Agroforestry Systems **47**: 153–162, 1999.

Maize and sesbania production in relay cropping at three landscape positions in Malawi

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Key words: improved fallow, nitrogen fertilizer, relay intercrop, *Sesbania sesban*, soil fertility replenishment

Abstract. The relay cropping of sesbania (*Sesbania sesban*) – a N_2-fixing legume – with maize (*Zea mays*) has been proposed as a strategy to increase soil fertility and food production in densely populated areas in southern Africa. We determined the production of relay-cropped maize and sesbania at three landscape positions under researcher-designed and farmer-managed conditions in southern Malawi. Three landscape positions (dambo valley or bottomland, dambo margin with < 12% slope, and steep slopes with > 12% slope) were examined in factorial combination with N sources for maize (no added N, relay-cropped sesbania, and calcium ammonium nitrate fertilizer). Relay cropping of sesbania with maize increased maize grain yield, as compared to unfertilized sole maize in two of three years. Split application of 96 kg N ha^{-1} as N fertilizer, however, was more effective than sesbania in increasing maize yields. Survival of sesbania seedlings and biomass production of sesbania were greater in the dambo valley and dambo margin than on steep slopes. Maize yields tended to be lower on steep slopes than in the dambo valley and dambo margin areas. Biomass production of sesbania and hence the potential benefits of intercropping sesbania with maize appear greater in the dambo valleys and dambo margins than on steep slopes.

Introduction

Per capita food production has declined in sub-Saharan Africa as a result of rapid population growth and declining soil fertility (Sanchez et al., 1997). Soil fertility can be replenished through nutrient inputs from organic and inorganic sources, but the replenishment of soil fertility from mineral fertilizers is constrained by prohibitive purchase prices. Hence, there is the need to investigate alternative organic-based technologies for small landholders in sub-Saharan Africa.

Land limitation in Malawi has caused farmers to cultivate dambos, which are bottomlands with poor drainage and seasonally waterlogged (Jiah, 1993; Kanyama-Phiri, 1993). Water management is a key issue to allowing productive use of dambos. In Malawi, dambos account for 259,000 ha or 12% of the total land area (CP Mzembe, Utilization of dambos for crop production in Malawi. Paper presented at the wetlands seminar at Kudya Discovery Lodge, Malawi, 11–13 November 1992). The increase in human population has also forced farmers to open fields on steep slopes with shallow, eroded soils that are marginal for arable cultivation (Banda et al., 1994). In Malawi, 45% of the total land area has > 12% slope, which under the Malawi Government land husbandry policy is classified as non-arable (Shaxon et al., 1977).

Beneficial effects of leucaena (*Leucaena leucocephala* (Lam.) de Wit), sesbania (*Sesbania sesban* (L.) Merr.), and pigeonpea (*Cajanus cajan* (L.) Millsp.) for soil fertility improvement have been demonstrated under alley cropping (Onim et al., 1990). Studies in southern Africa (Kwesiga and Coe, 1994; Kwesiga et al., 1999) have also demonstrated the potential of sesbania as a source of N when grown in rotation with maize (*Zea mays* L.). Sesbania nodulates heavily and can fix 100 to 350 kg of atmospheric N_2 ha^{-1} yr^{-1} (Brewbaker et al., 1990). The growth and biological N_2 fixation of sesbania, like other legumes, could be much reduced at unfavorable landscape positions in farmers' fields (Mahler et al., 1979).

Relay cropping of sesbania with maize has been proposed for soil fertility improvement in densely populated areas in southern Malawi (JA Maghembe, personal communication) – where maize is the staple food crop. Previous evaluation on relaying cropping of sesbania, however, has primarily been conducted in researcher-managed experiments on experiment stations. The objective of our study was to evaluate the effect of landscape position on production of relay-cropped sesbania and maize under farmer-managed conditions.

