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Agronomic and economic appraisal of alley cropping with *Leucaena diversifolia* on an acid soil in the highlands of Burundi

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Abstract. Although alley cropping has been shown elsewhere to permit continuous cropping, it has not been widely tested in the highlands of east and central Africa where it has the additional potential of controlling soil erosion. The effect of four rates (0, 30, 60 and 90 kg N ha^{-1}) of inorganic N on the performance of alley cropping using *Leucaena diversifolia* as the hedgerow species was studied in the central highlands of Burundi. Significant increase in maize yield (average of 26%) due to alley cropping was only first realised in 1992, three years after the commencement of the trial. In 1993, the average yield advantage of the alley cropping plots was 21%. The prunings augmented the response of maize yield to inorganic N in 1992 and 1993. Compared with the control, economic benefits over the five-year period for all the treatments were negative.

Introduction

Population pressure on agricultural land is a recognised problem in many parts of sub-Saharan Africa and the highlands of east and central Africa have some of the highest population densities on the continent. For example, in the central highlands of Burundi, land holding per family is estimated at 0.7 ha [Guinand et al., 1992]. This resulted in the almost total disappearance of fallowing and greatly increased continuous cropping. With little or no soil amendments, soil fertility and consequently crop yields decline. The decline in soil fertility is aggravated by soil erosion caused by hillside cultivation without erosion control measures. Alley cropping, a technology in which hedges of coppiceable trees are grown on contours and managed to produce green manure or mulch for the crops grown in the alley, could improve or maintain soil fertility and the hedges could serve as barriers against soil erosion. In addition to these two main benefits, wood and fodder [Kang et al., 1990] can be obtained from the hedges. Hedges suppress weeds during the non-cropping periods [Yamoah et al., 1986a]. Incorporating fallow periods in alley cropping when animals are allowed to graze the hedges, sustains the livestock and increases yields when cropping is resumed [Atta-Krah, 1990].

Whereas alley cropping has been found to improve yields on relatively fertile Entisols or Alfisols of moderate pH (about 6.0) in the humid lowlands of West Africa [Atta-Krah, 1990; Gichuru and Kang, 1989], on the highly acidic and Al-saturated soils of the highlands of east and central Africa alley cropping has not been extensively tested nor reported on. In what is probably the only published report on alley cropping from the east and central Africa highlands, the effect of alley cropping on crop yields in the highlands of Rwanda could not be determined because the authors did not indicate crop yields on control (no-hedge) plots [Yamoah and Burleigh, 1990].

An underlying principle of alley cropping is that in applying the prunings, atmospherically fixed N and nutrients recycled from deep soil layers by the fast-growing shrubs are supplied as green manure to the food crops. In this way resource-poor farmers can produce some of their food without recourse to usually unavailable and, when available, expensive inorganic fertilisers. Reliance on the prunings of shrubs as the sole source of nutrients, particularly N, for crop production in alley cropping has not always been successful [Yamoah et al., 1986b] because the efficiency of prunings of leucaena as a source of N is low [Kang et al., 1981b; Read et al., 1985] and N supplementation is recommended [Kang et al., 1981b]. In addition to N, P and K are sometimes applied even on the fertile Entisols in alley cropping trials [Atta-Krah, 1990].

Costs and benefits of alley cropping versus conventional cropping are rarely reported. Alley cropping is a technology with high labour requirements for establishing trees, cutting hedges and spreading and incorporating the prunings into the soil. In terms of benefits, the prunings are a source of nutrients and fuelwood or stakes are obtained from the hedges. In their economic analyses of maize production under alley cropping in northern Zambia, it is not clear whether Matthews et al. [1992] considered the added costs of labour or valued the fuelwood harvested. Therefore to obtain indications of the potential of alley cropping in the highlands of Burundi, net returns determined through a partial budget analysis were assessed.

