Reprinted from

Forest Ecology and Management

Forest Ecology and Management 91 (1997) 103–135

Growth and yield of eight agroforestry tree species in line plantings in Western Kenya and their effect on maize yields and soil properties

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Publication information: *Forest Ecology and Management* (ISSN 0378-1127). For 1997 volumes 90–99 are scheduled for publication. Subscription prices are available upon request from the Publisher. Subscriptions are accepted on a prepaid basis only and are entered on a calendar year basis. Issues are sent by surface mail except to the following countries where air delivery via SAL mail is ensured: Argentina, Australia, Brazil, Canada, Hong Kong, India, Israel, Japan, Malaysia, Mexico, New Zealand, Pakistan, PR China, Singapore, South Africa, South Korea, Taiwan, Thailand, USA. For all other countries airmail rates are available on request. Claims for missing issues should be made within six months of our publication (mailing) date.

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Growth and yield of eight agroforestry tree species in line plantings in Western Kenya and their effect on maize yields and soil properties

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Abstract

Between October 1988 and August 1992, field experiments were carried out in West Kenya to evaluate the suitability of *Leucaena leucocephala, L. collinsii, Gliricidia sepium, Calliandra calothyrsus, Sesbania sesban, S. grandiflora, Senna siamea* and *S. spectabilis* to provide a range of agroforestry products and services. The initial objective was to establish the growth rates and wood and leaf yields of these tree species, when planted in single rows. After the initial evaluation, it was evident that valuable additional information could be collected if the trees were converted to hedges and their effect on intercropped maize and soils was studied. At 21 months after planting, different species and provenances ranged in height between 3.5 and 6 m and varied considerably in phenotypic appearance. Wood production (1988–1990) varied from 3 to 33.8 t ha^{-1} and leaf production varied from 0.62 to 10.1 t ha^{-1}. During intercropping (1990–1992), leaf production varied from 0 to 10.9 t ha^{-1}. Maize yields were higher in association with *Leucaena* and *Gliricidia* than with *Calliandra, Sesbania* and *Senna*. Cumulative maize grain and stover yields over four seasons were positively correlated with the total amount of tree leaves applied (r^2 range, 0.70–0.95). The effect of tree leaf mulch on crop yields decreased over time for all species. Leaves with high nutrient contents, which decompose fast (*Leucaena, Gliricidia, Sesbania*) are likely to have been more effective in sustaining crop yields than leaves with lower nutrient contents (*Senna*) or more complex decomposition patterns (*Calliandra*). Simple ''leaf input–crop output'' budgets to calculate the reserves for N, P and K in different systems explained crop yield differences in some cases. Compared to the fertility status of ''zero-mulch'' control plots, the status of soil C, N, P, K, Ca, Mg and S was to varying degrees improved under *Leucaena, Gliricidia* and *Sesbania*, much less under *Calliandra* but not under *Senna*. First season grain yields were related to the soil fertility status at the end of the tree fallow. The results of these experiments suggest that under subhumid tropical conditions with soils of relatively poor nutrient status, where light and water are not likely to be the major limiting factors to crop production, the application of sufficient quantities of high quality tree mulch may positively influence maize yields. When agroforestry tree species with contrasting decomposition and nutrient release patterns are evaluated jointly, it is more difficult to demonstrate a general relationship between quantities of mulch applied and improvements in crop yields and soil fertility levels. Therefore, further chemical, physiological and phenotypic characterization of tree species with potential for fallow and intercropping systems is required.

Keywords: Calliandra; *Cassia*; Fallow; *Gliricidia*; Intercropping; Kenya; *Leucaena*; Nutrients; *Senna*; *Sesbania*

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PII S0378-1127(96)03885-6

1. Introduction

Subsistence farming systems in the highlands of Kenya occur in areas of high population density (100–1000 people per km^2), resulting in small farms (0.1–1.0 ha.) where continuous crop cultivation is the norm. Because fertilizer use is usually insufficient, farmers are experiencing a steady decline in crop productivity and soil fertility. The soils in western Kenya have low inherent fertility. Farmers normally grow two crops of maize and beans a year. The dominant soil types are acrisols, ferralsols and nitosols. These soils are mostly well drained and have a low pH ranging from 4.0 to 5.5 (H_2O 1:2.5). Consequently, aluminium (Al) toxicity is a potential threat and phosphorus (P) may be largely unavailable for plant nutrition (Onim et al., 1990). Onim et al. (1986) analyzed soils on farms in Western Kenya and found that P was deficient in 92% of the cases. Soils were also low in sodium (Na), potassium (K), magnesium (Mg), nitrogen (N) and carbon (C). Another on-farm survey (ICRAF, 1994) found that there were root restricting soil layers at less than 50 cm at ten farms out of a sample of 32 farms. Low available P and P fixation were found on half of the farms and high levels of Al saturation in the topsoil was found on four farms. Nearly half of the farms had low soil C levels of less than 1.5% in the topsoil.

Farmers generally realize the danger of soil fertility decline as a result of continuous cropping. Some try to practice sound soil fertility management by applying farm yard manure or inorganic fertilizers. However, a survey of 71 farmers showed that only 41% used fertilizers regularly and 50% of these farmers applied less than 5 kg N and 6 kg P ha^{-1} year^{-1} (Shepherd et al., 1993). These amounts are insufficient to balance nutrient exports through removal of grain and other produce (Smaling, 1993). Application of farmyard manure, although generally considered valuable, is often limited in quantity ($<$ 10 kg N ha^{-1} year^{-1}) and low in quality due to storage problems. In addition, most farmyard manure applications are derived from animal feed sources within the farm boundaries. Grazing outside the farm is limited to low quality roadside grasses. Thus, nutrient imports to the farm system are often negligible (Shepherd et al., 1993). Based on these survey results, literature research and on-farm experimentation, it was calculated that the loss of N from crop fields could amount to 76 kg ha^{-1} year^{-1}, compared to, for instance, positive N balances at west European dairy farms with high animal feedstuff inputs of 616 kg N ha^{-1} year^{-1} (Smaling, 1993).

It is expected that the introduction of multi-purpose (nitrogen fixing) trees and shrubs with an ability to recycle nutrients and to capture and access nutrients from deeper soil layers can have a positive impact on the farm N balance and on the overall nutrient status of crop fields. In addition to supplying extra nutrients to the system through N fixation, the trees must be able to penetrate soil layers which are difficult for crop roots to penetrate. They could thereby decrease nutrient losses resulting from leaching (Young, 1989, Nair, 1993, Sanchez, 1995).

In addition to soil fertility related constraints on crop production, forage shortage, especially during the dry season, is another widespread problem, further limiting farm productivity and the potential to generate cash income from milk and meat sales. Also, the demand for timber poles, fuelwood and fruits is high in rural areas and local towns. Considering the many potential constraints on farm productivity in smallholder practices in the tropics (Richards, 1985, Chambers et al., 1989), flexibility in the management of trees and the products and services they provide in support of agriculture is an important consideration for farmers with limited land. Much research has been carried out on the choice of tree species for farmers' woodlots (Hosier, 1984), for forage (Gutteridge and Shelton, 1994) and in combination with crops (Kang et al., 1990). There is also an increasing interest in improved fallow techniques where trees are used to restore the fertility of degraded crop land (ICRAF, 1992).

Evaluation and selection of trees on the basis of their ability to provide a number of these products and services simultaneously or sequentially is complicated. It needs phased research, both on station and on farm. A first step in identifying which tree species are suitable for multiple use on farms would be to study their survival, growth and yield under specified local edaphic and climatic conditions. Initial planting patterns should be kept simple, realistic and manageable. A possible, but certainly not exclusive, second step would be to study the effects of trees, managed in hedgerows, on food crops and soils in intercropping arrangements.[1]

Studying woody plants first in a tree fallow arrangement and subsequently as leaf producing hedges in a hedgerow intercropping system would allow us to add the dimension of varying the management of the system, depending on which products (wood, tree leaves or food crop components) are primarily pursued at a particular point in time.

Experiments to study tree growth and yield as well as tree-crop intercropping performance were established at the Maseno Agroforestry Research Centre in 1988 (Heineman et al., 1990). The site adaptability and potential use of a wide range of multi-purpose tree and shrub species (MPTS) was studied. The trees were grown in single row plantings and in hedgerow intercropping designs under edaphic and climatic conditions broadly representative of Western Kenya and other parts of the East African Highlands.

This paper reports the results of two adjacent tree evaluation trials, identical in their objectives and design, to compare a number of accessions and provenances of *Leucaena leucocephala*, *L. collinsii*, *Gliricidia sepium*, *Calliandra calothyrsus*, *Sesbania sesban*, *S. grandiflora*, *Senna (Cassia) siamea* and *S. spectabilis*. The initial objectives were to establish the growth rates and wood and leaf yields of these tree species, when planted in lines and to determine the available product range at various times after planting. After the initial two year tree evaluation phase, it was evident that valuable additional information could be collected if the effect of the trees, managed as hedges for mulch production, on intercropped maize and soils was also studied. Therefore, the experiment was extended beyond mid-1990 and the effect of the presence of trees on crop yields was studied during four successive cropping seasons. Soil samples taken at the end of the initial two year tree fallow phase provided a possibility to study the effect of mulch applications on soil fertility and subsequently the effect of differences in soil fertility on crop yields. The eight tree species were selected for evaluation because they are widely used in hedgerow intercropping with varying degrees of success. The choice of species and provenances was such that a potentially broad range in wood production, leaf production, leaf nutrient quality and leaf decomposition characteristics was included.

Thus, two clearly separate phases are recognized in these experiments. In the initial two years (phase 1: October 1988–July 1990), the growth and yield of the trees in single row plantings was monitored. Their survival and potential to produce firewood, building poles, leaf mulch and other products was assessed, while a phased thinning regime was imposed to reduce initial stocking rates to 50 and 25% over a two year period. The leaves from the thinnings we returned to the plots. In the following two years (phase 2: August 1990–August 1992), the trees were managed as coppiced hedges and the effect of the application of their prunings on four successive intercrops of maize was studied.

A much shorter paper, only focusing on preliminary results for *Leucaena* and *Gliricidia*, which did not yet include results on nutrient budgets, changes in soil fertility and possible relationships between all of the main components of the system (e.g. trees, crops and soils) was published previously (Heineman et al., 1995). For a comprehensive presentation and discussion of all results of both experiments, the current paper is recommended.

2. Materials and methods

2.1. Location and climate

The research site is located on the equator at 34° 35′ East, at 1500 m above sea level in Western Kenya. It is part of the Maseno Agroforestry Research Centre, a joint research facility of Kenya Forestry Research Institute (KEFRI), Kenya Agricultural Research Institute (KARI) and The International Centre for Research in Agroforestry (ICRAF). Rainfall is bimodal with the first rainy season from March to July and the second rainy season from September to December. Long term average annual

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[1] Note: The terms ‘intercropping food crops with trees’, ‘hedgerow intercropping’ and ‘alley cropping’ are used interchangeably in this paper. All these agroforestry land management practices refer to the same idea, first described by Kang et al. (1981).

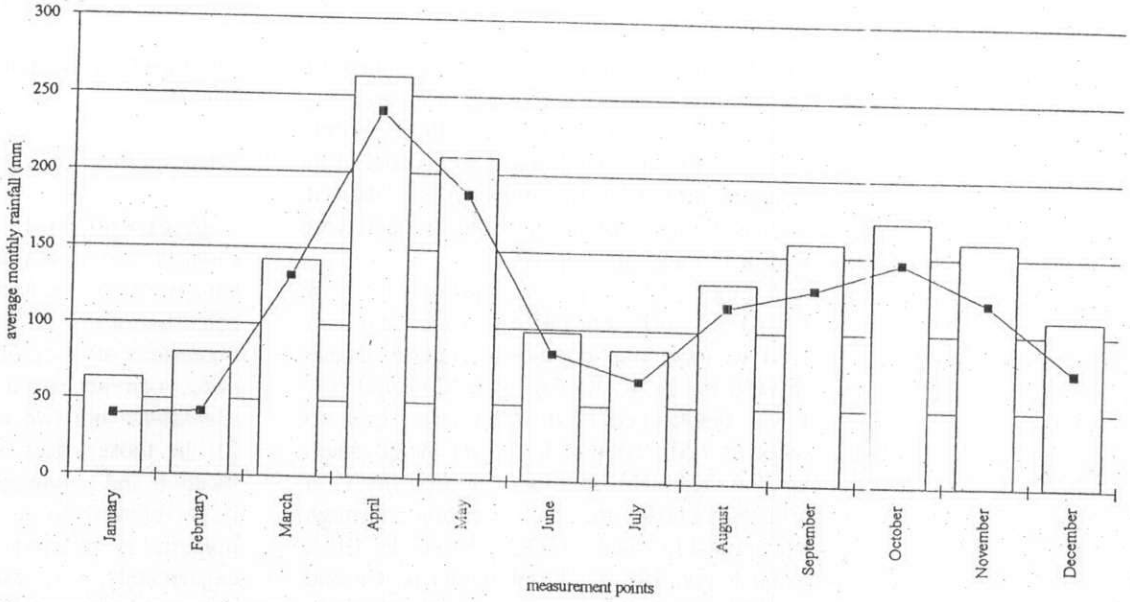


Fig. 1. Long term average rainfall at Maseno Veterinary Farm (42 year-average) and the 60% reliability curve (the amount of rainfall, likel to be exceeded in 6 out of 10 years); (mm month^{-1}).

rainfall is 1678 mm and six out of ten years at least 1377 mm should be received (Fig. 1), (Jaetzold and Schmidt, 1982). In Table 1, the rainfall data for 1988–92 are summarized by season. In all years except 1991, more rain was received than the published long term averages. The first half of 1988, before these experiments were established, was much wetter than usual. The amount of rainfall received in 1991 and especially in the second part of that year was lower than the long term average. Average potential evapotranspiration is 1738 mm per year. The mean annual day temperature is 20°C; average maximum and minimum daily temperatures are 31°C and 15°C respectively.

Table 1
Rainfall received between 1988 and 1992 at Maseno Agroforestry Research Centre, Western Kenya (mm year^{-1})

	1988 (a)	1989 (b)	1990 (c)	1991 (c)	1992 (d)
Long rains [1]	1465	1021	1175	964	1098
Short rains [2]	888	876	659	584	804
Annual total	2350	1897	1834	1548	1902

[1] Measured from January to July.
[2] Measured from August to December.
Source: (a) Maseno Forestry Nursery data, Ministry of Environment and Natural Resources, Kenya; (b) Mean values, based on Maseno Forestry Nursery data and Maseno Veterinary Farm data. (c) Mean values, based on Maseno Agroforestry Research Centre data and Veterinary Farm data. (d) Maseno Agroforestry Research Centre data.

2.2. Site and soil

The experimental site was located on former degraded pasture land. The slope in north to south direction was less than 2%. Couch grass (*Digitaria scalarum*) was the predominant vegetation. There were no trees on the site, prior to site preparation. In 1988, the soil was classified as a luvisol. It showed no distinct boundaries between horizons. Colour gradually changed with increasing depth from dark reddish brown to reddish brown. Soil depth exceeded 1.2 m. Soil texture was clayey to clay loam with a pH (H_2O; 1:2.5) of 5.5. Soil fertility changes between the start of the tree fallow phase and the end of the cropping phase were not determined in these experiments. However, one detailed dataset on soil chemical properties was collected, based on sampling experiments 1 and 2 plot by plot between the end of the tree fallow phase and the beginning of the cropping phase. The objective was twofold. Firstly, to determine whether there were any detectable differences in chemical soil fertility properties that could be attributed to the effect of different mulch applications during the previous two year fallow period. Secondly, it was hypothesized that if soils differed in some chemical properties in August 1990, then it might be possible to correlate these differences with subsequent differences in crop yields.

Thus, in August 1990, three samples of the top of the profile (0–20 cm) were taken in each treatment and bulked to form one composite sample. These were analysed for N, P, K, Ca, Mg, S, C and pH. The pH was determined in distilled water (soil to liquid ratio 1: 2.5). Total soil N was determined, following the Kjeldahl method, as described in Bremner (1960). Phosphorus was determined through the molybdenum-blue method (Olsen and Cole, 1954, Murphy and Riley, 1962). The elements K, Ca and Mg were determined colorimetrically (Mehlich et al., 1962, Hinga et al., 1980). Sulphur was determined with AAS. Carbon was determined, using the method developed by Walkley and Black (1934) Walkley (1947).