Materials and methods

A three-year researcher-designed and farmer-managed study was conducted on a watershed in southern Malawi (15°18.5′ S; 35°23.5′ E) at about 800 m elevation with mean annual rainfall of about 1150 mm. Rainfall distribution for the study period is presented in Table 1. The soils are classified as Utric Cambisol and Haplic Phaeozem (Venema, 1991).

Table 1. Rainfall distribution for the study site in southern Malawi.

Month	Rainfall (mm)		
	1995/96	1996/97	1997/98
October	0	0	37
November	99	21	48
December	274	301	699
January	203	308	421
February	268	368	15
March	490	199	198
April	74	89	25
May	9	0	0
Total	1419	1286	1443

The watershed is dominated by three landscape positions: dambo valley (bottomland), dambo margin, and steep slope. The dambo valley has < 12% slope and relatively high soil organic matter. The dambo margin also has < 12% slope and is fairly well drained. The steep slopes are characterized by eroded topsoil. The area has a population density of 126 persons km^{-2} with landholdings ranging between 0.42 and 0.64 hectares per farm family (Government of Malawi, 1993). Grain yields from local maize varieties average around 0.5 Mg ha^{-1} (Kanyama-Phiri et al., Preliminary findings on the potential for adoption of agroforestry technologies by smallholder farmers in Zomba and Ntcheu. Paper presented at the University of Malawi Research and Publications Committee Annual Conference, Mangochi, Malawi, 17–20 July 1995).

Experimental design and management

The trial in year 1 (1995/96) and year 2 (1996/97) was a split-plot design with three landscape positions (dambo valley, dambo margin, and steep slopes) as main plots and two N sources (no added N and relay-cropped sesbania) as subplots. In year 3, the treatments were a factorial combination of the three landscape positions and three N sources (no added N, relay-cropped sesbania, and 96 kg N ha^{-1} applied as calcium ammonium nitrate) in a split-plot design. In both experiments, eleven farmers' fields per landscape position served as replicates.

Soil was sampled in all plots at 0 to 15-cm depth before the initiation of the study to determine the initial soil fertility status. Soil samples were oven-dried at 70 °C for 48 hours, ground to pass through a 2-mm sieve and analyzed for organic C by acid dichromate digestion (Anderson and Ingram, 1993) and for pH and texture as described by Wendt (1996. Soil and Plant Analysis Laboratory Manual. Bunda College of Agriculture).

Land preparation was initiated in May–June of each year, soon after maize harvest. This involved the incorporation of maize stover and weeds within a small ridge created in the furrow of the ridge–furrow system from the previous cropping season. Early land preparation is a common practice in the watershed, and it takes advantage of post-season soil moisture that facilitates the decomposition of the crop residues. Final land preparation was concluded in October–November and involved ridge enlargement. In years 2 and 3, ridge enlargement included the incorporation of non-woody sesbania biomass into these ridges.

Three seeds of maize hybrid (MH18) were planted at 90 cm between planting stations on ridges 90 cm apart. This gave a population of about 37,000 plants ha^{-1}. Maize was first weeded after the crop reached about 60-cm height, and 'banking' – a second weeding operation involving remaking the ridges – was done at approximately tasseling.

Calcium ammonium nitrate (CAN) was split applied in year 3 at 96 kg N ha^{-1} – national fertilizer recommendation for maize. Half was applied at maize planting, and the other half was applied after the first weeding when maize had reached an average height of 60 cm.

A local variety of sesbania (accession number 034) was used because of its resistance to a defoliating beetle (*Mesoplathys ochroptera* Stal.). The seeds were first scarified using hot water treatment and then soaked in cold water overnight to break dormancy. They were sown the following day onto seedbeds containing a soil medium of 25% sand mixed with 75% forest soil. Two-month-old, bare-rooted seedlings were transplanted at first weeding into the maize field in every other furrow at one seedling per planting station – spaced 75 cm apart. This transplanting pattern gave a final population of 7400 trees ha^{-1}. The planting pattern of sesbania and maize in the ridge–furrow system is illustrated in Figure 1.