The objectives of the experiment were therefore to (1) compare the yields of crops under conventional and alley cropping, (2) evaluate the effect of external N fertiliser on alley cropping and (3) assess the economic performance of alley cropping compared with conventional (no-hedge) cropping.

Materials and methods

This trial was conducted in Mashitsi, Burundi. Mashitsi is located on longitude 34°51′ E and latitude 3°22′ S. at an elevation of 1600 m. Rainfall is bimodal (Fig. 1) and averaged 1100 mm yr^{-1} during the trial period (1989 to 1993). There are four months of dry season (precipitation < 50 mm) from June to September. Mean monthly maximum temperatures vary little during the year (Fig. 1) and the coldest months are during the dry season. The first cropping season is from October to February and the second from

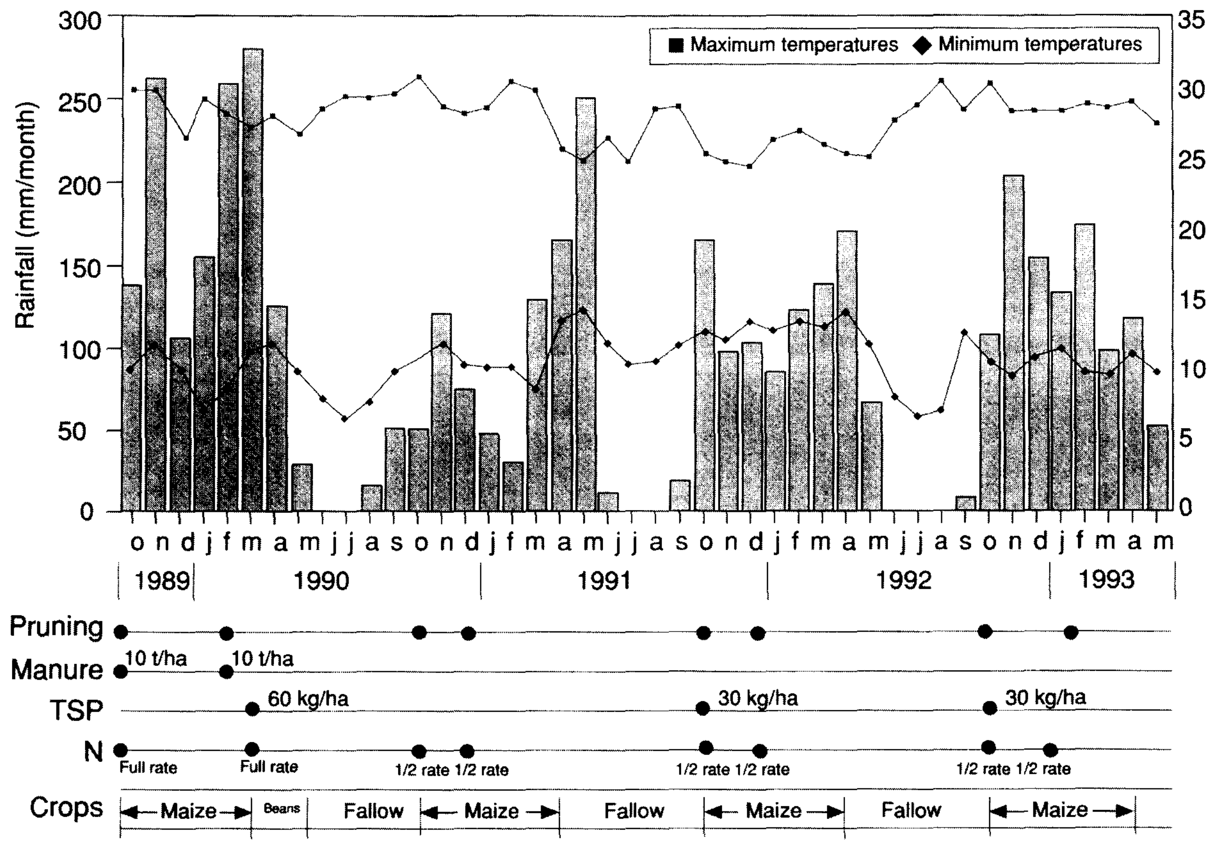

Fig. 1. Rainfall and temperatures at Mashitsi, Burundi during the period of the study and the chronology of experimental activities.