2.3. Experimental design

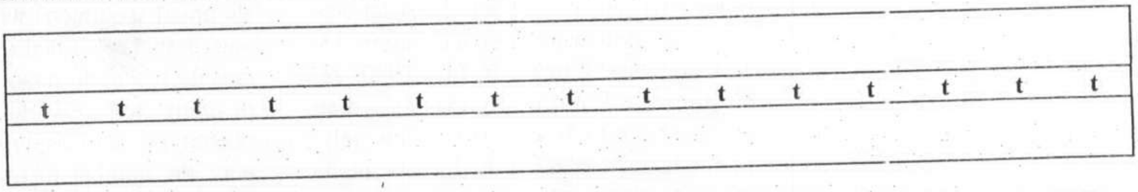
In experiment 1, five accessions of *L. leucocephala*, one accession of *L. collinsii* and six provenances of *G. sepium* were planted. Experiment 2 consisted of three accessions of *C. calothyrsus*, three accessions of *S. sesban*, one accession of *S. grandiflora*, one accession of *Senna* (synonym *Cassia*) *spectabilis* and two accessions of *S. siamea* (Table 2). In those cases where the full details of the location and parentage of the tree seed were known, it is referred to as a provenance, otherwise the material is referred to as an accession. The two experiments were randomized complete block designs with three replications. In October 1988, fifteen trees were planted in rows of 11.25 m length in the centre of each plot (Fig. 2). Trees were spaced at

Table 2
Tree species, provenances and accessions planted in Maseno, Kenya in October 1988

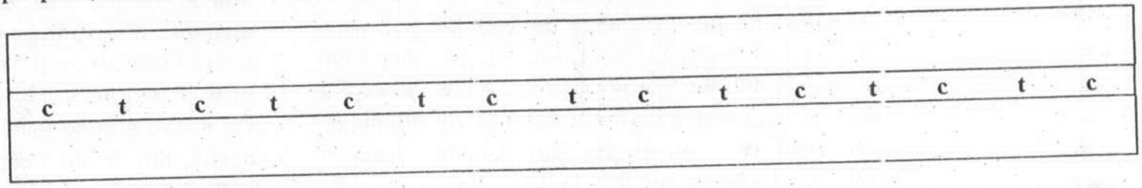
Species		Provenance or accession
Experiment 1		
Leucaena leucocephala	LL1	Kibwezi, Kenya
Leucaena leucocephala	LL2	K8, NFTA, Hawaii, USA
Leucaena leucocephala	LL3	Melinda, Belize
Leucaena leucocephala	LL4	Hengchun, Taiwan
Leucaena leucocephala	LL5	Ukwala, Siaya, Kenya
Leucaena collinsii	LL6	Kibwezi, Kenya
Gliricidia sepium	GS7	Gualan Zacapa, Guatemala. (OFI-collection number: OFI-15/84)
Gliricidia sepium	GS8	Playa Tamarindo, Guanacaste, Santa Cruz, Costa Rica. (OFI-12/86)
Gliricidia sepium	GS9	Pontezuela, Cartagena, Bolivar, Colombia. (OFI-24/86)
Gliricidia sepium	GS10	Monterrico, Taxisco, Santa Rosa, Guatemala. (OFI-58/87; 17/84)
Gliricidia sepium	GS11	Vado Hondo, Chiquimula, Chiquimula, Guatemala. (OFI-59/87; 16/84)
Gliricidia sepium	GS12	Playa Samala, Retalhuleu, Guayotenago, Guatemala. (OFI-60/87; 14/84)
Experiment 2		
Calliandra calothyrsus	CC1	Collection site unknown; general collection, Guatemala
Calliandra calothyrsus	CC2	Kibuye, Rwanda
Calliandra calothyrsus	CC3	Arboretum de Ruhande, Ruhande, Rwanda
Sesbania sesban	SS4	Kakamega, Kenya
Sesbania sesban	SS5	Mukururiati, Kenya
Sesbania sesban	SS6	Kiambu, Kenya
Sesbania grandiflora	SG7	General collection, Singapore
Senna (Cassia) spectabilis	CS8	Bugarama, Rwanda
Senna (Cassia) siamea	CSi9	Bugarama, Rwanda
Senna (Cassia) siamea	CSi10	Kwale, Kenya

Abbreviated species and provenance codes (e.g. LL1) are used in the text, tables and figures, where possible.

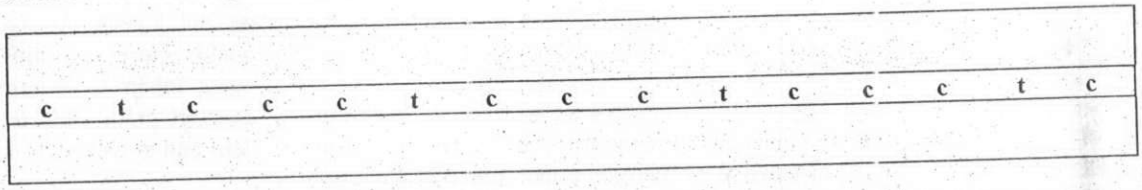
Phase Ia: October 1988. Planting of 15 trees per plot at 0.75 m in-row spacing, marked 't'. A 1.5 m wide strip on either side of the single line of trees was not cultivated in the first two years of the experiment. It received leaf mulch when trees were thinned.



Phase Ib: May 1989. Seven trees per plot are managed as trees at 1.5 m in-row spacing and 8 coppice stools per plot (marked 'c) are managed at heights varying from 0 to 75 cm.



Phase Ic: November 1989. Four trees per plot are managed as trees at 3.0 m in-row spacing and 11 coppice stools per plot are managed at heights varying from 0 to 75 cm until December 1989. Thereafter, all coppice stools are cut back to ground level.



End of Phase I: July 1990. The last four trees per plot (marked 'c*') are cut back to 50 cm and managed as coppice stools; the other eleven coppice stools in each plot are managed at ground level.
Start of Phase 2: September 1990. Four rows of maize per plot are sown (marked '----'). Phase 2 ends in August 1992 after four consecutive maize crops have been grown.

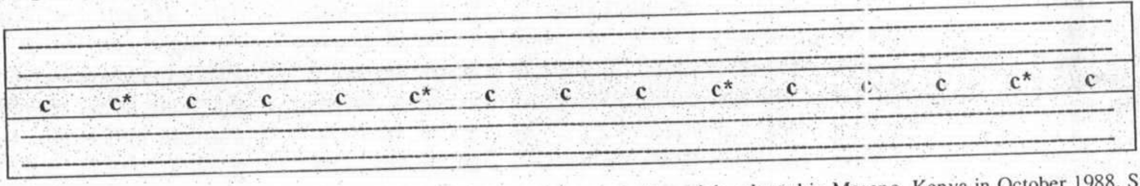


Fig. 2. Field layout and thinning (cutting) schedule for two tree species evaluation trials, planted in Maseno, Kenya in October 1988. Sin plot dimensions are 11.25 × 3.0 m.

0.75 m within rows. Individual plot width was 3 m. All plots were established almost exactly on the equator in east-west direction, thereby largely minimising the effect of shade between treatments.

2.4. Tree management

Trees were established from inoculated seedlings that nodulated at planting in October 1988. A recommended mixed strain *Rhizobium* (source: NifTA Hawaii) was received with the seed from the Oxfc Forestry Institute. Seed propagation and *Rhizobii* use with relevance to these experiments are (scribed in Macqueen (1993) and Hughes (199 Seedlings were fertilized at planting with 25 g diammonium phosphate (DAP) per tree, equival to 20 kg ha^{-1} of N and 22 kg ha^{-1} of P. In orde promote the production of firewood and wooden poles at the intermediate and final tree harvests, a phased thinning and coppice management regime was adopted in the first two years (Fig. 2). After 7.5 months, 8 trees per plot were thinned; after 13 months, 3 more trees were thinned. In July 1990, 21 months after planting, the last 4 trees, now spaced at 3 m in-row, were cut back to 50 cm. This is a widely adopted cutting height for hedges in hedgerow intercropping (Kang et al., 1990). From September 1990 onwards, tree stumps were managed as hedges for mulch production with 4 trees plot coppiced at 50 cm height and the 11 earlier thinned trees in each plot coppiced at ground level. From September 1990 until June 1992, the leaf production of ten successive hedge cuttings was measured. At all early thinnings, at the final tree harvest and during hedge management, the leaves were left in the plots as mulch, representing a potential nutrient input or nutrient return through recycling and woody products were removed, representing a nutrient export.

2.5. Maize management

In August 1990, maize was sown at 75 × 25 cm (53 333 plants ha^{-1}) without fertilizer. The first crop row was sown at 37.5 cm on either side of the hedge. Therefore, four rows of maize could be accommodated in each (former) tree evaluation plot. No land was lost for growing maize because the hedges were located in the centre of the plots between two maize rows, spaced 75 cm apart (Fig. 2). At the first crop harvest (January 1991), fresh maize cob and stover yields were determined. Grain yields were converted to t ha^{-1} dry grain at 13% moisture content. Stover yields were converted to t ha^{-1} dry stover. In 1991, maize was again sown in the first and second rainy season, and in 1992, it was sown in the first rainy season, following procedures identical to those of 1990.

2.6. Measurements on trees and crops

Tree height was measured by placing a graduated stick along the bole and recording the height of the highest living tip. Diameter at 5 cm above ground level was measured with vernier callipers. This measurement is referred to as the root collar diameter (rcd) measurement. Tree and shrub species used in agroforestry are known to vary considerably in above ground phenotypic appearance. Some are single-stemmed specimens with a clearly defined mainstem and branched, foliated crown. Other species more closely resemble bushes than trees and have several or many stems emerging from ground level. As tree phenotype can largely determine the use of its products, the number of individual stems at four heights above ground level was recorded. Calculations of the cross sectional areas at suitable heights along the bole(s) of the tree can assist in determining the amount of standing woody biomass non-destructively (Stewart et al., 1992). Therefore, the diameter of each stem of each tree was also determined at 50 cm above ground level. At each thinning and felling event, the fresh weight of mainstem wood, side branch wood and leaves was determined. Fresh leaf weight was also determined during hedge management. Sub-samples were taken to determine dry matter and in some cases to determine nutrient content of the leaves. At maize harvest, grain and stover yields were determined separately. Fresh samples were taken to determine dry matter contents and convert grain yield to t ha^{-1} at 13% moisture content and stover yield to t ha^{-1} dry matter.

3. Results

3.1. Phase I (October 1988–July 1990)

3.1.1. Height and diameter

The mean height of each species at 21 months after planting as well as diameter at ground level and diameter at 50 cm above ground level ($D50$) summarized in Table 3. In Table 4, the average monthly growth rates for height and diameter between planting and felling are summarized. In experiment 1, seedlings used for establishing LL1 to LL4 were four months older than seedlings used for LL5, LL6 and GS7-GS12. Seedling height and rcd at planting were used as covariates in the analysis of variance for height and rcd at later measurements. Initial seedling age and size did not have a significant effect on the height and rcd 7.5 months after planting or at any later measurement dates ($p = 0.05$). In general, *L. leucocephala* accessions were taller at 21 months after planting than *G. sepium* provenances, but had smaller root collar diameters and larger diameters at 50 cm above ground. In *G. sepium*, diameter fell off more rapidly with increasing height, i.e. stems were more heavily tapered. *Calliandra* was on average taller than *Sesbania* and *Senna*. *Calliandra* accessions also had larger rcd and *D*50 values. *S. grandiflora* (SG7) failed to grow and was removed shortly after planting. SG7 plots were treated identical in terms of maintenance to all other plots between 1988 and 1992, except that they did not receive any mulch in phase 1 or phase 2. Table 3 shows that the mainstems of most *L. leucocephala* accessions maintain a sizeable girth along their bole longer than mainstems of *G. sepium*. Therefore, *L. leucocephala* mainstems are more suitable as poles in fence making and building construction. The more spindly mainstems of *G. sepium* are suitable as stakes for supporting annual crops, like climbing beans. As *G. sepium* can be established fairly easily from cuttings, there is potential to use suitable sections of the mainstems to create hedges and live fences. Mainstems of *Calliandra* and *Senna* species are, like *Leucaena*, suitable for light construction purposes. Mainstem wood of *Sesbania* has a lower specific weight and is much more susceptible to decay. It is unsuitable for building applications but useful as a very fast growing source of low quality fuelwood. Its role in restoring soil fertility of degraded crop land under improved tree fallow regimes is currently investigated (ICRAF, 1992). Twigs and branches of all species are suitable as firewood after sufficient air drying.

Table 3
Mean height, diameter at ground level (rcd) and at 50 cm (*d*50) in *Leucaena, Gliricidia, Calliandra, Sesbania* and *Senna* (*Cassia*), 21 months after planting

Experiment 1

Leucaena leucocephala	LL1	LL2	LL3	LL4	LL5	Mean	sed	cv (%)	*p*
Height (cm)	448	496	474	501	451	474	30.5	6.4	0.400
rcd (cm)	8.7	11.9	9.2	9.6	9.1	9.7	0.37	3.8	0.005
*d*50 (cm)	6.8	6.8	6.7	6.2	4.5	6.2	0.32	5.2	0.008

Gliricidia sepium	GS7	GS8	GS9	GS10	GS11	GS12	Mean	sed	cv (%)	*p*
Height	427	342	401	384	439	462	409	54.6	13.3	0.410
rcd	10.7	10.9	12.4	13.8	11.0	13.1	12.0	1.3	10.7	0.220
*d*50	3.5	2.8	3.5	3.6	4.1	4.4	3.7	0.75	20.5	0.490

Experiment 2

Calliandra calothyrsus	CC1	CC2	CC3	Mean	sed	cv (%)	*p*
Height	543	522	514	526	30.5	7.1	0.680
rcd	12.9	10.6	11.5	11.6	2.18	23.0	0.630
*d*50	5.2	4.6	5.1	5.0	0.59	11.8	0.660

Sesbania sesban	SS4	SS5	SS6	Mean	sed	cv (%)	*p*
Height	533	527	354	471	14.1	3.7	0.009
rcd	10.6	11.0	5.3	9.0	1.11	15.2	0.059
*d*50	5.4	4.9	3.5	4.6	0.28	6.1	0.039

Senna (Cassia) spectabilis and *S. siamea*	CS8	CSi9	CSi10	Mean	sed	cv (%)	*p*
Height	602	451	377	476	46.4	11.9	0.076
rcd	12.5	8.9	8.3	9.9	0.52	6.5	0.026
*d*50	5.0	5.5	5.2	5.2	0.19	3.6	0.213

sed: standard error of the difference; cv: coefficient of variation (at plot level); *p*: significance level.

Table 4
Mean monthly rate of increase of height and root collar diameter for *Leucaena, Gliricidia, Calliandra, Sesbania* and *Senna* species between planting and felling at 21 months (cm month^{-1})

Experiment 1: *Leucaena* and *Gliricidia* species

Code	LL1	LL2	LL3	LL4	LL5	GS7	GS8	GS9	GS10	GS11	GS12
Height	19.2	21.0	20.7	22.5	21.0	20.2	16.4	19.3	18.4	20.9	22.2
rcd	0.40	0.55	0.41	0.44	0.43	0.50	0.51	0.59	0.66	0.52	0.62

Experiment 2: *Calliandra, Sesbania* and *Senna (Cassia)* species

Code	CC1	CC2	CC3	SS4	SS5	SS6	CS8	CSi9	CSi10
Height	25.7	25.1	24.7	24.5	23.4	15.9	29.3	21.6	18.2
rcd	0.62	0.50	0.55	0.50	0.51	0.24	0.60	0.42	0.39

3.1.2. Tree form

In Table 5, the mean number of stems per tree, counted at 0, 25, 50 and 130 cm above ground is summarized for each species. Both within and between species, considerable variation in the number of individual stems at various levels above the ground is noted. Different tree forms were present in these experiments, ranging from single stemmed trees (e.g. SS6) to shrubs with multiple mainstems, emerging from ground level (e.g. GS8). The development of the form and size of trees and shrubs determines to a large extent what use can be made of the woody parts, ranging from firewood to building materials.

3.1.3. Relationships between wood biomass and cross sectional area

Stewart et al. (1992) reported a simple but accurate and partially non-destructive technique to estimate the standing woody biomass in multi-stemmed trees and shrubs, using the sum of the cross sectional areas below breast height as the predictor variable. This method was tested for both experiments. In July 1990, the sum of the cross sectional areas (Σd^2) of each remaining sample tree at 50 cm above ground level was determined. Trees were then harvested and the yield of mainstem wood, branchwood and leaves was determined. A linear regression model of the form: $\text{wbm} = a + b\Sigma d^2$ was fitted, with the aim to predict total woody biomass (wbm) from total cross sectional area (csa). The model was fitted separately for each treatments in both experiments except LC6 and SG7. The datasets were small; only seven to eight observations of "csa" and "wbm" were available for individual provenances. The proportion of the variation (r^2) of "wbm" explained by the fitted line which could be accounted for was between 44 and 70% in 5 cases and above 70% in the remaining 15 cases (Table 6). Stewart et al. (1992) found a

Table 5
Number of individual stems of each accession or provenance at 0, 25, 50 and 130 cm above ground. Mean values (x) for provenances of *L. leucocephala, G. sepium, C. calothyrsus, S. sesban and Senna* (*Cassia*) *siamea*

Experiment 1: *Leucaena* and *Gliricidia* spp.