Plant measurements and management

Sesbania seedling survival was measured at 60 days after transplanting. Trees were cut at ground level at 10 months after transplanting, and above-ground biomass was determined from the 10 m by 10 m net plot area. Non-woody

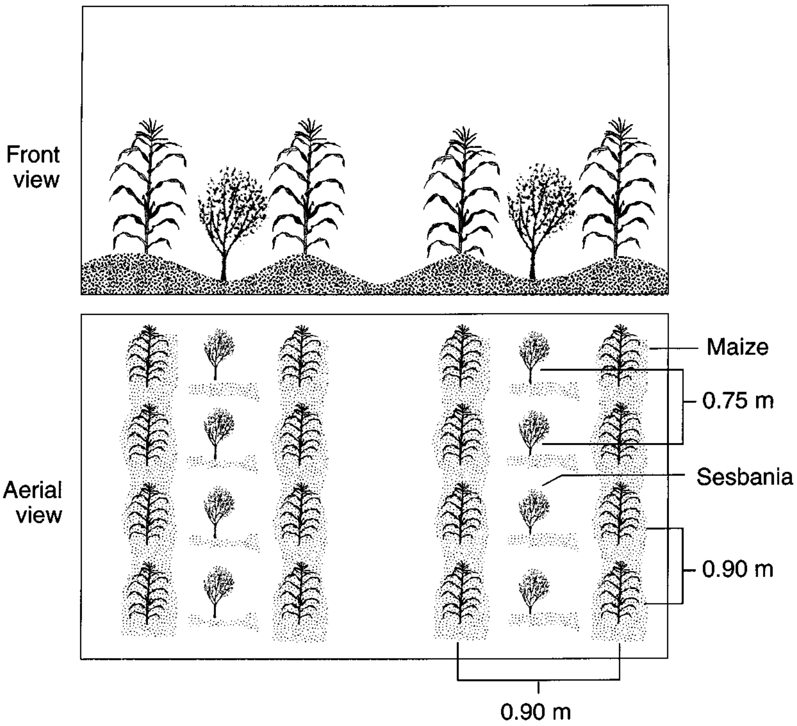

Figure 1. An illustration of the planting pattern for sesbania and maize in the ridge–furrow system in southern Malawi.

biomass, which included leaves, flowers, pods, and twigs, was stripped by hand and weighed fresh. A subsample was then oven dried at 70 °C for 48 hours to determine biomass on a dry weight basis. A subsample of the dried non-woody biomass was ground to pass through a 1-mm sieve and then analyzed for total N (Anderson and Ingram, 1993). A subsample of the woody biomass was oven dried at 105 °C for 72 hours to determine biomass production on a dry weight basis.

The non-woody biomass (leaves, flowers, pods, and twigs) was placed evenly in the furrows and covered by breaking half of the existing ridges and constructing a new ridge in the previous furrow. The woody biomass was removed from the plots.

Maize grain was harvested at physiological maturity from 10 m by 10 m plots. All the grain from the plot was shelled and weighed fresh. Then a subsample was weighed fresh, oven dried at 70 °C for 48 hours, and weighed to determine grain yield on dry weight basis. A subsample of maize stover was similarly oven dried at 70 °C for 48 hours to determine stover yield on a dry weight basis.

After harvest, maize stover was placed evenly in the furrow and incorporated within a ridge constructed in the previous furrow. Data were statistically analyzed using an MSTAT statistical package.

Results and discussion

Initial soil fertility status

Initial organic C and pH were highest on the dambo valley soils and lowest on the steep slopes. Hydraulic conductivity was higher on the steep slopes than in the dambo valley. Clay content and bulk density tended to be highest on soils of the dambo valley and the steep slopes. The soils on the steep slopes, despite relatively high clay content, were low in organic matter apparently due to the susceptibility of these soils to soil erosion. Thus, while the capacity of soil to build organic matter may be related to soil texture for the moderate slope landscape positions (Giller et al., 1997), this relationship might not hold for steep slopes such as those in this watershed. Erosion and runoff may contribute to relatively low water content of soils on steep slopes, and greater likelihood of water stress for plants growing on the steep slopes.

