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Fodder-quality improvement through contour planting of legume-shrub/grass mixtures in croplands of Rwanda highlands

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Abstract. The leguminous woody shrub species *Sesbania sesban* and *Calliandra calothyrsus* were planted with the grasses *Pennisetum purpureum* and *Setaria splendida* on contour lines in association with wheat and beans in order to improve the grass based fodder system in the Buberuka highlands of Rwanda. Setaria, calliandra and sesbania showed a higher productivity when shrub and grass species were mixed than in the sole stand. The crude protein yield of all grass-shrub mixtures was higher than in grasses alone and the crude protein of the grasses was increased when combined with a leguminous shrub. Calliandra with Setaria gave the highest fodder quality and showed the lowest competition with crops. An optimal system for satisfying dry matter and protein requirements of local and improved cattle was estimated by linear programming. Shortest length of fodder planting is obtained by the pennisetum based system in sole stand and in combination with calliandra. The crop loss was the least when Setaria was grown alone or in combination with calliandra. From production, nutrition and economic considerations it appears that leguminous shrubs have a role in improving fodder production in the Rwandan highlands.

Introduction

Rwanda is one of the most densely populated countries in Africa, its population density on arable land being more than 500 persons km^{-2} [Djimde, 1988]. Farm sizes are small and have decreased from 1 ha (with 0.74 ha for food crops) in 1987 to 0.87 ha (0.64 ha) in 1992 (CNA, 1991). The area of pasture land decreased annually by 11% between 1984 and 1989 with a 3.4% annual decrease in browseable fallow between 1980 and 1986. This has led to the disappearance of traditional livestock production systems and the introduction of zero-grazing with cut and carry fodder supply. Increasing cultivation intensity has also led to soil erosion problems.

The fodder supply comes mainly from the grasses *Pennisetum purpureum* and *Setaria splendida* planted on the contour lines, but their quantity and quality remains low, particularly in the dry season (Djimde, 1988). Many authors emphasize the important role of leguminous trees and shrubs which can provide a substantial supplement to the grass-based fodder of ruminants (Pfeiffer, 1990; Topark-Ngarm and Gutteridge, 1990; Amaning-Kwarteng, 1992). Leguminous trees and shrubs are richer in protein and minerals than tropical grasses, the leaf silica content of which is two to three times higher than in trees. Different authors stress that the quality of the grasses is very sensitive to seasonal climatic variation and varies considerably with maturity. This is reflected in their protein content (Egli, 1988), phosphorus content, crude fibre (Pfeiffer, 1990) and digestibility (Kitamura, 1985). In contrast tree legumes show more stable high quality fodder production throughout the year.

An experiment was designed to investigate the possibility of improving productivity and quality of fodder by growing grasses and fodder shrubs in two separate parallel rows on contour lines in crop land. The main objectives of this trial were to determine: 1. The quantity and quality of fodder from different grass and legume shrub combinations; 2. The interaction between grass and shrub grown on contour lines; 3. The influence of different grass and shrub combinations on adjacent crops.

Materials and methods

The experiment was conducted at Rwerere in the Buberuka Highlands, northern Rwanda (latitude 1°32′ S and longitude 29°53′ E , at an altitude of 2300 m). The mean annual temperature over a 28-year period was 15.7 °C, with a mean maximum of 20 °C and a mean minimum of 11.6 °C. The mean annual rainfall was 1257 mm with a distinct dry season from June to August and a short dry season in January. The experiment was laid out on a slope of about 45%. Using the USDA classification system (Soil Survey Staff, 1992), the soils were classified as oxic humitropept. The physical and chemical characteristics of the soil (0–30 cm) at the site were: clay content 41%, pH (1:2.5 soil to water) 4.4, organic carbon (Walkley Black) 2.8%, total nitrogen (macro-kjeldahl) 0.21%, available phosphorus (Bray I) 4.1 ppm, cations (atomic absorption technique after extraction with 1N NH_4 OA_C) Na 0.03 me/100 g, K 0.03 me/100 g, Ca 1.4 me/100 g, Mg 3.6 me/100 g and aluminium (unbuffered 1 M KCl) 3.6 me/100 g (IITA, 1979; Anderson and Ingram, 1989).