Height above ground (cm)	LL1	LL2	LL3	LL4	LL5	x	GS7	GS8	GS9	GS10	GS11	GS12	x	LC6
0	1.12	1.0	1.0	1.0	1.12	1.05	2.25	3.37	3.12	4.0	2.75	2.12	2.94	2.08
25	1.25	1.50	1.50	1.75	2.50	1.70	3.37	4.62	4.50	4.0	4.12	3.38	4.0	2.96
50	1.38	2.25	1.62	2.0	3.0	2.05	3.37	4.62	5.25	4.0	4.12	3.38	4.12	3.18
130	1.88	2.75	2.37	2.37	3.12	2.50	3.37	4.62	5.25	4.0	4.12	3.38	4.12	3.39

Experiment 2: *Calliandra, Sesbania* and *Senna* (*Cassia*) spp.

Height above ground (cm)	CC1	CC2	CC3	x	SS4	SS5	SS6	x	CS8	CSi9	CSi10	x
0	2.5	1.0	1.38	1.63	1.0	1.0	1.0	1.0	1.0	1.0	1.13	1.07
25	3.5	2.75	3.0	3.08	2.13	1.29	1.0	1.47	3.75	1.38	1.38	1.38
50	3.63	2.88	3.38	3.30	2.13	3.14	1.0	2.09	3.88	1.88	1.50	1.69
130	3.88	3.13	3.38	3.46	2.13	3.14	1.0	2.09	4.13	2.13	1.50	1.82

Table 6
Coefficients of determination (r^2) and significance levels (p) of a linear regression model, which predicts total woody biomass (wbm) from total cross sectional area (Σd^2) at 50 cm above ground level

	LL1	LL2	LL3	LL4	LL5	x
n	8	7	7	7	7	36
r^2	72.6	90.6	76.1	44.3	86.6	80.3
p	0.004	0.000	0.006	0.040	0.000	0.000

	GS7	GS8	GS9	GS10	GS11	GS12	x
n	8	8	8	8	8	7	47
r^2	90.6	99.3	94.8	80.4	96.0	94.5	89.3
p	0.000	0.000	0.000	0.000	0.000	0.000	0.000

	CC1	CC2	CC3	x
n	8	8	8	24
r^2	69.5	59.8	57.0	56.7
p	0.010	0.024	0.030	0.000

	SS4	SS5	SS6	x
n	8	8	7	23
r^2	94.4	92.9	96.4	94.9
p	0.000	0.000	0.000	0.000

	CSi9	CSi10	x	CS8
n	8	8	16	8
r^2	94.8	57.4	87.8	71.9
p	0.000	0.029	0.000	0.008

Based on harvesting seven to eight trees per treatment (n) at 21 months after planting. The equation for the regression model is: $\text{wbm} = a + b(\Sigma d^2)$. In the x column, r^2 and p values are given for models that predict total wood biomass for all provenances within a species.

similar range of values, although they determined "csa" at 30 cm above ground level and their sample size was larger ($n = 30$). In trees with a distinct shrub type appearance, like *Gliricidia*, several stems may sprout from low levels above the ground, with rapidly increasing numbers of side branches, adding to the complications of accurate measurement. Thus, a balance must be found between measuring a sufficient number of individual stems in each tree and not taking large numbers of diameter measurements, for instance at breast height, at the cost of accuracy. Our results confirm the earlier work by Stewart et al. (1992) that measuring the diameter of all mainstems at 30 to 50 cm above ground level is suitable for obtaining reliable cross sectional area values, and consequently reliable estimates of standing woody biomass. CSA measurements in this height range are much preferred to measuring a single diameter near the root collar. The latter is more likely to be influenced by trunk swellings and irregularities near the base of the tree.

3.1.4. Early coppice behaviour

Two months after the first thinning, the ability o trees to coppice was assessed by counting the num ber of coppice shoots on each cut stool (Table 7). *L leucocephala* on average produced 23 coppice shoot per stool, but LL5 was significantly less vigorou This early indication of its reduced vigour was late confirmed, when it produced fewer leaves in phase and 2. On the other hand, LC6 showed high coppic numbers after the first cutting but this was n matched by satisfactory leaf production later on. *G. sepium*, there was no apparent correlation b tween the number of initial coppice shoots and su sequent leaf production as illustrated by low sho numbers in GS12, combined with consistently sup rior leaf production in phase 1 and 2. In *Calliand* on average 12.7 coppice shoots were counted i tially. Differences between accessions were not s nificant ($p = 0.05$), but CC1 later turned out to the most abundant leaf producer. Although init coppice shoot numbers were twice as high in *L caena* than in *Calliandra*, long term leaf product (1988–1992) of the two species was comparat

Table 7
Initial coppice behaviour of *Leucaena leucocephala*, *Gliric sepium*, *Calliandra calothyrsus*, *Sesbania sesban*, *Senna* (*Ca spectabilis* and *Senna siamea*, measured as the number of cop shoots visible (no. c), two months after the first harvest

	LL1	LL2	LL3	LL4	LL5	Mean	sed	p	L
no. c	24.1	25.5	25.5	24.5	16.3	23.2	2.37	0.021	2

	GS7	GS8	GS9	GS10	GS11	GS12	Mean	sed	p
no. c	16.2	18.5	19.4	16.8	15.7	14.8	16.9	1.47	0

	CC1	CC2	CC3	Mean	sed	p
no. c	14.8	12.1	11.2	12.7	1.13	0.071

	CS8	CSi9	CSi10	Mean	sed	p
no. c	18.9	15.0	12.9	14.0	1.30	0.023

Once *S. sesban* was cut back to coppice height, it universally failed to regenerate, irrespective of the seed source used. The failure of *S. sesban* to coppice under hedge management, reported earlier by Evans and Rotar (1987) and Yamoah et al. (1989), effectively disqualifies it for use as a leaf producing species in intercropping systems. *S. spectabilis* (CS8) coppiced much more vigorously than either of the *S. siamea* accessions. The results obtained about early coppice behaviour show that this is not necessarily a reliable indicator of longer term leaf production. Coppice production must be monitored over a sufficiently long period of time, probably at least two years, to establish which provenances are good leaf producers under regular cutting management.

As pointed out previously, SG7 died early on and was removed within the first year. Effectively, these plots could be regarded as controls, which did not receive any mulch inputs but were subject to nutrient exports during the four successive cropping seasons of 1990–1992. The *S. sesban* provenances SS4, SS5 and SS6 did not receive any mulch inputs during phase 2 but were subject to continued biomass and nutrient exports through crop yields in phase 2. LC6 had a very limited input of mulch in phase 1 and 2, but also experienced continued nutrient exports through crop yields in phase 2.

3.1.5. Leaf yields in phase 1 (tree management) and in phase 2 (hedge management)

Leaf production data for phase 1 (October 1988–July 1990) and for phase 2 (August 1990–August 1992) are first discussed for experiment 1 (*Leucaena* and *Gliricidia*) and thereafter for experiment 2 (*Calliandra*, *Sesbania* and *Senna*).

3.1.5.1. Experiment 1. Table 8 summarizes mean fresh leaf yields per tree between establishment and 21 months after planting. In *L. leucocephala*, LL2 was significantly more productive than the other accessions at 7.5 months after planting. Leaf production of *L. collinsii* (LC6) was already low at this

Table 8

Mean leaf yield (kg tree^{-1}; fresh weight) of trees at 7.5, 13 and 21 months after planting of *Leucaena*, *Gliricidia*, *Calliandra*, *Sesbania* and *Senna (Cassia)* species

Months after planting	LL1	LL2	LL3	LL4	LL5	Mean	sed	*p*	LC6
7.5	1.73	3.17	1.50	1.83	1.19	1.88	0.37	0.006	0.68
13	8.58	5.78	8.00	9.44	6.49	7.46	1.35	0.16	2.07
21	10.82	12.77	13.36	12.76	9.71	11.89	1.54	0.25	2.09

Months after planting	GS7	GS8	GS9	GS10	GS11	GS12	Mean	sed	*p*
7.5	0.64	0.67	0.61	0.63	0.74	1.34	0.77	0.184	0.018
13	2.63	2.5	3.58	3.87	3.93	5.77	3.71	0.72	0.011
21	4.09	2.97	4.69	7.44	4.32	8.96	5.41	1.99	0.015

Months after planting	CC1	CC2	CC3	Mean	sed	*p*
7.5	1.78	1.92	1.71	1.80	0.552	0.931
13	4.71	5.27	4.90	4.96	1.732	0.949
21	11.40	12.40	13.70	12.50	2.60	0.708

Months after planting	SS4	SS5	SS6	Mean	sed	*p*
7.5	2.83	0.95	0.91	1.57	0.712	0.117
13	5.20	3.91	1.04	3.38	1.804	0.174
21	7.60	4.40	0.0	4.0	1.23	0.049

Months after planting	CS8	CSi9	CSi10	Mean	sed	*p*
7.5	1.18	1.12	1.01	1.10	0.306	0.852
13	4.69	4.64	1.56	3.63	1.062	0.067
21	4.47	7.37	3.44	5.10	1.061	0.119

early age. At 13 months after planting, average leaf yield per tree was not significantly different ($p = 0.05$) for the five *L. leucocephala* accessions, but the mean leaf yield was four times higher than at the initial harvest. Low productivity of LC6 continued. At 21 months after planting, the overall mean fresh leaf yield was 12 kg/tree, 60% more than at the previous cutting, but differences between accessions were insignificant.

In *G. sepium*, GS12 was significantly more productive than the other provenances at the first, second and final harvest ($p = 0.05$). GS12 has come out as a provenance of consistently high productivity in many MPTS evaluation experiments around the tropics (Simons and Dunsdon, 1993). At the second harvest, the mean leaf yield per tree (i.e. the average value of six *Gliricidia* provenances) was five times higher than at the first harvest. At final harvest, the mean fresh leaf yield was 5.4 kg/tree, 46% higher than at the second harvest. A comparison of dry matter leaf production of *Leucaena* and *Gliricidia* during the first 21 months showed that *L. leucocephala* was on average three times more productive than *G. sepium*.

3.1.5.2. Experiment 2. In *C. calothyrsus*, no significant differences ($p = 0.05$) in mean leaf production per tree were observed at 7.5 months after planting. The three accessions remained similar in leaf productivity at later thinning dates; mean leaf yield was 2.75 times higher at 13 months then at 7.5 months; at 21 months it was nearly seven times higher than at the first thinning.

In *S. sesban*, SS4 appeared more productive than the other accessions at all three thinning dates. However, because of high between plot coefficients of variation (cv's), the observed yield differences were not significant at both 7.5 and 13 months ($p > 0.05$). At 13 months, SS6 had died; no leaves were harvested from this accession. At final harvest, SS4 produced 7.6 kg of fresh leaves/tree and SS5 produced 4.4 kg. Mean leaf yields were twice as high at 13 months as at the first thinning. At 21 months, the two surviving accessions produced seven to eight times more leaves than at the first thinning.

S. spectabilis and *S. siamea* produced similar amounts of fresh leaves at the first thinning: 1.1 kg per tree. From the second thinning onwards, CSi10 was consistently less productive. At 21 months, CS8 was less productive than CSi9, whereas at 13 months, they had comparable leaf production.

Comparing leaf production between species during the first 21 months after planting, *C. calothyrsus* was on average three times more productive than *Senna* species in dry matter equivalents. Partly because of the large variation in leaf production between accessions and partly because of the lower dry matter content of *S. sesban* leaves, it was the least productive species in phase 1.

3.1.5.3. Total leaf production: 1988–1992. The total amount of leaves applied to the plots, expressed in dry matter equivalents, during tree management and during subsequent hedge management is shown in Table 9. LL1–LL4 were comparable in production, whereas LL5 was approximately 25% lower in productivity. Leaf production of LC6 was low; only

Table 9
Total leaf yield (t ha^{-1}; dry matter) of *Leucaena*, *Gliricidia*, *Calliandra*, *Sesbania* and *Senna* (*Cassia*) species during tree management phase 1 (1988–1990) and during hedge management phase 2 (1990–1992), retained in the plots

	LL1	LL2	LL3	LL4	LL5	Mean	LC6
1988–90	9.16	10.1	9.19	9.58	6.96	9.00	3.40
1990–92	9.98	10.05	8.76	9.83	7.77	9.28	2.15
Total	19.14	20.15	17.95	19.41	14.73	18.28	5.55

	GS7	GS8	GS9	GS10	GS11	GS12	Mean
1988–90	2.64	2.31	3.24	3.77	3.35	5.02	3.39
1990–92	2.52	4.22	6.83	6.55	5.97	7.38	5.58
Total	5.16	6.53	10.07	10.32	9.32	12.4	8.97

	CC1	CC2	CC3	Mean
1988–90	9.26	9.76	9.14	9.39
1990–92	9.36	7.03	6.38	7.59
Total	18.62	16.79	15.52	16.98

	SS4	SS5	SS6	Mean
1988–90	5.24	3.06	0.62	2.97
1990–92	0	0	0	0
Total	5.24	3.06	0.62	2.97

	CS8	CSi9	CSi10	Mean
1988–90	5.46	4.70	2.58	4.25
1990–92	10.9	1.73	1.51	4.71
Total	16.36	6.43	4.09	8.96

5.55 t ha^{-1} of dry matter was produced over 4 years. The five *L. leucocephala* accessions were approximately as productive in phase 1 under tree management as in phase 2 under hedge management. In *G. sepium*, GS12 was the most productive provenance over the four year period. Average productivity of *Gliricidia* was 32% lower than that of *L. leucocephala*. *Gliricidia* leaf production was 65% higher under hedge management than under tree fallow, both measured over a two year period. *L. leucocephala* and *G. sepium* leaves have comparable N, P and K contents and decomposition characteristics, but *L. leucocephala* leaves have a higher dry matter content. Therefore, in the conversion from fresh yields to dry weight equivalents, the leaf biomass figures of *L. leucocephala* increased nearly 40% relative to the figures for *G. sepium*. As a result, a considerable range of leaf productivity figures for material of comparable quality was available for calculating the effect of tree leaves on maize yields in experiment 1. *C. calothyrsus* was comparable in leaf production to *L. leucocephala* during phase 1 and slightly less productive in phase 2. Different seed sources of *C. calothyrsus* were not significantly different in productivity ($p = 0.05$). Over four years, *S. spectabilis* was comparable in productivity to *Leucaena* and *Calliandra*, but it was especially productive in phase 2, when it was managed as a hedge. Both *S. siamea* accessions were much less productive than *S. spectabilis* and rapidly declined in leaf productivity, once they were managed as hedges. In *S. sesban*, there were marked differences in leaf production in phase one. SS4 was more productive than SS5; SS6 was a very poor leaf producer. In phase 2, none of the *S. sesban* accessions produced leaves under coppice management. As a result, overall yields for the four year period were the lowest of all species tested.

The data in Table 8 show, as expected, a relationship between leaf yield and the age of the tree at cutting. A regression equation of the form $Y = a + bX$ was used to describe the relationship between Y (leaf yield) and X (tree age between planting and 21 months) separately for the two groups of five *L. leucocephala* accessions and six *G. sepium* provenances. For *Leucaena*, 90% of the variation in leaf yields could be described by the single equation: $Y = -3 + 0.73X$. In the case of *Gliricidia*, only 62% of the variation in leaf yields was described by the single equation: $Y = -1.3 + 0.33X$. For the three *C. calothyrsus* accessions, 97% of the variation in leaf yields could be described with the single equation: $Y = -4.69 + 0.803X$. In *S. sesban*, only 59% of the variation in leaf yields could be described with the single equation: $Y = -0.90 + 0.33X$, if SS6, which produced no leaves at 21 months after planting, was excluded from the analysis. For *S. siamea*, only 58% of the variation in leaf yields could be described with the single equation: $Y = -0.7 + 0.29X$. A possible explanation for the difference in ability to predict leaf yields accurately from tree age in *Leucaena, Gliricidia, Calliandra, Sesbania* and *Cassia* is discussed later.

3.1.6. Wood yields

Wood production in 1990–1992, before the trees were managed as hedges, is summarized in Table 10. Total wood yield of each species and provenance in phase 1 is summarized in Table 11. In both experiments, similar to the findings for leaf biomass, production of wood per individual tree increased significantly for species and provenances from the first cutting to the second cutting to the final cutting. The only exception was the decrease in side branch wood in *S. sesban* between 13 and 21 months. This may be explained by the reduced vigour of the species as it got older. Also leaf yields did not increase in SS5 and SS6 during the same period.