Maize yields

In year 1, our main interest was to determine whether the introduction of sesbania into maize plots (relay cropping) affected maize grain yield. The maize crop appeared to benefit from the association with sesbania because maize grain yields were consistently higher ($P < 0.05$) in the maize–sesbania intercrop than with sole maize (Tables 3 and 4). The presence of sesbania in

Table 2. Soil characteristics as affected by landscape position for 33 on-farm field sites in southern Malawi.

Soil property	Dambo valley	Dambo margin	Steep slope	Standard error
Organic C (g kg^{-1})	21.1	15.3	8.7	3.6
pH	6.5	6.1	5.3	0.4
Bulk density (g cm^{-3})	1.3	1.2	1.4	0.1
Hydraulic conductivity (cm hr^{-1})	5.4	7.2	7.2	0.6
Sand (%)	45	40	36	2.6
Clay (%)	37	32	42	2.9

the intercrop may have improved water availability to the maize crop by reducing runoff and increasing water infiltration in the furrow. The shading of the tree may also have reduced evaporation.

Sesbania may have contributed to weed suppression. Less weeds were observed in the maize–sesbania plots than in the sole maize plots (unpublished data). Although sesbania might be expected to compete with maize, competition would be reduced as a result of the spatial and temporal separation arising from planting sesbania as a relay crop in the furrow.

The effects of the sesbania biomass incorporated at the end of the first growing season were monitored in year 2 of the study. In the first four weeks after maize planting, there were no differences in the color of the maize growing in the sesbania and the control plots. By the second month the unfertilized maize started yellowing – a clear sign of N deficiency. The maize grain and stover yields, however, were not significantly higher following sesbania (Tables 3 and 4).

The effects of sesbania biomass incorporated at the end of the second cropping season (year 2) were measured in year 3. In the first month, there were no differences in the appearance of maize in the control, sesbania, and N fertilizer plots. By the second month, however, the maize in the control plots started yellowing as in the previous year, while maize in the sesbania and N fertilizer treatments remained green. The superiority of N fertilizer as compared to sesbania became evident following topdressing of N fertilizer when the fertilized maize was greener with bigger cobs than the maize in the sesbania treatment.

Maize grain and stover yields were highest for N fertilizer (Table 4), but yields were higher for sesbania than the no N control. Although N fertilizer gave higher maize grain and stover yields than sesbania, the prohibitive costs of the fertilizer would limit its use by the smallholder farmers in Malawi. Consequently, the sesbania system could offer an attractive option for soil improvement, especially on the fields of resource-poor farmers.

In year 1, maize yield was not affected by landscape position (Table 3). In subsequent years, maize yield tended to be lowest on the steep slope and highest in the dambo margin and dambo valley. These grain yields appear to

Table 3. Analysis of variance for the effect of landscape position and N source on maize yield in farmers' fields in southern Malawi.

Source of variation	df	Significance level			df	Significance level	
		Grain yield, Year 1	Grain yield, Year 2	Stover yield, Year 2		Grain yield, Year 3	Stover yield, Year 3
Farmers	10	NS	0.05	0.05	10	NS	0.01
Landscape (L)	2	NS	0.17	0.10	2	0.12	0.05
N source (N)	1	0.05	NS	NS	2	0.001	0.001
L × N	2	NS	NS	NS	4	0.17	NS

NS = not significant.

Table 4. Effect of N source and landscape position on maize yield in farmers' fields in southern Malawi.