A single plot consisted of a cropped area with a double row of fodder planted along the centre. The treatments compared different species compositions of the fodder lines, which were combinations of grasses and leguminous woody shrubs. The shrubs used were *Calliandra calothyrsus* (from Kibuye, Rwanda) and *Sesbania sesban* (from Nyabisindu, Rwanda). The grasses were local selections of *Pennisetum purpureum* and *Setaria splendida*. The 8 treatments were:

1. Double row of *Calliandra calothyrsus*
2. Double row of *Sesbania sesban*
3. Double row of *Pennisetum purpureum*
4. Double row of *Setaria splendida*
5. A row of *Calliandra calothyrsus* with a row of *Setaria splendida*
6. A row of *Calliandra calothyrsus* with a row of *Pennisetum purpureum*

7. A row of *Sesbania sesban* with a row of *Setaria splendida*
8. A row of *Sesbania sesban* with a row of *Pennisetum purpureum*

The experiment was laid out in a randomized block design, replicated three times. Plots were 8 m long by 5 m wide, with the central 8 m long fodder line planted along the contour. In plots with a shrub/grass combination (treatments 5, 6, 7 and 8), shrubs were planted above the grass lines. The within row spacing for both shrubs and grasses was 0.25 m, while the between row spacing was 0.5 m. The shrubs were transplanted at 3 months old on 8 April 1988, and the grasses planted on 7 October 1988 since previous experience had shown that better growth is obtained if the shrubs have time to establish before the more competitive grasses are added. 175 kg ha^{-1} of compound fertilizer (N, P, K, 17–17–17) was applied to the entire experiment immediately prior to establishment of the trial in April 1988. No further external inputs were used during the experiment.

Wheat (*Triticum aestivum*) followed by beans (*Phaseolus vulgaris*) were sown each year on both sides of the fodder line. The beans (cv Bataaf) were sown in September or October and harvested in January or February, and the wheat (cv Muhonyore) was sown in March and harvested in July or August. The wheat was sown in rows 0.2 m apart and the beans (2 seeds/hole) in rows 0.4 m apart with an in-row spacing of 0.2 m. Crops were weeded twice each season, any weeds in the fodder lines being removed at the same time. The shrubs were cut regularly at a height of 0.5 m, while grasses were cut at approximately 0.2 m, both these estimated from earlier work to be optimal heights. The last harvest took place on 25 May 1992.

Fodder strips were cut when they were judged to be interfering excessively with the adjacent crops, so that cutting intervals varied according to season and state of the cropping sequence. After the initial cut, the interval between cuts varied from 34 to over 200 days. 1 kg (fresh weight) samples of leaves and twigs were dried for 48 hours at 60° and weighed to determine the dry matter and for further analysis. P, K, Ca and Mg were analyzed after ashing at 560° for 16 hours. P was determined using the vanadomolybdate method, and P, K, Ca and Mg were measured by atomic absorption spectrometry. Nitrogen (N) was analyzed using the macro – Kjeldahl procedure and crude protein (CP) calculated as $N \times 6.25$. Cellulose was analyzed gravimetrically through acid detergent fibre using the method of Van Soest and Wine (IITA, 1979; Anderson and Ingram, 1989; Tekalign et al., 1991).

Results and discussion

Fodder production

By October 1992, the highest total dry leafy biomass production (including leaves and twigs less than 1cm diameter) was from pure pennisetum, followed by pennisetum combined with the legumes (Table 1).

Table 1. Total dry biomass production from fodder lines in October 1993, 48 months after establishment of the grasses and 54-months after that of the shrubs in the Buberuka Highlands of Rwanda.

Treatment	Grass (single row) (kgm^{-1})	Shrub (single row) (kgm^{-1})	Total (double row) (kgm^{-1})
Calliandra (2 rows)	–	3.0	6.1
Sesbania (2 rows)	–	2.0	4.1
Setaria (2 rows)	3.2	–	6.5
Pennisetum (2 rows)	13.4	–	26.7
Calliandra + Setaria	3.8	4.1	7.9
Calliandra + Pennisetum	11.9	3.6	15.5
Sesbania + Setaria	4.6	2.6	7.2
Sesbania + Pennisetum	12.2	2.6	14.8
SED (df)	0.88 (10)	0.37 (10)	1.06 (14)

Productivity of all four components varied considerably throughout the 54 month period, depending on the time between cuts. Other sources of variation are therefore seen most clearly if productivity per day is studied. This is defined as the productivity of a cut divided by the number of days since the previous cut (Figure 1). Production of both grasses tended to increase until about 1000 days after sowing and then decreased. A similar trend was observed in Burundi by Vancoppenolis (1983) in favourable conditions, though he observed a rapid decrease after two years in a less fertile environment. Similar results were reported by Tadesse (1990) in Ethiopia and by Pfeiffer (1990) in the Western Usambara Mountains of Tanzania.