3.2. Phase 2 (July 1990–August 1992)

3.2.1. Maize yields

Maize yields are summarized by season and yield component (grain, stover) for experiment 1 and 2 in Tables 12 and 13.

3.2.1.1. Experiment 1. In experiment 1, there were significant differences ($p < 0.01$) in grain and stover yields in the first two cropping seasons with high yields in association with LL1–LL5 and GS12. Low yields were recorded in association with LC6 and GS7–GS11. Yields in the first two seasons after the tree fallow ranged from 43% above to 35% below the mean yield for the experiment. Compared with control yields (SG7 in experiment 2), the average performance of experiment 1 was 60% higher in the first year and some treatments were 120% higher than the control yield. Grain yields and stover yields in the first two seasons were highly correlated ($r = 0.98$ and $r = 0.93$ respectively), suggesting that maize plants were healthy with well developed grain cobs and that the partitioning of dry matter between the vegetative and reproductive parts took place under suitable (i.e. average) climatic conditions for this maize variety. In the third season, maize yields were very low. Much less rain than normal was received between September 1991 and January 1992 and it was also poorly distributed (Table 1). The sudden drop in grain yields, but not in stover yields, can be attributed to the failing rains. As a result, crop development took place under severe moisture stress, an unusual situation in the highlands of western

Table 10
Wood production (kg tree^{-1}; fresh weight) of *Leucaena*, *Gliricidia*, *Calliandra*, *Sesbania* and *Cassia* during phase 1 (1988–1990)

Months after planting	Wood type	LL1	LL2	LL3	LL4	LL5	Mean	sed	p	LC6
7.5	ms	0.85	1.27	0.82	0.89	0.53	0.87	0.239	0.135	0.13
7.5	sb	0.72	1.93	0.52	0.78	0.53	0.9	0.284	0.005	0.20
13	ms	5.98	5.96	5.62	7.49	4.29	5.87	1.304	0.282	1.07
13	sb	2.49	2.38	2.11	2.78	1.64	2.28	0.557	0.387	0.52
21	ms	8.91	16.20	12.81	11.78	9.44	11.83	2.967	0.270	2.14
21	sb	8.94	13.93	9.71	10.04	7.15	9.95	1.862	0.123	2.27

Months after planting	Wood type	GS7	GS8	GS9	GS10	GS11	GS12	Mean	sed	p
7.5	ms	0.65	0.64	0.64	0.46	0.73	1.38	0.75	0.201	0.014
7.5	sb	0	0	0	0	0	0	0	0	0
13	ms	2.16	2.09	2.83	2.38	4.31	4.27	3.01	0.903	0.094
13	sb	1.41	1.26	1.82	2.16	2.3	4.08	2.17	0.596	0.009
21	ms	10.1	8.1	14.3	16.8	14	18.5	13.6	4.690	0.353
21	sb	0	0	0	0	0	0	0	0	0

Months after planting	Wood type	CC1	CC2	CC3	Mean	sed	p
7.5	ms	1.60	1.86	1.78	1.75	0.70	0.93
7.5	sb	1.02	1.35	0.96	1.11	0.32	0.49
13	ms	6.93	6.27	6.36	6.52	2.10	0.94
13	sb	4.10	4.27	3.77	4.04	1.20	0.92
21	ms	16.29	14.80	13.39	14.80	3.72	0.77
21	sb	13.20	11.02	10.69	11.64	1.22	0.29

Months after planting	Wood type	SS4	SS5	SS6	Mean	sed	p
7.5	ms	3.75	3.05	0.93	2.58	1.67	0.32
7.5	sb	4.28	4.72	0.96	3.32	3.17	0.50
13	ms	7.48	7.36	1.78	5.54	2.31	0.11
13	sb	7.04	4.53	1.53	4.37	1.59	0.06
21	ms	9.11	9.79	1.17	6.70	1.45	0.04
21	sb	4.29	1.20	0.00	1.83	0.93	0.08

Months after planting	Wood type	CS8	CSi9	CSi10	Mean	sed	p
7.5	ms	1.12	0.56	0.43	0.70	0.27	0.12
7.5	sb	0.43	0.65	0.58	0.56	0.23	0.65
13	ms	6.32	4.39	1.40	4.04	1.39	0.06
13	sb	3.04	3.27	1.44	2.59	0.64	0.09
21	ms	13.61	8.11	4.25	8.66	0.71	0.01
21	sb	2.12	5.91	3.94	3.99	0.92	0.11

Wood type: ms, mainstem wood; sb, side branch wood.

Table 11
Total wood yield (Σw, dry weight) from harvesting *Leucaena, Gliricidia, Calliandra, Sesbania* and *Senna* (*Cassia*) species at 7.5, 13 and 21 months after planting and exported from the plots

	LL1	LL2	LL3	LL4	LL5	LC6	GS7	GS8	GS9	GS10	GS11	GS12
Σw(t ha^{-1})	17.3	26.0	19.3	20.1	14.3	3.0	5.8	5.0	7.9	8.7	8.5	11.3

	CC1	CC2	CC3	SS4	SS5	SS6	SG7	CS8	CSi9	CSi10
Σw(t ha^{-1})	33.8	29.9	29.1	15.5	13.0	3.2	0.0	19.0	12.1	9.0

Side branch wood and mainstem wood combined.

Kenya. In this season, the average grain to stover ratio changed significantly from more than 1:1 to 0.3:1. Proportionally more stover was produced at the expense of grain production, suggesting that cob formation and grain development were impaired by drought conditions. Despite the restrictions imposed by the weather, Table 12 shows that the highest grain yields continued to be in association with some of the *L. leucocephala* treatments which also gave high yields in the first two seasons (LL1–LL2). In the fourth cropping season, when rainfall was back to normal levels, yields recovered. However, grain yield differences were no longer significant at $p = 0.05$.

Between 1990 and 1992, the mean grain yield in experiment 1 declined from 4.16 t ha^{-1} to 3.27 t ha^{-1} (to 0.53 t ha^{-1}) to 2.89 t ha^{-1}. The benefits of applying varying amounts of mulch to the plots during the tree fallow are most visible in the first cropping season. The initial yield of 4.16 t ha^{-1} would be considered high in the study area. This

Table 12
Yield (t ha^{-1}) of maize grain and stover in plots intercropped with *Leucaena* and *Gliricidia* during four consecutive seasons (1990–92) and total yields

Species code	Cropping season								Total yield 1990–1992	
	Short rains 1990		Long rains 1991		Short rains 1991		Long rains 1992			
	Grain	Stover	Grain	Stover	Grain	Stover	Grain	Stover	Grain	Stover
LL1	6.28	6.15	5.04	3.09	0.96	2.04	3.68	2.97	15.96	12.26
LL2	4.98	4.95	4.16	2.50	0.83	1.99	3.66	2.73	13.63	12.16
LL3	5.57	5.70	3.57	2.63	0.63	1.86	2.81	2.31	12.57	12.49
LL4	5.04	5.10	4.12	2.65	0.63	1.84	2.62	2.44	12.41	12.03
LL5	4.96	5.19	3.33	2.46	0.63	1.71	2.78	2.19	11.70	11.55
LC6	3.77	4.03	2.30	1.81	0.25	1.26	1.82	1.72	8.14	8.82
GS7	2.50	3.36	2.24	2.09	0.28	1.58	2.05	1.97	7.07	8.99
GS8	3.35	4.16	2.64	2.03	0.30	1.57	2.97	2.50	9.26	10.26
GS9	3.19	3.83	3.26	2.25	0.54	2.03	3.13	2.63	10.13	10.73
GS10	3.12	4.15	2.89	2.44	0.51	2.02	3.43	2.96	9.96	11.56
GS11	3.22	3.85	1.85	1.66	0.29	1.35	2.33	3.15	7.69	10.01
GS12	3.90	4.33	3.82	2.85	0.52	2.12	3.35	3.10	11.59	12.39
Mean	4.16	4.57	3.27	2.37	0.53	1.78	2.89	2.55	10.84	11.27
sed	0.727	0.41	0.63	0.34	0.249	0.29	0.594	0.64	1.454	1.149
p [1]	0.006	< .001	0.002	0.013	0.162	0.09	0.068	0.461	< .001	0.004
cv [2]	17.5	11.0	23.6	17.6	57.6	19.9	25.2	30.5	16.4	12.5
g:s [3]	0.91:1		1.40:1		0.30:1		1.13:1		0.96:1	

Grain yields expressed at 13% moisture content; stover yields expressed as dry matter.

[1] The p value represents the level of significance of the difference between treatment means.

[2] Coefficient of variation of plots within blocks.

[3] Grain to stover ratio.

Table 13
Yield (t ha^{-1}) of maize grain and stover in plots intercropped with *Calliandra*, *Sesbania* and *Senna* (*Cassia*) during four consecutive seasons (1990–92) and total yields

Species code	Cropping season								Total yield 1990–199	
	Short rains 1990		Long rains 1991		Short rains 1991		Long rains 1992			
	Grain	Stover	Grain	Stover	Grain	Stover	Grain	Stover	Grain	Stover
CC1	4.64	4.17	2.83	1.94	0.87	2.20	1.62	1.52	9.96	9.83
CC2	4.89	4.12	2.96	1.80	0.84	2.27	1.91	1.73	10.60	9.92
CC3	5.17	4.27	3.33	2.18	0.97	2.28	2.20	1.66	11.67	10.39
SS4	3.54	3.49	3.29	1.86	0.65	1.94	2.48	1.85	9.96	9.14
SS5	3.53	3.35	2.56	2.29	0.87	2.10	2.07	1.79	9.03	9.53
SS6	2.16	2.21	2.49	1.98	0.56	2.01	2.12	1.71	7.33	7.91
SG7	2.08	2.44	2.83	1.74	0.56	1.77	2.18	1.68	7.65	7.63
CS8	4.04	3.36	2.67	1.86	0.36	1.63	2.86	2.00	9.93	8.85
CSi9	4.00	4.03	2.88	1.90	0.64	1.92	2.07	1.45	9.59	9.30
CSi10	3.88	4.09	2.88	1.81	0.66	2.08	2.37	1.84	9.79	9.82
Mean	3.79	3.55	2.85	1.93	0.70	2.02	2.19	1.72	9.53	9.22
sed	0.642	0.573	0.353	0.183	0.183	0.244	0.479	0.274	1.83	1.23
p [1]	0.011	0.045	0.312	0.136	0.091	0.220	0.493	0.713	0.007	0.009
cv [2]	20.7	19.8	15.2	11.60	32.2	14.8	26.8	19.5	11.9	12.3
g:s [3]	1.07:1		1.48:1		0.35:1		1.27:1		1.03:1	

Grain yield expressed at 13% moisture content; stover yield expressed as dry matter.

[1] The p value represents the level of significance of the difference between treatment means.

[2] Coefficient of variation of plots within blocks.

[3] Grain to stover ratio.

yield level can only be achieved by using substantial amounts of inorganic fertilizers or, as demonstrated in this study, through carefully managed intercropping with suitable tree species.

3.2.1.2. Experiment 2. In experiment 2, yields were on average lower in the first two cropping seasons than in experiment 1. Differences in grain and stover yields were only significant ($p = 0.05$) in the first season. Yields were higher than average in *Calliandra* (CC1–CC3) and *Senna* (CS8, CSi9–CSi10). SS6 gave relatively low grain and stover yields. Low yields were also recorded in the SG7 control treatment. The mean grain yield in this treatment over four seasons was 1.91 t ha^{-1}. The first season it was 2.08 t ha^{-1}, followed by 2.83, 0.56 and 2.18 t ha^{-1}. Without the addition of fertilizers or leaf mulch, an average grain yield of 2.0 t ha^{-1} is within the expected range on this soil type, provided soil fertility has not been largely depleted by continuous cultivation. When the rains fail, grain yields are likely to be well below 1 t ha^{-1} on this soil type. In the second season, average grain yields had decreased by 25% and stover yields by 46%. Differences were no longer significant ($p = 0.05$). The mean grain and stover yields in the first two seasons ranged from 24% above to 30% below the mean yield for the experiment. In the third, failed season, grain and stover yields were very low and comparable to those in experiment 1. The effect that the failing rains had on maize yields during the third cropping season are discussed at the end of this paper. In the last season, grain and stover yields recovered, but not as much as in experiment 1. Mean grain yields in the last season were 28% lower in experiment 2 than in experiment 1. In the course of the four cropping seasons, grain yields declined from 3.79 to 2.85 (to 0.70) to 2.19 t ha^{-1}.

The rate at which crop yields declined over time varied by species. Grain yields in the last season, expressed as a percentage of grain yields in the first season, were on average 90% for *Gliricidia*, 76% for *Sesbania*, 61% for *Senna*, 58% for *Leucaena* and a surprisingly low 39% for *Calliandra*.

3.3. Nutrient budgets: mulch inputs minus crop exports

Partial nutrient budgets were constructed for each treatment in both experiments. The N, P and K contents of tree leaves and maize grain and stover were determined. The balance between nutrients retained through mulch additions and nutrients removed in crop harvests was then calculated, starting with the situation at the end of the fallow phase, and recalculating the situation as maize cropping progressed through four seasons. Nutrient exports in crop components in experiment 1 during the first season were in the range of 44 to 101 kg ha^{-1} of N, 9 to 20 kg ha^{-1} of P and 28 to 58 kg ha^{-1} of K. The amount of nutrients retained in the plots until the end of 1990 ranged from 103 to 414 kg ha^{-1} of N, 9 to 31 kg ha^{-1} of P and 59 to 191 kg ha^{-1} of K (Table 14 a, b and c). Successive maize crops did not benefit from mulch applications as much as the first crop because under hedge management over a period of six months (first half of 1991), much less mulch could be returned to the plots than during the initial two year tree fallow. For instance, in the first half of 1991, returns of N were between 21 and 111 kg ha^{-1}; between 1.6 and 8.4 kg ha^{-1} of P was returned and returns of K were between 9.8 and 51 kg ha^{-1}. As the nutrient reserves for N, P, K and possibly other elements in the soil were depleted to varying degrees during the maize cropping phase, it was expected that crop yields would decline. However, the estimated nutrient reserves declined much faster in some treatments than in others. As a result, nutrient reserves for N, P and K at the end of the experiment varied considerably between treatments. In a number of treatments, especially P had changed from initially positive values to negative values by mid-1992. In experiment 2, the amount of nutrients retained in the plots through mulching until the end of 1990 ranged from 0 to 351 kg ha^{-1} of N, 0 to 28 kg ha^{-1} of P and 0 to 121 kg ha^{-1} of K (Table 15 a, b and c). By mid-1992, after four successive cropping seasons, most *Sesbania* and *Cassia* treatments faced N, P and K nutrient deficits.

The estimated N reserves are probably inflated as no correction factor could be applied for N losses due to leaching. Average concentrations of foliar N, P and K were used for each tree species. Separate figures could not be determined for each provenance within species or for each mulch application between 1988 and 1992. Similarly, separate samples were not collected to determine the extend of treatment related differences in the N, P and K contents of maize grain and stover at each harvest. Instead, average figures were used, based on a limited succession of foliar and grain analysis. The calculated nutrient budgets are first approximations and should not be seen as more than preliminary estimates. The concentrations of N, P and K in the leaves of LL, GS, CC, SS, CSp and CSi are summarized in Table 16.

If tree leaves had been analysed for their nutrient contents at each hedge cutting and if maize grain and stover had been analysed similarly for their nutrient contents at each harvest, our estimates of nutrient transfers between system components would have been more accurate and the corresponding "input-output regression equations" would have described an even higher proportion of the observed variation. However, at the time of the experiment, we did not have the technical and logistical capacity to carry out this part of the study at more detail than we did. If we had been able to analyse foliar material continuously, it is likely that we would have been able to show that the foliar nutrient concentrations in the tree leaves and the crop components fell between 1990 and 1992 as the cumulative amount of nutrients, removed from the site in crop harvests, increased. Heineman (unpublished data) found this in another intercropping experiment at the same site.