February to June. However, the transition between the two seasons is not distinct.

The experiment was established on an acid soil (pH H_2O, 4.3). Other chemical properties as determined by standard methods were: organic C, 1.0%; total N, 0.09% and exchangeable Al, Ca, Mg, K, and Na, 1.85, 0.42, 0.04, 0.08 and 0.02 $cmol_c$ kg^{-1}, respectively, Available P by the method of Olsen-Dabin [Dabin, 1967] was 23 mg kg^{-1}. The soil has been classified as an Ultic Haplustox.

Treatments and experimental design

Treatments were full factorial combinations of four fertiliser levels – 0, 30, 60, and 90 kg N ha^{-1} and two cropping systems – alley cropping with *Leucaena diversifolia* hedgerows and conventional cropping (without hedgerows), thus a total of eight treatments. Treatments were arranged in randomised complete blocks and replicated three times. A plot consisted of two hedges 4 m apart with two meters left on the non-alley side of each hedge giving a total plot width of 8 m. A hedge was 5 m long and the leucaena seedlings were spaced at 0.25 m within the hedge.

Hedgerow management

Hedges were established at the end of November 1988 and were pruned for the first time in October 1989. Dates of subsequent prunings are shown in Fig. 1. Pruning height was 50 cm and at each pruning, harvested biomass was divided into leaves and twigs (subsequently referred to as prunings), and stems and branches. The prunings were chopped into small pieces and incorporated into the soil. Samples were taken to the laboratory to determine dry weight. The plant materials were dried at 105 °C for 48 h. Roots of hedges in plots adjacent to the no-hedge (control) plots were pruned to prevent mining of the control plot soils by leucaena roots.

Crop and soil management

On these infertile soils, Burundian farmers plant maize only after the fertility status has been improved by regular additions over several seasons of animal manure and compost. When maize is planted, farmers continue to apply manure and compost. In order to mimic farmers' practice and to be able to grow crops, we applied manure, lime and fertiliser. The crops sown and the quantities of external nutrients applied are shown in Fig. 1 Manure (10 t ha^{-1}, fresh weight) was broadcast and incorporated into the soil. N (as urea) and P (as triple superphosphate) were applied in shallow furrows dug along the planting row, covered with soil and the seeds were then sown. In 1991 and 1992, half of the required urea was applied at planting and the remaining half banded along the rows about six weeks later. In addition to the external inputs indicated, 2 t ha^{-1} of lime (obtained from Cibitoke, Burundi) were also applied in October 1989. Maize was space at 80 × 40 cm with the rows next to the hedge planted 40 cm away, so that the hedges did not replace any row of maize. Spacing of the only bean crop sown in March 1990 was 50 × 40 cm. Plots were fallowed in the March–June seasons of 1991 and 1992 because the maize that was planted the previous October was harvested too late (in April) to permit the sowing to beans. This also allowed the hedges more time for re-growth and accumulation of biomass before the next maize crop. Each season, crop residues were retained on the plots and incorporated into the soil.

Economic analyses

To determine the relative profitability of various treatments, partial budgets were drawn up. A partial budget is a method of assessing the benefits and costs of a technology relative to not using the technology. Therefore, only costs and benefits that change between the control (no-hedge and without N) and the treatment are considered. The principal benefits of the treatments were crop yield increases and in the case of alley cropping fuelwood. Major costs included (1) seedlings, valued at Burundi francs (BIF) 5 $seedling^{-1}$ (BIF 240 = US$ 1), the price at private nurseries, (2) labour for transplanting seedlings, cutting hedges and spreading the biomass and was valued at the prevailing wage rate of BIF 120 day^{-1}, (3) cost of the fertiliser and (4) the value of lost crop yields. A kg of N fertiliser was valued at BIF 217 and maize at BIF 44 kg^{-1}. Net benefits were discounted at an annual rate of 20%.