N source	Grain yield (Mg ha^{-1})			Stover yield (Mg ha^{-1})		
	Dambo valley	Dambo margin	Steep slope	Dambo valley	Dambo margin	Steep slope
Year 1						
No added N	1.03	1.03	0.95			
Sesbania	1.65	1.36	0.95			
SED		0.17				
Year 2						
No added N	1.30	1.09	0.51	1.72	1.82	0.98
Sesbania	1.37	1.10	0.52	1.65	1.76	1.06
SED		0.47			0.41	
Year 3						
No added N	0.67	0.44	0.29	0.81	0.63	0.53
Sesbania	1.10	1.18	0.88	1.98	1.34	1.07
Mineral fertilizer	3.12	2.87	1.51	2.52	2.85	2.00
SED		0.32			0.31	

SED = standard error of the difference of means.

reflect the higher soil fertility status (Table 2) and likely lower water stress in the dambo valley and margin as compared to the steep slopes.

Tree biomass

In year 1, plant survival at 60 days after transplanting was higher in the dambo valley and dambo margin than on the steep slopes (Table 5). It was not surprising, therefore, that sesbania biomass was also highest at those landscape positions. Nitrogen in non-woody biomass, which was incorporated into the soil, followed similar trends.

Table 5. Survival, biomass production, and N content of sesbania at three landscape positions in farmers' fields in southern Malawi.

Parameter	Dambo valley	Dambo margin	Steep slope	Standard error
Year 1				
Seedling survival at 60 days (%)	92	84	70	3.0
Non-woody biomass[a] (Mg ha^{-1})	2.15	1.24	0.68	0.43
Wood biomass (Mg ha^{-1})	5.17	2.50	1.10	1.10
N in non-woody biomass (kg ha^{-1})	59	26	16	12
Year 2				
Non-woody biomass (Mg ha^{-1})	4.71	3.88	0.57	0.88
Wood biomass (Mg ha^{-1})	2.31	2.69	1.08	0.39
N in non-woody biomass (kg ha^{-1})	103	85	21	15

[a] Non-woody biomass includes leaves, flowers, pods, and twigs. This biomass was incorporated into the soil after cutting the sesbania.

The high yields of sesbania from the dambo valley may have resulted from the high water table, deep soils, and relatively higher soil fertility. Smallholder farmers could therefore take advantage of extended soil water availability in the dambo valley and dambo margin to raise sesbania plants for green manures. Poor tree growth and biomass production on the steep slopes pose challenges to the improvement of soil fertility status of these soils.

Conclusions

This is the first study, which to our knowledge quantifies production of a sesbania–maize system under on-farm conditions at different landscape positions. It is also the first study that has been conducted in partnership with the smallholder farmers in the study area.

The results show that both opportunities and challenges exist for maize and sesbania production under relay cropping at the three landscape positions. The opportunities for production of sesbania biomass appear to be confined to the dambo valleys and dambo margins. At these lower landscape positions, increases in applied sesbania biomass result in increased maize grain yields. With appropriate sesbania management, smallholder farmers could replenish nutrient-depleted soils with much needed N for the associated maize crop. Sesbania could reduce the dependence on mineral N fertilizer, which is beyond the reach of many smallholder farmers in the watershed. The sesbania fuelwood provides an added benefit that would minimize the dependence of the smallholder farmers on the neighboring forest reserves, which are under increasing threat of deforestation.

Sesbania–maize intercropping, however, was not particularly suited to the steep slopes in this watershed. The trees produced insufficient biomass for a significant contribution to soil fertility improvement, hence crop yields were low. Further studies are needed to determine alternative technologies for this steep landscape position, with eroded and low-fertility soils. There is an urgent need of soil-improving technologies for steep-slope fields because younger and more vulnerable farm groups, such as women-headed households, are often confined to this challenging landscape position.

Acknowledgement

The authors are greatly indebted to the Rockefeller Foundation for funding the research. ICRAF is sincerely acknowledged for providing sesbania seedlings and laboratory facilities for soil analysis.

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