Assuming that nutrients are an important limiting factor for crop growth at this site, there is scope to look for a relationship between the amount and type of mulch applied through tree leaves (i.e. ultimately the amount of nutrients made available to the crop) and grain and stover yields, produced in a specific tree-crop association. If such a relationship does exist, it would be based on the premise that trees were able to access soil nutrients from locations and reserves that would otherwise not be utilized by maize crops in monoculture. In the case of the Leguminosae, additional N would also be supplied to the system through biological nitrogen fixation. Thus, correlations between tree leaf production and maize yields were first calculated for experiments 1 and 2 separately. The potential loss of nutrients through the removal of the woody parts of the trees in phase 1

Table 14

a. Nitrogen budget (kg ha^{-1}) for experiment 1, based on tree leaf inputs (1988–1992) and maize crop removals (1990–1992)

	LL1	LL2	LL3	LL4	LL5	LC6	GS7	GS8	GS9	GS10	GS11	GS12
1 input phase 1 + sr90	380.9	414.4	376.3	390.9	292.6	127.4	113.9	103.2	147.1	165.6	144.2	206.3
2 export sr90	100.5	80.0	90.3	81.4	81.0	61.9	44.4	57.8	54.4	55.2	54.9	64.9
3 balance after sr90	280.4	334.4	286.0	309.5	211.7	65.5	69.5	45.4	92.7	110.5	89.4	141.5
4 input 1r91	102.9	110.7	87.9	100.7	76.2	21.4	71.0	68.2	95.0	93.2	85.0	106.4
5 bal. before ex. 1r91	383.3	445.1	373.9	410.2	287.9	86.9	140.5	113.5	187.6	203.6	174.3	247.9
6 export 1r91	71.8	59.0	53.0	59.3	49.4	34.7	35.3	39.6	47.6	44.4	28.9	56.8
7 balance after 1r91	311.5	386.1	321.0	350.9	238.4	52.2	105.2	74.0	140.0	159.3	145.5	191.0
8 input sr91	70.8	65.9	64.1	74.4	59.8	15.3	26.1	17.9	41.8	34.6	34.6	47.1
9 bal. before ex. sr 91	382.4	451.9	385.0	425.3	298.2	67.5	131.3	91.8	181.7	193.9	180.1	238.2
10 export sr91	20.6	18.9	16.0	16.0	15.3	8.9	10.7	10.9	15.8	15.5	9.81	16.1
11 balance after sr91	361.7	433.0	369.0	409.4	282.9	58.6	120.5	80.9	165.9	178.5	170.3	222.1
12 input 1r92	120.7	120.3	105.4	118.5	90.8	32.4	56.8	43.2	75.0	74.3	68.2	81.8
13 bal. before ex. 1r92	482.4	553.3	474.4	527.9	373.7	91.0	177.3	124.1	240.9	252.7	238.5	303.9
14 export 1r92	55.8	54.5	42.8	41.3	41.9	28.8	32.6	45.6	48.0	53.0	41.4	52.7
15 balance after 1r92	426.6	498.9	431.5	486.6	331.8	62.2	144.7	78.5	192.9	199.7	197.1	251.1

b. Phosphorus budget (kg ha^{-1}) for experiment 1, based on tree leaf inputs (1988–1992) and maize crop removals (1990–1992)

	LL1	LL2	LL3	LL4	LL5	LC6	GS7	GS8	GS9	GS10	GS11	GS12
1 input phase 1 + sr90	28.9	31.4	28.5	29.6	22.2	9.7	8.9	8.1	11.5	13.0	11.3	16.2
2 export sr90	19.9	15.9	18.0	16.2	16.1	12.4	9.0	11.7	11.0	11.2	11.1	13.0
3 balance after sr90	9.0	15.5	10.6	13.4	6.0	−2.7	−0.1	−3.6	0.6	1.8	0.3	3.2
4 input lr91	7.8	8.4	6.7	7.6	5.8	1.6	5.6	5.3	7.4	7.3	6.7	8.3
5 bal. before ex. lr91	16.8	23.9	17.2	21.1	11.8	−1.1	5.5	1.7	8.0	9.1	6.9	11.5
6 export lr91	13.8	11.3	10.3	11.4	9.6	6.8	7.0	7.7	9.2	8.7	5.7	11.1
7 balance after lr91	3.0	12.6	6.9	9.7	2.2	−7.9	−1.5	−6.0	−1.2	0.4	1.2	0.5
8 input sr91	5.4	5.0	4.9	5.6	4.5	1.2	2.0	1.4	3.3	2.7	2.7	3.7
9 bal. before ex. sr91	8.3	17.6	11.8	15.3	6.7	−6.7	0.5	−4.6	2.1	3.1	3.9	4.2
10 export sr91	4.4	4.0	3.5	3.5	3.3	2.0	2.5	2.5	3.5	3.4	2.2	3.6
11 balance after sr91	4.0	13.6	8.3	11.8	3.4	−8.7	−1.9	−7.1	−1.5	−0.4	1.7	0.6
12 input lr92	9.2	9.1	8.0	9.0	6.9	2.5	4.5	3.4	5.9	5.8	5.3	6.4
13 bal. before ex. lr92	13.1	22.7	16.3	20.8	10.3	−6.3	2.5	−3.7	4.4	5.5	7.1	7.0
14 export lr92	10.9	10.6	8.4	8.2	8.2	5.7	6.5	8.9	9.4	10.4	8.4	10.4
15 balance after lr92	2.2	12.1	7.9	12.7	2.1	−12.0	−3.9	−12.6	−5.0	−4.9	−1.4	−3.4

c. Potassium budget (kg ha^{-1}) for experiment 1, based on tree leaf inputs (1988–1992) and maize crop removals (1990–1992)

	LL1	LL2	LL3	LL4	LL5	LC6	GS7	GS8	GS9	GS10	GS11	GS12
1 input phase 1 + sr90	175.5	190.9	173.3	180.1	134.8	58.7	67.0	60.7	86.5	97.4	84.8	121.4
2 export sr90	58.3	46.7	53.0	47.7	47.8	36.8	28.1	35.8	33.4	34.8	33.6	38.9
3 balance after sr90	117.1	144.2	120.3	132.4	87.0	21.9	38.9	24.9	53.1	62.7	51.2	82.4
4 input lr91	47.4	51.0	40.5	46.4	35.1	9.8	41.8	40.1	55.9	54.8	50.0	62.6
5 bal. before ex. lr91	164.5	195.2	160.8	178.8	122.1	31.7	80.7	65.0	109.0	117.5	101.2	145.0
6 export lr91	37.0	30.3	28.6	30.9	26.7	19.0	20.3	21.6	25.3	24.8	16.4	30.8
7 balance after lr91	127.5	164.9	132.2	147.9	95.4	12.7	60.5	43.4	83.7	92.7	84.8	114.3
8 input sr91	32.6	30.3	29.5	34.3	27.6	7.1	15.3	10.5	24.6	20.4	20.4	27.7
9 bal. before ex. sr91	160.1	195.3	161.8	182.1	122.9	19.8	75.8	53.9	108.3	113.1	105.2	142.0
10 export sr91	14.7	14.0	12.4	12.3	11.6	7.7	9.5	9.6	13.0	12.8	8.3	13.4
11 balance after sr91	145.4	181.3	149.3	169.8	111.3	12.1	66.3	44.4	95.3	100.3	96.9	128.6
12 input lr92	55.6	55.4	48.5	54.6	41.8	14.9	33.4	25.4	44.1	43.7	40.1	48.1
13 bal. before ex. lr92	201.0	236.8	197.9	224.4	153.1	27.0	99.7	69.8	139.4	143.9	137.0	176.7
14 export lr92	30.8	29.5	23.8	23.7	23.0	16.6	18.8	25.4	26.8	29.8	26.2	30.2
15 balance after lr92	170.1	207.3	174.1	200.7	130.1	10.4	80.8	44.4	112.6	144.2	110.7	146.5

1, input phase 1 + sr90, nutrient inputs from hedges during phase 1 (Oct. 1988–Jul. 1990) and during the first cropping season (Sep. 1990–Jan. 1991).
2, export sr90, nutrient export, resulting from maize and grain yields of first cropping season.
3, balance after sr90, 1,2.
4, input 1r91, nutrient input from hedges during the second cropping season (Mar. 1991–Jul. 1991).
5, bal. before ex. 1R91, nutrient balance before exports from the second season maize and grain yields are subtracted.
6, export 1r91, nutrient export, resulting from maize and grain yields of the second cropping season.
7, balance after 1r91, 5,6.
8, input sr91, nutrient input from hedges during the third cropping season (Sep. 1991–Jan. 1992).
9, bal. before ex. Sr91, nutrient balance before exports from the third season maize and grain yields are subtracted.
10, export sr91, nutrient export, resulting from maize and grain yields of the third cropping season.
11, balance after sr91, 9,10.
12, input 1r92, nutrient input from hedges during the fourth cropping season (Mar. 1992–Jul. 1992).
13, bal. before ex. 1R92, nutrient balance before exports from the fourth season maize and grain yields are subtracted.
14, export 1r92, nutrient export, resulting from maize and grain yields of the fourth cropping season.
15, balance after 1r92, 13–15 balance after 1r92.

Note: In Table 14 and Table 15 and in the text, the word ''input'' is used where we refer to leaf mulch, originating from trees, being retained in the plots. The only undisputed real input to the system from outside its boundaries is the fixation of atmospheric nitrogen. For all other nutrient elements, it remains to be determined whether we can use the term ''inputs'' here, or whether it would be more appropriate to use the term nutrient ''transfers''. If the trees genuinely access soil nutrient pools that were previously outside the reach of the food crops, then the term ''inputs'' could still be used. If the trees merely recycle and capture nutrients that were within the soil profile that is shared by trees and crops, then it would be more appropriate to refer to these redistribution activities of the trees as nutrient ''transfers''.

Table 15

a. Nitrogen budget (kg ha^{-1}) for experiment 2, based on tree leaf inputs (1988–1992) and maize crop removals (1990–1992)

	CC1	CC2	CC3	SS4	SS5	SS6	SG7	CS8	CSI9	CS10
1 input phase 1 + sr90	337.2	351.2	327.6	182.9	106.8	21.6	0.0	187.2	142.5	81.8
2 export sr90	72.4	75.0	78.9	56.8	56.0	35.0	35.2	61.8	64.5	63.5
3 balance after sr90	264.2	276.2	248.7	126.1	50.8	−13.4	−35.2	125.5	78.0	18.3
4 input lr91	115.6	89.9	75.6	0.0	0.0	0.0	0.0	103.5	40.2	33.3
5 bal. before ex. lr91	380.4	366.1	324.3	126.1	50.8	−13.4	−35.2	228.9	118.1	51.7
6 export lr91	41.3	42.1	48.1	46.1	39.9	37.6	40.3	39.1	41.7	41.2
7 balance after lr91	339.1	324.1	276.2	80.0	10.9	−51.0	−75.5	189.8	76.5	10.4
8 input sr91	76.6	55.7	49.2	0.0	0.0	0.0	0.0	68.4	0.3	0.2
9 bal. before ex. sr 91	415.7	379.8	325.5	80.0	10.9	−51.0	−75.5	258.2	76.8	10.6
10 export sr91	20.4	20.4	21.9	16.7	19.9	16.0	14.8	11.9	16.4	17.4
11 balance after sr91	395.3	359.4	303.6	63.4	−9.0	−67.0	−90.4	246.3	60.3	−6.8
12 input lr92	107.0	77.3	78.3	0.0	0.0	0.0	0.0	107.2	0.0	0.0
13 bal. before ex. lr 92	502.3	436.7	381.9	63.4	−9.0	−67.0	−90.4	353.5	60.3	−6.8
14 export lr92	25.6	29.9	32.8	36.9	32.0	32.2	32.7	41.9	30.4	35.6
15 balance after lr92	476.7	406.8	349.0	26.5	−41.0	−99.2	−123.1	311.6	30.0	−42.4

b. Phosphorus budget (kg ha^{-1}) for experiment 2, based on tree leaf inputs (1988–1992) and maize crop removals (1990–1992)

	CC1	CC2	CC3	SS4	SS5	SS6	SG7	CS8	CSI9	CS10
1 input phase 1 + sr90	26.6	27.7	25.9	14.7	8.6	1.7	0.0	17.7	13.5	7.7
2 export sr90	14.3	14.7	15.5	11.3	11.1	7.0	7.1	12.1	12.8	12.7
3 balance after sr90	12.3	13.0	10.4	3.4	−2.5	−5.2	−7.1	5.6	0.7	−4.9
4 input lr91	9.1	7.1	6.0	0.0	0.0	0.0	0.0	9.8	3.8	3.2
5 bal. before ex. lr91	21.5	20.1	16.4	3.4	−2.5	−5.2	−7.1	15.4	4.5	−1.8
6 export lr91	8.0	8.1	9.3	8.8	7.9	7.4	7.7	7.6	8.0	7.9
7 balance after lr91	13.48	12.03	7.09	−5.41	−10.38	−12.59	−14.84	7.86	−3.57	−9.69
8 input sr91	6.05	4.40	3.89	0.00	0.00	0.00	0.00	6.48	0.03	0.02
9 bal. before ex. sr91	19.52	16.43	10.98	−5.41	−10.38	−12.59	−14.84	14.34	−3.54	−9.67
110 export sr91	4.4	4.4	4.7	3.6	4.3	3.5	3.2	2.7	3.6	3.8
11 balance after sr91	15.1	12.0	6.3	−9.0	−14.6	−16.1	−18.1	11.7	−7.1	−13.5
12 input lr92	8.5	6.1	6.2	0.0	0.0	0.0	0.0	10.2	0.0	0.0
13 bal. before ex. lr 92	23.6	18.1	12.5	−9.0	−14.6	−16.1	−18.1	21.8	−7.1	−13.5
14 export lr92	5.1	5.9	6.4	7.2	6.3	6.3	6.4	8.1	5.9	6.9
15 balance after lr92	18.5	12.2	6.1	−16.2	−20.9	−22.4	−24.5	13.7	−13.0	−20.4

c. Potassium budget (kg ha^{-1}) for experiment 2, based on tree leaf inputs (1988–1992) and maize crop removals (1990–1992)

	CC1	CC2	CC3	SS4	SS5	SS6	SG7	CS8	CSI9	CS10
1 input phase 1 + sr90	116.3	121.2	113.0	83.8	49.0	9.9	0.0	88.0	67.0	38.5
2 export sr90	41.9	41.9	43.8	33.0	32.2	20.6	21.5	34.4	37.8	37.6
3 balance after sr90	75.2	79.3	69.2	50.8	16.7	−10.6	−21.5	53.7	29.2	0.9
4 input lr91	39.9	31.0	26.1	0.0	0.0	0.0	0.0	48.6	18.9	15.7
5 bal. before ex. lr91	115.1	110.3	95.3	50.8	16.7	−10.6	−21.5	102.3	48.1	16.6
6 export lr91	21.9	21.7	25.2	3.3	22.6	20.7	20.8	20.8	21.9	21.4
7 balance after lr91	93.2	88.7	70.1	27.5	−5.9	−31.4	−42.3	81.5	26.3	−4.8
8 input sr91	26.4	19.2	17.0	0.0	0.0	0.0	0.0	32.2	0.1	0.1
9 bal. before ex. sr91	119.7	107.9	87.1	27.5	−5.9	−31.4	−42.3	113.7	26.4	−4.8
10 export sr91	15.2	15.5	16.1	12.9	14.7	12.9	11.7	10.1	12.8	13.7
11 balance after sr91	104.4	92.4	71.0	14.5	−20.6	−44.3	−54.0	103.5	13.6	−18.5
12 input lr92	36.9	26.7	27.0	0.0	0.0	0.0	0.0	50.4	0.0	0.0
13 bal. before ex. lr92	141.4	119.1	98.0	14.5	−20.6	−44.3	−54.0	153.9	13.6	−18.5
14 export lr92	14.7	17.0	17.8	20.0	18.0	17.8	17.8	22.3	16.2	19.5
15 balance after lr92	126.7	102.1	80.2	−5.4	−38.6	−62.1	−71.8	131.6	−2.6	−38.0

Legend: see Table 14.

was also taken into account. A simple regression equation of the form $Y = a + bX$ was used to test whether crop yield Y (grain, stover or total crop yield) was related to tree leaf biomass X (tree leaves applied; or tree leaves applied minus wood removed). In second instance, leaf biomass applied was converted to the N, P or K equivalents for each treatment and the effect of this recalculation on the predictive ability of the regression equations was tested. Because different species have different leaf nutrient concentrations and decomposition characteristics, separate analysis were carried out for both experiments, and for each species within an experiment. Finally, an analysis for all species combined was carried out to test how much of the predictive ability of this relationship was lost by combining a collection of tree species with widely differing leaf qualities.