Results

Production of hedges

At the first cutting done 10 months after establishment, when the N fertiliser treatments had not yet been applied, an average of 0.6 t ha^{-1} of dry prunings and 1.3 t ha^{-1} of woody biomass were harvested and all incorporated into the soil. The average height of leucaena at this time was 1.92 m. Subsequently, application of N did not influence hedge production. Pruning yields were 3.56, 2.07 and 2.25 t ha^{-1} and wood yields were 3.88, 4.96 and 3.88 t ha^{-1} in 1990, 1991 and 1992, respectively. The quantities of prunings applied represent an input of from 21 kg N ha^{-1} (in 1989) to 125 kg N ha^{-1} (in 1990). In 1990, the hedges were cut three times, the reason for the higher quantities of prunings than in 1991 and 1992, when hedges were cut only twice per year.

Crop yields

The first maize crop, planted in October 1989, was severely stunted. In February, 1990 when the maize plants were removed to make way for the next crop, only a few plants had tasselled and hardly any had ears. The hedges competed with and reduced the average yield of maize stover from 0.8 t ha^{-1} on the no-hedge plots to 0.5 t ha^{-1} on the alley cropping plots. The bean crop of the first season of 1990 was successful probably due to the addition of triple superphosphate and the continued release of nutrients from the manure applied earlier. Bean yield from the alley cropping plots was less than that from the plots without hedges by 21% (Table 1). Alley cropping had no effect on the grain yield of maize in 1991 (Table 1). In succeeding crops in 1992 and 1993,

Table 1. The effect of cropping systems and N rate on the yields (t ha^{-1}) of beans and maize in Mashitsi, Burundi.

N rate (kg ha^{-1})	No hedge	Alley cropping	Mean
Beans (June 1990)			
0	1.3	0.9	1.1
30	1.4	1.0	1.2
60	1.7	1.2	1.4
90	1.4	1.3	1.3
Mean	1.4	1.1	
Standard Error of Differences (SED): cropping system, 0.1; N rate, 0.1; cropping system × N rate, 0.2			
Maize (March 1991)			
0	0.9	1.0	1.0
30	1.1	1.0	1.1
60	1.3	1.2	1.2
90	0.9	0.9	0.9
Mean	1.1	1.0	
SED: cropping system, 0.1; N rate, 0.1; cropping system × N rate, 0.2			
Maize (March 1992)			
0	1.1	1.8	1.4
30	1.8	2.1	2.0
60	1.9	2.4	2.1
90	2.0	2.1	2.0
Mean	1.7	2.1	
SED: cropping system, 0.1; N rate, 0.2; cropping system × N rate, 0.3			
Maize (March 1993)			
0	1.4	1.6	1.5
30	1.9	2.4	2.2
60	2.3	2.8	2.6
90	2.3	2.7	2.5
Mean	2.0	2.4	
SED: cropping system, 0.1; N rate, 0.1; cropping system × N rate, 0.2			

positive significant gains in maize grain yields due to alley cropping were, on average, 26% and 21%, respectively.

Maize grain yield in 1991 was not influenced by N (Table 1). In 1992 and 1993, maize grain yields increased with increasing levels of N. Maximum yields were obtained at 65 kg N ha^{-1} in 1992 and 72 kg N ha^{-1} in 1993 when data were fitted to quadratic curves. Cropping systems and N-rate interaction was not significant in any year.

Economic analyses

Compared with the no-hedge, no-N control plots, virtually all the treatments gave positive net benefits in the fourth and fifth years (Table 2) but these were offset by the negative returns in the first three years resulting in negative net benefits for the five-year period. Lower benefits were obtained from the N-fertilised alley cropping plots than from those without fertiliser.

