indirect (erosion control, fuelwood, or livestock feed) benefits. Considering the observed advantage of leucaena over calliandra hedgerow-intercropped maize (of 2.6 Mg grain ha^{-1} yr^{-1}) and also the yield decline of calliandra maize relative to control, farmers would be ill advised to attempt alley cropping with calliandra in the central highlands of Kenya (and Embu in particular). The marginal returns to nitrogen fertilizer of only 500 kg of maize will not offset the cost of 100 kg N fertilizer that was invested in producing that maize. However, the higher returns of 1.5 Mg ha^{-1} greater maize yield due to addition of leucaena prunings (containing 116 kg N) than with the addition of 100 kg N fertilizer occurs because of the additional nutrients contained in the prunings (Palm, 1995) and the indirect benefits of organic matter to soils (Woomer et al., 1994).

In general, it has been pointed out that the advantages of alley cropping seems to rest in the complementarity of resource capture (Ong and Black, 1995); its disadvantages in establishment costs and labor requirements (Hernandez et al., 1995). To a large extent, the potential benefits are site- and tree-crop specific (Woomer et al., 1995) and depend upon the adaptions made by farmers to best suit their needs (Fujisaka et al., 1995).

In conclusion, results from this study indicate that alley cropping with leucaena is advantageous in the subhumid highlands of Kenya. On the other hand, inclusion of calliandra hedges on cropland adversely affected crop yields, though farmers in the region highly appreciate it as livestock feed. Assuming that a farmer is willing to invest in tree establishment and has sufficient labor for hedgerow management, leucaena offers potential advantages in terms of increased maize yield compared to calliandra. Also, considering that smallholdings in the central highlands of Kenya occur in sloping, densely populated landscapes where livestock feed and fuel are scarce, the indirect benefits of alley cropping may also offer incentive for this system, however, our findings clearly demonstrate that depending on the choice of species, below-ground competition may pose a serious hazard to crop productivity.

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