In Table 17, regression equations for experiment 1 are tabulated. In step 1, *Leucaena* and *Gliricidia* were first analysed separately. Species specific regression equations are based on only 6 pairs of leaf yield and crop yield observations. The relationship between the amount of mulch applied and the amount of crop yield obtained is in both species positive, but r^2 values are higher in *Leucaena* than in *Gliricidia*. For the *Leucaena* model, r^2 values for first season yields increased significantly, from 0.55 to 0.92, if a separate predictor term was added to account for potential nutrient exports in the wood component. Upto 77% of the variation in crop yields could be accounted for, when cumulative (1990–1992) maize yields were regressed on *Leucaena* leaf inputs ($p < 0.05$). In the case of *Gliricidia*, between 50% ($p = 0.11$) and 68% ($p = 0.04$) of the variation in cumulative grain and stover yields could be described. When the datasets for *Leucaena* and *Gliricidia* were combined ($n = 12$), the amount of variation in crop yields that could be described ranged from 72 to 93%, depending on which (combination of) predictor variable(s) and response variables were chosen, with the majority of the r^2 values lying between 75 and 85% ($p = 0.000$). The amount of variation described was in general higher for cumulative maize grain than for cumulative maize stover, suggesting that the positive effects of mulch are more directly translated in gains in grain yield than stover yield (Table 17). The amount of variation described by the model that used leaf yield as the sole predictor did not decline significantly over time, suggesting that leaf applications were an effective means of increasing crop yields throughout phase 2 (1990–1992) and that the positive effect of applying tree leaves was not entirely cancelled by large nutrient export as a result of the first crop harvest, or increased below ground competition between trees and crops. The r^2 values for the first cropping season of the combined *Leucaena–Gliricidia* model increased by 11% when a separate term was added to account for the removals in the wood component.

Table 16
Average N, P and K nutrient concentration of leaves of *Leucaena* (LL, LC) *Gliricidia* (GS), *Calliandra* (CC), *Sesbania* (SS) and *Cassia* (CSp, CSi) species, applied as mulch between 1988 and 1992 (expressed as % of dry matter)

Species code:	LL	LC	GS	CC	SS	CSp	CSi
N	3.56	3.56	3.57	3.42	3.49	2.85	2.85
P	0.27	0.27	0.28	0.27	0.28	0.27	0.27
K	1.64	1.64	2.10	1.18	1.60	1.34	1.34

In Table 18, similar regression equations, r^2 values and their significance levels are given for experiment 2. A constraint in experiment 2 for carrying out species by species regression analysis is, that the number of pairs of leaf yield and maize yield observations is very low; *Calliandra* ($n = 3$), *Cassia* ($n = 3$) and *Sesbania* ($n = 4$). Therefore, significant correlations and meaningful regression equations between tree leaf inputs and maize yield outputs would only be expected if there was a very strong relation between inputs and outputs and if leaf production and maize yield data points were adequately spaced. In *Calliandra*, the "b-term" in all equations was negative, suggesting that the effect of tree mulch or just the presence of this species on crop yields might possibly be negative. The p values of the three regression equations that describe cumulative maize yields from *Calliandra* leaf inputs are not significant ($p > 0.05$). In *Sesbania*, strongly positive correlations were found between tree leaf inputs and crop outputs, both for the first season and for the cumulative yield of four successive seasons. In *Cassia*, the values of the "b-term", i.e. the contributions of leaf mulch to maize yield changes, were generally much smaller (close to zero) than those observed in any

Table 17

Experiment 1: Regression equations of the form: $Y = a + bX - cZ$, to predict maize yields (Y) from *Leucaena* and *Gliricidia* tree leaf applications (X), and wood removals (Z) with their respective coefficients of determination (r^2) and significance levels (p values)

Regression equation	r^2	p
Experiment 1: *Leucaena leucocephala* and *L. collinsii* ($n = 6$)		
$Y_{\mathrm{grsr90}} = 3.15 + 0.21 X_{\mathrm{I}}$	59.2	0.074
$Y_{\mathrm{stsr90}} = 3.58 + 0.17 X_{\mathrm{I}}$	52.8	0.102
$Y_{\mathrm{allsr90}} = 6.73 + 0.38 X_{\mathrm{I}}$	56.4	0.085
$Y_{\mathrm{grsr90}} = 1.49 + 0.81 X_{\mathrm{I}} - 0.22 Z_{\mathrm{I}}$	90.5	0.029
$Y_{\mathrm{stsr90}} = 1.93 + 0.78 X_{\mathrm{I}} - 0.22 Z_{\mathrm{I}}$	94.0	0.015
$Y_{\mathrm{allsr90}} = 3.42 + 1.59 X_{\mathrm{I}} - 0.43 Z_{\mathrm{I}}$	92.4	0.021
$Y_{\mathrm{gr4s}} = 5.85 + 0.40 X_{\mathrm{I/II}}$	76.6	0.022
$Y_{\mathrm{st4s}} = 7.37 + 0.28 X_{\mathrm{I/II}}$	76.6	0.022
$Y_{\mathrm{all4s}} = 13.2 + 0.68 X_{\mathrm{I/II}}$	77.3	0.021
Experiment 1: *Gliricidia sepium* ($n = 6$)		
$Y_{\mathrm{grsr90}} = 2.01 + 0.29 X_{\mathrm{I}}$	46.1	0.138
$Y_{\mathrm{stsr90}} = 3.16 + 0.19 X_{\mathrm{I}}$	32.7	0.236
$Y_{\mathrm{allsr90}} = 5.18 + 0.48 X_{\mathrm{I}}$	42.2	0.162
$Y_{\mathrm{grsr90}} = 2.13 + 0.20 X_{\mathrm{I}} + 0.03 Z_{\mathrm{I}}$	46.4	0.393
$Y_{\mathrm{stsr90}} = 2.48 + 0.70 X_{\mathrm{I}} - 0.16 Z_{\mathrm{I}}$	48.4	0.371
$Y_{\mathrm{allsr90}} = 4.61 + 0.90 X_{\mathrm{I}} - 0.13 Z_{\mathrm{I}}$	44.4	0.415
$Y_{\mathrm{gr4s}} = 4.00 + 0.56 X_{\mathrm{I/II}}$	50.4	0.114
$Y_{\mathrm{st4s}} = 6.22 + 0.47 X_{\mathrm{I/II}}$	68.2	0.043
$Y_{\mathrm{all4s}} = 10.2 + 1.02 X_{\mathrm{I/II}}$	59.3	0.073
Leucaena and *Gliricidia* combined ($n = 12$)		
$Y_{\mathrm{grsr90}} = 2.15 + 0.35 X_{\mathrm{I}}$	83.1	0.000
$Y_{\mathrm{stsr90}} = 3.18 + 0.24 X_{\mathrm{I}}$	76.8	0.000
$Y_{\mathrm{allsr90}} = 5.33 + 0.59 X_{\mathrm{I}}$	81.2	0.000
$Y_{\mathrm{grsr90}} = 1.88 + 0.70 X_{\mathrm{I}} - 0.20 Z_{\mathrm{I}}$	93.3	0.000
$Y_{\mathrm{stsr90}} = 2.98 + 0.50 X_{\mathrm{I}} - 0.15 Z_{\mathrm{I}}$	88.8	0.000
$Y_{\mathrm{allsr90}} = 4.86 + 1.20 X_{\mathrm{I}} - 0.35 Z_{\mathrm{I}}$	92.2	0.000
$Y_{\mathrm{gr4s}} = 6.35 + 0.66 X_{\mathrm{I}}$	77.7	0.000
$Y_{\mathrm{st4s}} = 8.85 + 0.36 X_{\mathrm{I}}$	62.5	0.002
$Y_{\mathrm{all4s}} = 15.2 + 1.02 X_{\mathrm{I}}$	73.7	0.000
$Y_{\mathrm{gr4s}} = 5.17 + 0.44 X_{\mathrm{I/II}}$	80.0	0.000
$Y_{\mathrm{st4s}} = 8.05 + 0.25 X_{\mathrm{I/II}}$	71.6	0.000
$Y_{\mathrm{all4s}} = 13.2 + 0.69 X_{\mathrm{I/II}}$	78.8	0.000

Predictors:

X_{I}; leaf biomass of phase 1 (applied between October 1988 and July 1990)

$X_{\mathrm{I/II}}$; leaf biomass of phase 1 and 2 (applied between October 1988 and August 1992)

Z_{I}; wood component (removed between October 1988 and July 1990)

Responses:

Y_{grsr90}; grain yield short rains 1990

Y_{stsr90}; stover yield short rains 1990

Y_{allsr90}; total yield short rains 1990

Y_{gr4s}; cumulative grain yield of all four seasons

Table 17 (continued)

Y_{st4s}; cumulative stover yield of four all seasons

Y_{all4s}; cumulative total yield of four all seasons

All equations are based on tree and crop yields, expressed in dry matter (t ha^{-1}); ($n = 6$; *Leucaena* and *Gliricidia* analysed separately). The a, b and c terms have, where applicable, been rounded to 2 decimal places.

other species, suggesting that *Cassia* leaves had a much smaller effect in either enhancing or inhibiting crop yields that leaves of *Leucaena, Gliricidia, Calliandra* or *Sesbania*. A combined model for experiment 2 with *Calliandra, Sesbania* and *Cassia* ($n = 10$) described maize grain yields to a similar extent as comparable models for experiment 1 during the first cropping season ($r^2 = 0.86$). Stover yields were not correlated to tree leaf applications as closely as grain yields ($r^2 = 0.64$).

A combined analysis for all species was also carried out because there are situations where a preliminary indication is required of the approximate effect of the mulch of a wider range of tree species on crop yields (Table 19). Variation in grain yields in the first season was accounted for to a large extent by leaf inputs ($r^2 = 0.84$; $p = 0.000$). Stover yields were less well described ($r^2 = 0.64$; $p = 0.000$). The "b-term" in the overall regression equation, which can be seen as a measure of the average effectiveness of tree leaves to enhance crop yields, was 0.28 for grain and 0.21 for stover respectively. Four years of leaf applications from a variety of tree species and provenances could account for 61% of the variation in total grain yields and 51% of variation in total stover yields (Table 19). Because the "b-term" in the regression equations for *Calliandra* was shown to be possibly negative and b was very small in the case of *Senna*, it was decided to carry out further regression analysis whereby either *Calliandra* or *Senna* or both species were removed from the dataset. Removing *Calliandra* or *Senna* separately increased the r^2 values for grain from 61 to 68 and 66% respectively. Stover r^2 values increased from 51 to 66 and 61% respectively. When *Calliandra* or *Senna* were removed simultaneously, grain and stover r^2 values increased markedly to 76 and 84% respectively ($p = 0.000$), suggesting that grouping the data for *Leucaena, Gliricidia* and *Sesbania* is justified, possibly because the nutrient contents of their leaves is comparable, whereas the leaves of *Calliandra* and *Senna* clearly seem to have a different effect on crop yields. In addition, there is increasing evidence that *Calliandra* is too competitive (below ground) for hedgerow intercropping (Hairiah et al., 1989; Heineman, 1996).

Regressions equations, based on the N, P and K contents of each leaf type were also developed. For N and P, the fit of the relationship between inputs and outputs did not change significantly in experiment 1 (Table 19). This result was expected, considering that *Leucaena* and *Gliricidia* have comparable N and P contents in their leaves. When tree leaf biomass was expressed as K, the r^2 value for predicting cumulative grain yields declined from 80.0 to 73.2% and the r^2 value for predicting cumulative stover yield increased from 71.6 to 77.4%, confirming that K is stored in a higher proportion in the exported stover than in the exported grain. In experiment 2, converting each tree leaf type to its N, P or K equivalent did not improve the fit of the combined regression models although the species used in this experiment varied significantly in N and K contents (Table 19). This may provide some additional evidence that factors other than leaf N, P and K contents influenced the effectiveness of the mulch of *Calliandra* and *Senna* in supplying nutrients to intercropped maize. Therefore, factors other than the effect of leaf mulch may have to be taken in to account for *C. calothyrsus*.

3.4. Soils

Coefficients of variation for soil analytical data can be fairly high as a result of micro site variation in soil properties, even if all analytical procedures are carried out properly. When the analysis is based on a relatively limited number of sub-samples from each treatment, this can increase the cv values further. Against this background, cv values higher than 20% were only calculated in the case of P and S. For all other soil properties (7 out of 9), the cv values were below 20%, suggesting that these experiments were carried out on a relatively uniform site and that laboratory procedures, necessary to obtain analytical results with acceptable precision, were adhered to.

Table 18

Experiment 2: Regression equations of the form: $Y = a + bX - cZ$, to predict maize yields (Y) from *Calliandra, Sesbania* and *Senna (Cassia)* tree leaf applications (X), and wood removals (Z) with their respective coefficients of determination (r^2) and significance levels (p values)

Experiment 2: *Calliandra calothyrsus* ($n = 3$)

Regression equation	r^2	p
$Y_{\mathrm{grsr90}} = 8.18 - 0.33X_{\mathrm{I}}$	18.8	0.715
$Y_{\mathrm{stsr90}} = 6.27 - 0.21X_{\mathrm{I}}$	91.4	0.190
$Y_{\mathrm{allsr90}} = 14.4 - 0.54X_{\mathrm{I}}$	34.0	0.603
$Y_{\mathrm{gr4s}} = 19.9 - 0.54X_{\mathrm{I/II}}$	94.0	0.158
$Y_{\mathrm{st4s}} = 13.0 - 0.17X_{\mathrm{I/II}}$	78.9	0.304
$Y_{\mathrm{all4s}} = 32.8 - 0.71X_{\mathrm{I/II}}$	90.9	0.196
Experiment 2: *Sesbania sesban* and *S. grandiflora* ($n = 4$)		
$Y_{\mathrm{grsr90}} = 2.12 + 0.32X_{\mathrm{I}}$	86.1	0.072
$Y_{\mathrm{stsr90}} = 2.32 + 0.25X_{\mathrm{I}}$	85.9	0.073
$Y_{\mathrm{allsr90}} = 4.44 + 0.56X_{\mathrm{I}}$	86.9	0.068
$Y_{\mathrm{grsr90}} = 1.95 - 0.13X_{\mathrm{I}} + 0.15Z_{\mathrm{I}}$	97.4	0.163
$Y_{\mathrm{stsr90}} = 2.24 + 0.04X_{\mathrm{I}} + 0.07Z_{\mathrm{I}}$	89.9	0.317
$Y_{\mathrm{allsr90}} = 4.19 - 0.10X_{\mathrm{I}} + 0.22Z_{\mathrm{I}}$	94.6	0.232
$Y_{\mathrm{gr4s}} = 7.38 + 0.50X_{\mathrm{I/II}}$	95.2	0.025
$Y_{\mathrm{st4s}} = 7.82 + 0.33X_{\mathrm{I/II}}$	72.4	0.149
$Y_{\mathrm{all4s}} = 15.2 + 0.83X_{\mathrm{I/II}}$	91.4	0.044
Experiment 2: *Cassia spectabilis* and *C. siamea* ($n = 3$)		
$Y_{\mathrm{grsr90}} = 3.76 + 0.04X_{\mathrm{I}}$	96.3	0.123
$Y_{\mathrm{stsr90}} = 4.73 - 0.19X_{\mathrm{I}}$	73.9	0.342
$Y_{\mathrm{allsr90}} = 8.49 - 0.14X_{\mathrm{I}}$	58.8	0.444
$Y_{\mathrm{gr4s}} = 9.61 + 0.02X_{\mathrm{I/II}}$	48.0	0.513
$Y_{\mathrm{st4s}} = 9.94 - 0.07X_{\mathrm{I/II}}$	85.9	0.245
$Y_{\mathrm{all4s}} = 19.5 - 0.05X_{\mathrm{I/II}}$	54.1	0.474
Calliandra, Sesbania and *Cassia* combined ($n = 10$)		
$Y_{\mathrm{grsr90}} = 2.44 + 0.27X_{\mathrm{I}}$	86.1	0.000
$Y_{\mathrm{stsr90}} = 2.73 + 0.17X_{\mathrm{I}}$	63.5	< 0.01
$Y_{\mathrm{allsr90}} = 5.16 + 0.44X_{\mathrm{I}}$	78.8	0.000
$Y_{\mathrm{grsr90}} = 2.44 + 0.32X_{\mathrm{I}} - 0.01Z_{\mathrm{I}}$	86.2	0.001
$Y_{\mathrm{stsr90}} = 2.75 + 0.30X_{\mathrm{I}} - 0.04Z_{\mathrm{I}}$	64.9	< 0.05
$Y_{\mathrm{allsr90}} = 5.19 + 0.61X_{\mathrm{I}} - 0.05Z_{\mathrm{I}}$	79.2	< 0.01
$Y_{\mathrm{gr4s}} = 7.97 + 0.30X_{\mathrm{I}}$	75.0	0.000
$Y_{\mathrm{st4s}} = 8.26 + 0.18X_{\mathrm{I}}$	60.0	0.008
$Y_{\mathrm{all4s}} = 16.2 + 0.48X_{\mathrm{I}}$	72.4	0.000
$Y_{\mathrm{gr4s}} = 8.38 + 0.14X_{\mathrm{I/II}}$	58.4	0.01
$Y_{\mathrm{st4s}} = 8.57 + 0.08X_{\mathrm{I/II}}$	40.0	0.05
$Y_{\mathrm{all4s}} = 16.9 + 0.21X_{\mathrm{I/II}}$	53.1	< 0.05

All equations are based on tree and crop yields, expressed in dry matter (t ha^{-1}); ($n = 3,4$ or 3, depending on species). The a, b and c terms have, where applicable, been rounded to 2 decimal places. For predictors and responses see Table 17.