The sensitivity analyses of the partial budgets are shown in Table 3. Only the no-hedge plots where 60 kg N ha^{-1} had been applied showed a net gain

Table 2. Net present values (in US$) of partial budget of treatments compared to the control (no hedge and no fertiliser).

Treatment	Year					Accumulated total
	1	2	3	4	5	
No hedge + 30 kg N ha^{-1}	–44	–37	–30	24	10	–77
No hedge + 60 kg N ha^{-1}	–67	19	–14	20	22	–20
No hedge + 90 kg N ha^{-1}	–89	–74	–61	12	40	–172
Alley cropping + 0 N ha^{-1}	–46	–47	–30	24	23	–73
Alley cropping + 30 N ha^{-1}	–90	–83	–59	24	–18	–226
Alley cropping + 60 N ha^{-1}	–113	–102	–74	27	29	–233
Alley cropping + 90 N ha^{-1}	–135	–46	–90	1	11	–259

Table 3. Sensitivity analyses of the partial budgets. Cumulative net present values (in US$) in year 5.

Treatments	Increase price of maize by 50% (1)	Decrease cost of seedlings by 50% (2)	Change discount rate to 10% (3)	Factor 1 + 2
No hedge + 30 kg N ha^{-1}	–36	–77	–81	–36
No hedge + 60 kg N ha^{-1}	54	–20	–4	54
No hedge + 90 kg N ha^{-1}	–98	–172	–185	–98
Alley cropping + 0 N ha^{-1}	–97	–57	–147	–32
Alley cropping + 30 N ha^{-1}	–122	–126	–213	–57
Alley cropping + 60 N ha^{-1}	–145	–168	–258	–80
Alley cropping + 90 N ha^{-1}	–185	–196	–304	–120

of US$ 54 over the control when the price of maize was increased by 50%. Net present values (NPV) of all other treatments were negative and remained negative whether the cost per seedling was reduced by 50%, the discount rate was changed from 20% to 10% or the price of the maize and the cost of seedlings were varied simultaneously.

Discussion

Significant positive responses to alley cropping with *L. diversifolia* were obtained after three years of regular addition of prunings. This is probably the first report of a significant response of maize to prunings in alley cropping on an acid, infertile soil, albeit modified by external inputs in imitation of farmers' practices, in the sub-humid highlands of east and central Africa. Although alley cropping is practised to support crop production through nutrient (mainly N) additions via the prunings, the application of other nutrients to remove any deficiencies that may hinder the full performance of the technology is common. Working on an Entisol of pH 6.0, Atta-Krah [1990] applied 45 to 60 kg ha^{-1} of each of N, P, and K. In addition to 2 t ha^{-1} of lime, Matthews et al. [1992] applied 250 kg ha^{-1} of single superphosphate and 200 kg ha^{-1} of KCl. The successful agronomic use of *L. diversifolia* in alley cropping is important because *L. diversifolia*, unlike *L. leucocephala*, is tolerant to soil acidity [Hutton, 1990] because its roots are able to absorb calcium [Brewbaker, 1987]. On the same acid soil with high Al saturation, *L. diversifolia* from three different sources grew at a rate of 14–17 cm mo^{-1} in the first year and yielded 1.2–2.0 t ha^{-1} yr^{-1} leaf dry matter during a three-year period, whereas four seed sources of *L. leucocephala* grew at 2.7–5.0 cm mo^{-1} and produced only 0.1–0.6 t ha^{-1} yr^{-1} leaf dry matter (E. Akyeampong, unpub.). The performance of *L. diversifolia* was not significantly different from that of *Calliandra calothyrsus*. Other useful attributes of *L. diversifolia* are its resistance to the leucaena psyllid and that it grows in the highlands.