Note: due to the very small value of n in the case of *Calliandra calothyrsus* and *Cassia* spp., it is not possible to calculate the effect of adding a term for "wood removed", because there are not enough degrees of freedom for a multiple regression analysis.

Table 19

Coefficients of determination (r^2) and significance levels (p) for regression equations to predict first season and total (cumulative 1990–1992) maize yields from first season and total (cumulative 1988–1992) biomass, and from the amount of nitrogen (N), phosphorus (P) and potassium (K), in the leaves of *Leucaena*, *Gliricidia*, *Calliandra*, *Sesbania* and *Senna* (*Cassia*) species, when applied as mulch to maize intercrops

Yield component	Predictor	Experiment 1 (4 seasons)		Experiment 2 (4 seasons)		Experiment 1 and 2 combined; grain 1 season and leaf phase 1(a); grain 4 seasons and leaf phase 1(b); grain 4 seasons and leaf phase 1 and 2(c)					
		r^2	p	r^2	p	r^2(a)	p (a)	r^2(b)	p (b)	r^2(c)	p (c)
Grain	Biomass	80.0	0.000	58.4	0.010	84.1	0.000	68.9	0.000	60.6	0.000
Grain	N	80.0	0.000	59.3	0.009	81.9	0.000	69.5	0.000	63.9	0.000
Grain	P	79.8	0.000	57.3	0.011	83.6	0.000	69.1	0.000	58.7	0.000
Grain	K	73.2	0.000	59.0	0.009	71.8	0.000	74.9	0.000	57.9	0.000
Stover	Biomass	71.6	0.000	40.0	0.050	63.6	0.000	49.2	0.000	51.4	0.000
Stover	N	70.2	0.000	44.2	0.036	65.7	0.000	53.3	0.000	57.5	0.000
Stover	P	73.1	0.000	37.7	0.059	63.8	0.000	50.1	0.000	50.1	0.000
Stover	K	77.4	0.000	38.1	0.057	76.5	0.000	73.7	0.000	70.8	0.000
Total	Biomass	78.8	0.000	53.1	0.017	78.9	0.000	63.7	0.000	60.0	0.000
Total	N	78.3	0.000	55.7	0.013	78.8	0.000	66.1	0.000	64.8	0.000
Total	P	79.3	0.000	51.4	0.020	78.7	0.000	64.3	0.000	58.3	0.000
Total	K	76.8	0.000	52.6	0.018	78.5	0.000	78.9	0.000	67.2	0.000

For experiment 1 $n = 12$, $n = 10$ for experiment 2, $n = 22$ for the combined analysis, all calculations are based on t ha^{-1} dry matter for inputs (tree leaves or their nutrient equivalents) and outputs (maize grain, maize stover and total yield).

Table 20

Mean values of selected soil chemical parameters in experiment 1, based on analysing one composite sample per plot, collected in August 1990 from the top 20 cm of the profile

Element unit	pH	N (%)	C (%)	C:N	P (ppm)	K (m.e.%)	Ca (m.e.%)	Mg (m.e.%)	S (ppm)
LL1	3.83	0.23	1.85	8.18	8.67	0.63	3.10	2.00	31.4
LL2	3.73	0.24	1.92	8.02	6.00	0.63	2.70	1.88	28.7
LL3	3.77	0.22	2.04	9.15	7.33	0.60	2.50	1.91	28.4
LL4	3.80	0.19	1.99	10.3	7.33	0.63	2.77	1.80	26.5
LL5	3.87	0.21	1.88	8.80	6.00	0.53	2.60	1.65	30.6
LC6	3.97	0.18	1.78	10.54	4.33	0.33	2.30	1.33	26.1
Mean for *Leucaena*	3.83	0.21	1.91	9.17	6.61	0.56	2.66	1.76	28.6
GS7	4.17	0.19	2.09	11.33	9.83	0.50	2.97	1.68	30.1
GS8	4.10	0.18	1.90	10.42	10.17	0.47	2.83	1.54	30.3
GS9	4.10	0.19	2.09	12.0	15.83	0.47	2.97	1.77	33.7
GS10	4.20	0.20	1.99	9.88	5.17	0.57	3.13	1.91	26.5
GS11	4.10	0.19	1.99	10.48	11.00	0.47	2.83	1.72	25.7
GS12	4.17	0.18	2.15	11.79	6.50	0.50	3.20	1.92	25.3
Mean for *Gliricidia*	4.14	0.18	2.04	10.98	9.75	0.50	2.99	1.76	28.6
Mean for Exp. 1	3.98	0.20	1.97	10.07	8.18	0.53	2.83	1.76	28.6
sed	0.114	0.022	0.128	1.69	2.64	0.077	0.26	0.13	5.50
p [1]	<.001	0.15	0.20	0.33	0.016	0.02	0.06	0.003	0.90
cv [2] (%)	3.5	13.4	8.0	20.5	39.4	17.9	11.2	9.3	23.5

[1] p value: level of statistical significance.

[2] cv value: coefficient of variation of plot level.

3.4.1. Experiment 1

Table 20 shows that there were significant differences for the soil properties pH, P, K and Mg approximately two years after the trees were planted. The topsoil was more acid under *Leucaena* treatments ($p < .001$). Although not statistically significant, total soil N appeared to be higher under *Leucaena* than under *Gliricidia*, with the exception of LC6, which received relatively little leaf biomass in phase 1. Soil C levels did not differ significantly between treatments. However, it is observed that LC6 again showed a relatively low figure. Soil P levels were on average higher under *Gliricidia* than under *Leucaena* ($p = 0.016$). At low mulch application rates, there was significantly less P in LC6 than in 4 out of 6 *Gliricidia* treatments. Levels of soil P were also more uniform under *Leucaena* than under *Gliricidia*. Soil K levels differed significantly between treatments ($p = 0.02$). With the exception of LC6, soil K levels were mostly higher under *Leucaena* than under *Gliricidia*. Soil K levels under LC6 were nearly 40% lower than the average level the experiment. Although soil Ca levels were not significantly different ($p = 0.06$), they were on average slightly lower under *Leucaena* than under *Gliricidia* and the lowest value was found under LC6. Soil Mg levels varied significantly ($p = 0.003$). They were 25% lower under LC6 than the experimental mean. Between *L. leucocephala* treatments and *Gliricidia* treatments, differences were sometimes statistically significant but in general more limited. Sulphur (S) levels in the soil did not differ between treatments.

3.4.2. Experiment 2

Table 21 shows that there were significant differences for the soil properties pH, N, K, Ca and Mg approximately 2 years after tree establishment. Although soil acidity (pH) varied significantly ($p = 0.008$), the differences were small (4.13–4.27) and probably not of agronomic significance. Much less variation in pH was found than in experiment 1. There was no clear pattern in pH increase or decrease, related to species. However, the lowest pH value (4.13) was found in treatment SG7, the control treatment. Total soil N levels varied between 0.18

Table 21
Mean values of selected soil chemical parameters in experiment 2

Element unit	pH	N (%)	C (%)	C:N	P (ppm)	K (m.e,%)	Ca (m.e.%)	Mg (m.e.%)	S (ppm)
CC1	4.27	0.18	1.45	7.96	5.76	0.57	3.37	1.83	23.0
CC2	4.17	0.18	1.86	10.86	4.83	0.47	3.40	1.59	25.7
CC3	4.27	0.23	1.72	7.65	7.83	0.60	3.53	1.85	21.1
Mean for *Calliandra*	4.24	0.20	1.68	8.82	6.14	0.55	3.43	1.76	23.3
SS4	4.27	0.25	1.84	7.38	6.67	0.57	3.57	1.58	35.7
SS5	4.20	0.23	1.59	6.83	5.33	0.57	3.27	1.41	21.8
SS6	4.17	0.22	1.39	6.41	7.33	0.40	2.53	1.41	26.1
Mean for *Sesbania*	4.21	0.23	1.61	6.87	6.44	0.51	3.12	1.47	27.9
SG7	4.13	0.21	1.53	7.61	4.67	0.43	2.23	1.30	22.2
CSp8	4.20	0.21	1.76	8.39	5.00	0.40	2.50	1.36	13.8
CSi9	4.13	0.20	1.71	8.56	5.00	0.43	2.53	1.23	24.5
CSi10	4.17	0.27	1.75	6.80	4.33	0.53	2.73	1.27	23.0
Mean for *Senna*	4.17	0.23	1.74	7.91	4.78	0.45	2.59	1.29	20.4
Mean for Exp. 2	4.20	0.22	1.66	7.85	5.67	0.50	2.97	1.49	23.7
sed	0.039	0.02	0.162	1.11	1.53	0.068	0.28	0.111	5.34
p [1]	0.008	0.008	0.11	0.041	0.34	0.041	< 0.001	< 0.001	0.091
cv [2] (%)	1.1	11.6	12.0	17.3	33.1	16.8	11.6	9.1	27.6

Data based on analysing one composite sample per plot, collected in August 1990 from the top 20 cm of the profile.

1. p value: level of statistical significance.
2. cv value: coefficient of variation at plot level.

and 0.23% ($p = 0.008$). Below average values were detected in soils associated with *Calliandra* and above average values were detected under *S. sesban*. Soil C and soil P levels did not differ significantly between treatments. Soil K levels varied between 0.40 and 0.60 m.e.% ($p = 0.041$). They were on average higher under *Calliandra* and *S. sesban* than under *Senna* and SG7. A similar pattern was seen in Ca and Mg. Differences were highly significant ($p < 0.001$). Above average values for Ca and Mg were detected in soils under *Calliandra* and the most productive *S. sesban* accession (SS4). Under SS6, SG7 and under *Senna*, Ca and Mg values were markedly reduced. Soil sulphur (S) levels did not differ significantly between any of the 10 treatments, but a rather large range of values was detected (13.8–35.7 ppm).

Comparing the results of soil analysis in experiment 1 and 2, it is noted that, on average, soil C was 16% lower in experiment 2 than in experiment 1. Mean P levels were 30% lower in experiment 2. There was more variation in Ca and Mg values in experiment 2. The results for SG7 show that not applying any form of (*Calliandra, Sesbania* or *Senna*) mulch during the two year fallow period may lead to a relative decline in most soil chemical properties in the topsoil profile, even before cropping took place. The reduced soil N levels under *Calliandra* may have been caused by net N immobilisation, while the large quantities of mulch decomposed slowly.

3.5. Relationships between mulch applications, soil chemical properties and crop yields

The effect of initial mulch applications in phase 1 on soil properties, measured immediately after the termination of the tree fallow in August 1990, were calculated for each species in experiment 1 and 2 separately (Table 22). In all cases, the question was, whether adding varying amounts of a particular mulch type had significantly changed soil chemical properties, compared to not adding any mulch in phase 1, as was the practice in treatment SG7 in experiment 2.

In experiment 1, two years of mulch application was effective in changing soil pH, N, K and Mg. When both species were combined for mulch input and their effect on each soil property was tested separately, significant positive correlation were found with the following r^2 values and p values: pH (0.76; 0.000), N (0.45; 0.013) and K (0.70; 0.000). After these preliminary investigations, the effect of applying varying amounts of each mulch type

Table 22
Values of a (intercept), b (slope), r^2 (coefficient of determination) and p (significance level) for regression equations, that describe: (i) relationships between amount of tree leaves applied and soil fertility status of selected soil nutrient elements, and (ii) soil fertility status of selected soil nutrient elements and maize grain yields in the first season after the tree fallow ended

Experiment 1: *Leucaena* plus SG7 in experiment 2 as control ($n = 7$)[1]

Soil element	a	b	r^2	p
pH	4.11	−0.03	95	0.000
C	1.59	0.03	81	0.006
P	4.16	0.27	62	0.040
K	0.36	0.02	78	0.009
Ca	2.19	0.05	62	0.040
Mg	1.22	0.06	89	0.001
S	23.5	0.53	58	0.045
Experiment 1: *Gliricidia* plus SG7 in experiment 2 as control ($n = 7$)				
C	1.6	1.02	83	0.004
Ca	2.29	0.16	91	0.001
Mg	1.29	0.11	94	0.000
Experiment 2: *Calliandra* plus SG7 in experiment 2 as control ($n = 4$)				
Ca	2.24	0.12	97	0.013
Experiment 2: *Sesbania* plus SG7 in experiment 2 as control ($n = 4$)				
pH	4.14	0.023	97	0.02
N	0.21	0.008	99	0.006
Experiment 1: *Leucaena* plus SG7 in experiment 2 as control ($n = 7$)[2]				
pH	38.2	−8.7	76	0.01
C	−8.0	0.8	69	0.02
P	−0.13	70.0	74	0.013
K	−0.64	8.7	56	0.05
Ca	−5.4	[illegible].9	70	0.02
Mg	−2.9	4.5	84	0.004
S	−6.34	0.4	81	0.006

[1] Predictor: leaf input phase 1 (October 1988 to July 1990); response: soil chemical properties in the top 20 cm of the profile in August 1990.

[2] Predictor: soil chemical properties in the top 20 cm of the profile in August 1990; response: maize grain yield in the short rainy season of 1990, immediately after the end of the tree fallow.

(*Leucaena, Gliricidia*) on soil fertility status was tested. For *Leucocephala* and *L. collinsii*, all tested top soil properties, except total soil N, were significantly changed and were dependent on the rate of mulch applied. *Leucaena* mulch lowered the pH, compared to control plots. All other properties were increased. The r^2 values of regression equations that described these relationships ranged from 0.58 to 0.95. Corresponding p values ranged from 0.045 to 0.000. The contribution of *Gliricidia* mulch to changes in the fertility status of the topsoil were not as strong as in *Leucaena, Gliricidia* did not change soil pH or soil N status. However, soil C status was significantly improved under some *Gliricidia* treatments, as well as Ca and Mg.

In experiment 2, two years of mulch application was less effective in changing soil chemical properties by the end of the follow phase. When all species were combined for mulch input and their effect on each soil property was tested separately, a significant positive correlation was found only with soil Mg ($r^2 = 0.56$; $p = 0.013$). In *Calliandra*, a significant correlation between inputs and soil Ca was found ($r^2 = 0.97$; $p = 0.013$). A high r^2 value was also found for Mg, but the relationship was not significant ($p = 0.14$). In *Sesbania*, mulch applications significantly changed soil pH ($p = 0.02$) and soil N ($p = 0.006$). High r^2 values were also found for soil C, soil K and soil Mg, but these relationships were not significant ($p = 0.11$, 0.10 and 0.09 respectively). In *Senna*, no significant relationships between mulch applications and changes in soil fertility indicators were found.

The second question is whether differences in the soil fertility status of the top soil, immediately after the tree fallow phase ended, could be used to predict crop yields in the season(s) that followed. For *Leucaena*, all soil fertility properties were used to develop relationships between grain yields in the first season after the tree fallow and each soil nutrient element individually. Grain yields were negatively correlated with pH ($p = 0.001$), but positively with soil C, P, K, Ca, Mg and S status. When all soil properties were entered in a stepwise, multiple regression analysis, 85% of the variation in maize grain yields could be attributed to differences in soil Mg levels in August 1990 ($p = 0.004$). Adding soil S, N, K and Ca in separate steps accounted for the remaining 15% of the variation in crop yields. Thus, the most powerful relationship between soil fertility status under *Leucaena*, just prior to cropping, and first season maize grain yields, appeared to be for Mg. It is recalled that the relationship between *Leucaena* mulch inputs and soil Mg status was also strongly positive and had one of the highest r^2 values ($r^2 = 89.0$; $p = 0.001$). For *Gliricidia*, again all soil fertility properties were used individually to develop relationships between grain yields in the first season after the tree fallow and the soil nutrient element in question. No significant correlations were found. Only 53% of the variation in grain yields could be explained from differences in soil Mg levels ($p = 0.06$). For experiment 2, no significant relationships were found between the status of a single soil property and maize grain yields in the first cropping season after the fallow, either when all species were combined ($n = 10$) or when the analysis was done for each species separately with the inclusion of SG7 as the control ($n = 4$).

4. Discussion

4.1. Choice of germplasm

In the section on leaf yield in phase 1 (Section 3.1.5), it was shown that the development of leaf yield between planting and 21 months could be described adequately with a single regression equation, resulting in high r^2 values, in the case of *Leucaena* and *Calliandra*, but not so in the case of *Gliricidia, Sesbania* and *Cassia*. The p values were significant in the case of *Leucaena* and *Gliricidia*. However, the poorer predictive ability of the equation for *G. sepium* is due to the fact that the six evaluated provenances varied increasingly in productivity as trees became older. At 21 months, leaf productivity in *Gliricidia* varied by a factor of three, depending on provenance. In *L. leucocephala*, there was only a 30% difference in leaf yield between the least performing (LL5) and best performing accession (LL2) at 21 months after planting. These findings may suggest that the genetic variation in the planting material of *G. sepium* was larger than that of *L. leucocephala*. The *G. sepium* material consisted of taxonomically and genetically distinct provenances, collected in Central America as part of the Central American Dry Zone Hardwoods Programme of the Oxford Forestry Institute. In contrast, the *L. leucocephala* material consisted of seed sources of which only the collection point was known but not necessarily the actual provenance. The five *L. leucocephala* accessions are possibly all based on a few related accessions with a narrow genetic base. The apparent lack of genetic variation could partly explain the comparable growth and yield performance of the five *L. leucocephala* accessions when they were evaluated under a strictly regulated management regime on a uniform site. Although the three regression equations for *Calliandra, Sesbania* and *Cassia* all had significant p values, the poorer predictive ability of the single regression functions for *Sesbania* and *Senna* were due to the fact that different provenances increasingly varied in productivity as trees became older, suggesting that genetically distinct planting material was used for these species. The planting material used for *C. calothyrsus* was genetically probably more uniform.

4.2. The effect of drought on maize yields in the second half of 1991

Considering the sudden, significant, decline in maize yields in the short rains of 1991, it is noted that small, underdeveloped grain cobs and a failure of the plants to complete grain filling is a typical feature of maize, grown under rainfall regimes unsuitably low for the variety in question. The maize variety used in these experiments, Hybrid 512 (Kenya Seed Company) was originally developed for medium altitude areas (5000 ft a.s.l.) with well distributed, bimodal rainfall. It is unsuitable for drier areas. The within-plot variation of grain yield was much higher in the third cropping season (57.6%) than in the previous two seasons (mean = 21%), suggesting that the crop was significantly stressed for moisture and that the potential effects of mulch applications between 1988 and 1991 were not translated effectively into grain yield increases during this season. Thus, the crop may have switched from being largely limited by the availability of nutrients to being limited primarily by low availability of moisture. The fact that grain yields recovered universally in the fourth season, may be due to a surge in nutrient availability upon rewetting of the soil profile, when rains resumed in early 1992.

4.3. Limitations in estimating the size of nutrient reserves and transfers between system components

The main cause for differences in crop yields within and between seasons might be that different treatments recycle widely different amounts of nutrients, as shown for N, P and K in Table 14 a, b, c and Table 15 a, b and c. However, the higher the nutrient status, the higher the grain yields and the higher the nutrient exports. Since the balance of nutrient imports, transfers and exports is difficult to predict, the effect of large nutrient returns is not always as one would expect. Nutrient losses by leaching tend to increase with the size of the pool. Therefore, treatments with large N reserves, like some of the best *L. leucocephala* treatments, might produce crop yields below their expected level if the maize crop is not able to fully capitalize in each season on the large amounts of mulch supplied through tree harvests and hedge management. Unfortunately, comparable budgets for Ca, Mg, S, C and micro nutrients could not be drawn up due to limitations in logistic and analytical capacity. Had these additional budgets been available, perhaps more could have been achieved in identifying a possible (complex of) most limiting nutrient(s).

4.4. The site specific nature of the experimental findings

Looking at the relationships between tree leaf application and crop yields, the results of experiment 1 indicate that, even with datasets of limited size ($n = 6$ to $n = 12$), high r^2 values, based on strongly positive correlations, can be established, which relate the longer term effects of *Leucaena* and *Gliricidia* leaf mulch to cumulative maize yields under the edaphic and climatic conditions, prevailing at this experimental site. The amount of variation in crop yields that can be described with each equation depends on which predictor and response variables are combined in the analysis. However, these regression equations are site specific, valid only for a narrowly defined and carefully executed hedge and crop management regime. Extrapolating these findings to other sites might not necessarily result in similarly high correlations between inputs and outputs. Especially when factors other than nutrients (e.g. water or light) are suspected of strongly limiting crop production, one should not expect to establish similar nutrients based input-output relationships (Akyeampong et al., 1992, Ong, 1995, Howard et al., 1995).

4.5. *Calliandra and Senna: special cases in hedgerow intercropping?*

The failure to establish a clear correlation between *Calliandra* leaf inputs and maize outputs may be due either to the small size of the dataset or *Calliandra* may actually have had a negative effect on crop yields, related to high levels of polyphenols in its leaves and its slow rate of decomposition (Handayanto et al., 1994). More research into the effect of *Calliandra* mulch on crop yields is justified, especially since the species is increasingly seen as an alternative to *Leucaena* (Macqueen, 1994). Experiments, comparable to the ones discussed here, with many more *Calliandra* provenances and with a good spread in leaf productivity and mulching rates, would be needed. In addition, the finding by Hairiah et al. (1989) that *Calliandra* may have a tendency to establish a network of lateral feeder roots at shallow depth (0.5–1.0 m) could explain why maize yields have been lower than expected from a species with such a high leaf production potential. Although the findings of Hairiah et al. (1989) were based on work in Indonesia, Heineman (1996) found similar effects of low maize yields in association with high yielding *Calliandra* in hedgerow intercropping experiments in western Kenya.

In regression equations, linking maize yields with applications of *Senna* leaves, r^2 values were moderate to high, but none of the described patterns had significant p values. This may again be due in part because the number of available data pairs was very limited. Alternatively, the apparent lack of a sizeable positive or negative effect of *Cassia* leaves on crop yields may be partly explained from its much lower N contents. No conclusive statements can be made about its effect on crop yields. A combined model for all species in experiment 2 did not described cumulative crop yields from tree leaf yields as adequately as similar models did for the first season only. The lower r^2 values suggest that factors other than the amount of leaves applied influenced maize yields in the longer term. If *Calliandra* leaves have a negative effect on crop yields and if *Senna* leaves, at the mulching rates used, have a limited effect on crop yields, then this would obviously contribute to a significantly reduced fit for a model that seeks to relate crop yields with tree leaf inputs.

In summary, variation in leaf quality, decomposition and nutrient release characteristics of leaves of *Calliandra* and *Senna* may have confounded the more direct relationship between leaf input and crop output that appears to operate for groups of species and provenances which are similar in nutrient content and decomposition characteristics, like *Leucaena*, *Gliricidia* and *Sesbania*.

4.6. *Soil changes under Leucaena and Gliricidia: a continuum?*

The soil analysis results for experiment 1 suggest that applying varying amounts of tree leaf mulch of comparable quality even for a relatively short period of time can improve soil chemical properties. Compared to applying no mulch (SG7 in experiment 2), applying sufficient amounts of *Leucaena* mulch can influence the most important soil properties positively, but not necessarily total soil N. It was shown that *Leucaena* mulch lowered the pH. Although it is known that leguminous crops in general can cause soil acidification, our observation that only *Leucaena* treatments experienced a significant decline in pH suggests that this effect is either species specific within the Leguminosae or may become only apparent when a minimum mulching rate is reached. The apparent acidifying effect of *Leucaena* mulch did not seem to negatively influence other soil properties. In the absence of applying significant amounts of either *Leucaena* or *Gliricidia* mulch during the two year tree fallow (LC6), virtually all indicators of soil chemical fertility moved towards relatively lower values then when some mulch was applied. The observed increase in soil C in some *Leucaena* treatments may be important, as this demonstrates that high quality tree leaf mulch can contribute to rebuilding the soil organic matter status of impoverished agricultural soils. The increase in soil P status may be important in light of the fact that crop cultivation at this site took place under acid conditions, where P could become unavailable for plant uptake due to aluminium toxicity. The increase in soil Ca and Mg levels shows that, although N fixing trees are preferentially selected for tree fallow and intercropping systems, they might actually make a contribution to maintaining the soil fertility status of other important, possibly limiting, elements. Considering that the N, P and K contents of the leaves of *Leucaena* and *Gliricidia* are comparable, the reason that *Gliricidia* mulch did not seem to influence soil chemical properties as much as *Leucaena* mulch, could be due to the fact that the application rates of *Gliricidia* for all tested provenances were much lower than those of the *L. leucocephala* accessions. *Gliricidia* might have represented the lower end of a range of mulching levels, whereby *Leucaena* application rates were needed to change soil chemical properties significantly.

4.7. The lack of correlation between tree, crop and soil productivity aspects in experiment 2

The number of available data points to calculate correlations between leaf inputs, soil status and crop outputs for individual species in experiment 2 was very limited ($n = 4$). To obtain significant relationships with very small datasets requires high levels of correlation. The amounts of leaf material applied through each species would need to be well spaced, ideally with one low producing provenance, one high producing provenance and one average provenance. The same requirement applies for the soil nutrient values and crop yields. Table 9 shows that this requirement was not met in the case of *Calliandra*, where the three accessions produced comparable amounts of leaf biomass in phase 1. The lack of correlation found for *Senna* could be attributable to the fact that the data for *S. spectabilis* and *S. siamea* had to be combined to obtain the minimum number of degrees of freedom to carry out a regression analysis. Differences in leaf quality between *S. spectabilis* and *S. siamea* may have confounded possible effects on soil fertility status. *Sesbania* leaf quality and decomposition characteristics are comparable with *Leucaena* and *Gliricidia*, rather than with *Calliandra* and *Senna*. It is noted that its mulch influenced more soil properties in a positive direction than *Calliandra* or *Senna* mulch. The limitations in the use of regression analysis results, based on low numbers of independent data pairs, is fully recognized and would in future call for MPTS evaluation experiments with larger numbers of provenance entries for each species.

4.8. Was a single soil nutrient element most limiting to crop growth and yield?

When grain yields in the first season were regressed on individual soil properties for the combined dataset of experiment 1 and 2 ($n = 22$), significant relationships were found for pH ($p = 0.009$), K ($p = 0.003$) and Mg ($p = 0.016$). However, the amount of variation in grain yields that could be explained from differences in each single soil chemical property was very limited ($r^2 = 25–35\%$). Whereas it was possible for some tree species to show the effect of mulch applications on soil fertility status, it proved much more difficult to correlate grain yields in the first season with soil fertility status, directly after the tree fallow. This is understandable if we consider that a relationship between changes in soil properties, caused by differential mulch applications, and subsequent maize yields, is likely to depend on the relative sizes of the soil nutrient pool and the size of the nutrient additions through tree leaf mulch. If the nutrient additions are relatively small compared to the size of the initial soil nutrient pool, then it should be difficult to demonstrate a change in soil properties as a result of mulch additions. Subsequently, showing a relationship between current soil nutrient status and future crop yields will be difficult to achieve. However, if leaf based nutrient additions are substantial compared to the available soil pool, then it might be possible to establish a relationship between nutrient inputs during the tree fallow phase, soil status at the end of this phase and crop outputs in the season(s) that follow the change from tree fallow to intercropping. It is thus possible, but not proven, that maize grown in the soils under experiment 1 and 2 was limited by a complex of nutrients that included Mg and that *Leucaena* mulch was most effective in reducing this limitation by increasing levels of soil Mg and other limiting elements, leading to higher overall nutrient availability for plant uptake. Unfortunately, it was not possible to analyse maize grain and stover samples for their nutrient contents every season for each different treatment separately. This could have provided further evidence in support of the hypothesis that maize yields were controlled by limitations for a specific (complex of) nutrient element(s), and that some tree species were more effective than others in alleviating these specific nutrient limitations to maize.

4.9. Experimental design limitations and opportunities: Are we measuring treatment effects or design artefacts?

A sequential tree fallow intercropping experiment that lasts four years and covers four cropping seasons is by some workers considered a short term experiment. The total time it would take for crop yields in treatment plots to approximate control yields could not be determined in this study. However, the steady decline in maize yields in all treatments suggests that crops were benefiting less from mulch applications as time progressed. Alternatively, it is regularly suggested that crop yields in intercropping experiments decline as root competition from hedges increases over time. This is certainly cause for concern in semi-arid areas, where soil moisture is often the most limiting factor by far to crop growth and yield. However, if hedges are managed periodically and are severely cut back at the start of each season, the danger that tree roots compete for nutrients and water with crops can be significantly reduced under the sub-humid conditions, prevalent in Western Kenya. Every time the hedges are pruned, the root to shoot ratio is suddenly altered and a significant proportion of nutrients re-enters the soil nutrient pool via sloughed off root biomass.

Future experiments, that combine principles of tree fallow and hedgerow intercropping, should preferably have a longer time frame, include more tree species, be based on well documented seed material and incorporate relevant experimental design modifications. These improvements could provide additional information on which trees are suitable for use in agroforestry systems where the production of fuelwood, fodder and building materials in a tree fallow phase is followed by intercropping for food production. Changes in experimental design may include plots with more than one line of trees or square plots with trees planted in blocks. The use of wider border and guard areas around individual plots is nearly always preferable and thus strongly recommended. Context sensitive evidence to suggest that the specific results presented in this paper are based on design artefacts rather than treatment effects could not be produced by the authors.

5. Conclusion

The results presented in this paper provide some evidence that positive effects of MPTS on soils and crops can be demonstrated under certain circumstances. The right tree species must be used and the tree fallow and intercropping phases must be managed primarily to the benefit of the crop. This includes, inter alia, very regular and timely tree and hedge management and placement of tree mulch close to the base of the maize plants, so that the nutrients in the decomposing mulch are located where they have a high chance of being utilized by young maize roots. Proper mulch placement may also have a moisture conserving effect and reduce soil erosion (Kiepe, 1995).

The timing of mulch placement in order to aim for a degree of synchrony between nutrient release and crop uptake is investigated by several agroforestry research groups, but was not included in this study. However, it is hypothesized that, the faster a tree mulch decomposes, the higher the chance that especially N may be lost for crop uptake. Thus, the more important it would be to establish a relationship between the key climatic parameters involved in decomposition, mulch quality characteristics and crop nutrient uptake requirements.

The objectives of this experiment did not allow us to determine which proportion of the nutrient transfer between trees and crops was based on accessing previously unused, deeper soil layers, and which proportion was based on redistributing nutrients that would have been available to the food crop, at some point in time, independent of the presence of trees. If these systems rely only on transferring nutrients from subsoil to topsoil, then the increase in crop yields would be temporary and an element of accelerated nutrient depletion could be associated with them. Lasting positive effects of the trees are more likely to be expected in terms of improved soil structure, due to soil organic matter increase, and protection against soil erosion, provided the experimental lay-out is correctly sited on sloping land. It appears that in the long run, these systems may need the occasional "real" input of mineral nutrients through the use of purchased manures, fertilizers, compost, waste materials, etc.

Perhaps a cycle of two to three years tree fallow, followed by two to three years hedgerow intercropping, might be acceptable to farmers, if judicious tree and hedge management can be guaranteed and if hedge plant populations are such that the minimum amount of mulch will be produced to make an impact on crops and soils. The system then incorporates spatial and sequential elements of agroforestry practices. Crop yields will have to be maintained at levels that compensate for the additional labour, needed to manage these improved systems. Otherwise, it would be very difficult to motivate resource poor farmers to make the extra effort. It would create exaggerated expectations if we suggested that adding trees to cropland would automatically lead to closed, self sustaining food production systems. However, our results show that well managed trees in crop land can make a positive contribution towards the objectives of productivity and sustainability in food crop production. This will remain the major attraction from the users' point of view for reintroducing trees on small farms in the tropics, where food production is the major constraint, and thus the farmer's top priority.

Acknowledgements

The work described in this paper was carried out as part of the Agroforestry Research Network for Africa (AFRENA) programme in East Africa between 1987 and 1992. The directors and staff of ICRAF, KEFRI and KARI are acknowledged with thanks for their invaluable help in facilitating and supporting the work at the Maseno Agroforestry Research Centre in Western Kenya. USAID co-funded the research as part of the ICRAF-AFRENA programme in East Africa. The Dutch Ministry of Foreign Affairs (DGIS) supported the first author financially between 1987 and 1992, while he was on secondment at ICRAF. We are very grateful for the constructive comments received on earlier drafts from Drs. A. Akyeampong, P. Beckett, J. Burley, P. Cooper, M. Hailu, J. Ingram, A. Niang, A. Pottinger, P. Savill, A. Simons and H. Wright and two anonymous referees. Prof. Hüttl and his staff at the Brandenburgische Technische Universität Cottbus are acknowledged for their encouragement to present our work at their conference and support its subsequent publication. This paper has been produced under project R5040 of the Forestry Research Programme (FRP) of the British Overseas Development Administration (ODA).

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0378-1127/97/$17.00

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