The quantities of biomass applied in 1989 (0.6 t ha^{-1}) and 1990 (3.6 t ha^{-1}) appeared insufficient to produce a response over and above the competitive effect of the hedges. In other studies, the lack of response to alley cropping has been attributed to low quantities of prunings that were applied [Szott et al., 1992]. Even on a relatively fertile soil, more than 6 t ha^{-1} yr^{-1} of prunings were required to obtain positive responses to alley cropping [Gichuru and Kang, 1989; Atta-Krah, 1990]. In Nigeria, Kang et al. [1981a] obtained 3.2 t ha^{-1} of maize by applying 2.67 t ha^{-1} of prunings of *L. leucocephala*. However, it was not clear how this maize yield compared with a no-hedge control plot.

The significantly higher yields from alley cropping plots compared with the control obtained in 1992 and 1993 were almost certainly due to the cumulative effect of the prunings [Read et al., 1985] and were probably accelerated by the seasonal fallowing introduced after the maize harvest of March

1991. The role of this fallow period in contributing to the observed positive responses can only be ascertained in a different trial with a continuously cropped alley plot as control. Such a system was studied by Atta-Krah [1990] who reported a 35% increase in maize yield in the plots with a fallow period over the continuous alley cropping plots and a 50% increase over the no-hedge plots. In spite of the high population densities, short-term fallowing is practised in the highlands of Burundi [Guinand et al., 1992], and thus such a modification to continuous cropping in the alley ways may be acceptable to farmers.

Although prunings improved maize yield over the control, in 1992 and 1993, without N they could only sustain maize yields of 1.6 to 1.7 t ha^{-1}. Similarly, in many trials from diverse environments, although alley cropping resulted in significant maize yields above the control, the ability to produce maize yields above 2 t ha^{-1} on prunings alone without external N was limited [Kang et al., 1981a; ICRAF, 1992; Yamoah and Burleigh, 1990; Rosecrance et al., 1992; Matthews et al., 1992].

That the alley cropping by N rates interaction were not significant suggests that the principal role of the prunings was as a source of N as found by Dalland et al. [1993]. With prunings, the inorganic N needed to produce a given level of maize was reduced. At the lower end of the production scale, prunings alone sustained yields that were equivalent to applying 16 to 22 kg N ha^{-1}. The maximum yields obtained by applying 65 kg N ha^{-1} to 70 kg N ha^{-1} on the non-alley cropping plots was achieved by applying about 40 kg ha^{-1} less of inorganic N on the alley cropping plots. These savings, notwithstanding, the use external inputs alone or in combination with alley cropping did not prove profitable over the five-year period. The crops probably did not manifest the full response to N because of deficiencies in other nutrients possibly P; the quantities of P supplied through the triple superphosphate was low.

The net benefits of the treatments compared with the control remain negative whether the price of maize is increased by 50%, the cost of seedlings is decreased by 50% or the discount rate is reduced to 10%. The large negative returns incurred in the first three years is a disincentive to the adoption of this technology. It is consistent with an evaluation with 50 farmers in western Kenya where alley cropping was found to be unprofitable on 80% of the farms [Swinkels and Ndufa, 1994]. Unlike other agricultural technologies such as the use of hybrid maize in which state subsidies could improve profitability to farmers, the major recurrent cost – labour to manage the hedges – can hardly be manipulated.

Whereas Szott et al. [1992] found that crop yields in both alley cropping and non-alley cropping systems declined with time, the results of this experiment showed increasing crop yield with time even, on the control plots. This was due, in part, to the improvement in the fertility status of the soil, since exports of nutrients were restricted to those removed in the grains as all crops residues were retained on the plots and also due to the introduction of the fallow period. In addition, greater seasonal rainfall is likely to have contributed to the increasing maize yields observed from 1991 to 1993. Rainfall for the November to March period of 1990/91, 1991/92 and 1992/93 was 446 mm, 499 mm and 777 mm, respectively. The experiment will be continued to determine the long-term sustainability and to assess the profitability of the technology.

In conclusion, these results have shown the potential of alley cropping in improving crops yields on an acid infertile soil in a sub-humid environment. To make it economically attractive, management strategies such as fallowing and reducing the cost of establishment are needed to obtain the positive effect early.

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