About 30 % of the remaining variation in productivity of the grasses could be explained by linear regression on mean daily rainfall during growth period and did not appear to be related to temperature. For example, fitting a smooth curve for age plus a linear rainfall effect (Genstat, 1993) to the daily production of pennisetum gave an estimated effect of rainfall as 0.0146 (se = 0.0058, t = 2.51, P = 0.03) g m^{-1} day^{-1} per mm rainfall. The corresponding result for setaria is 0.0088 (se = 0.0011, t = 8.23, $P < 0.001$) g m^{-1} day^{-1} per mm rainfall, with a similar conclusion.

Survival rate of sesbania decreased from 81% after the fourth cut on 16 April 1990 (25 months after transplanting) to 23% after 29 months. After 48 months and 8 cuts, its survival was only 4%, compared with 95% survival of calliandra at this stage. The only clear trend in tree production was due to the sesbania mortality. No relationship with rainfall or temperature could be found. Fitting a smooth trend plus rainfall effect gave parameter estimates of 0.0016 (se = 0.0016, t = 1.0, P = 0.33) and 0.0026 (se = 0.0014, t = 1.8, P = 0.10) g m^{-1} day^{-1} per mm rainfall for calliandra and sesbania respectively.

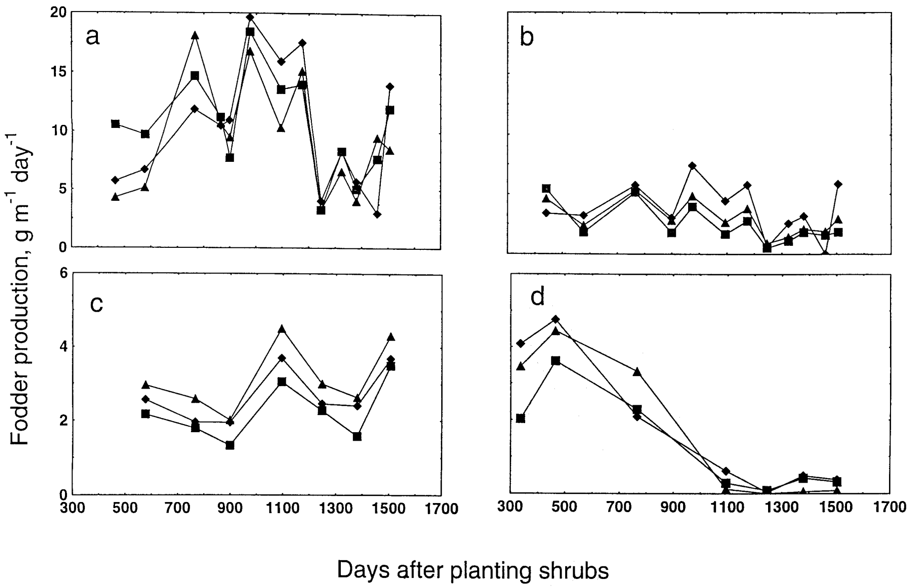

Figure 1. Dry matter production of grasses, shrubs and mixtures (gm^{-1} d^{-1}) in the B uberuka highlands of Rwanda. Pure species values are for a double rows (total production/2) (a) pennisetum (no association ■, associated with calliandra ▲, associated with sesbania ◆). (b) setaria (no association ■, associated with calliandra ▲, associated with sesbania ◆). (c) Calliandra (no association ■, associated with setaria ▲, associated with pennisetum ◆). (d) Sesbania (no association ■, associated with *setaria* ▲, associated with pennisetum, ◆).

Fodder quality

Chemical analysis showed that the crude protein (CP) content of shrubs were higher than those of the grasses and their cellulose content was lower (Table 2). The calcium and phosphorus contents of the shrubs were also considerably higher than those of the grasses. These results indicate the higher nutritive value of the shrubs and confirm results of other authors (Skerman and Riveros, 1990; Pfeiffer, 1990; Egli, 1988; Topark-Ngarm and Gutteridge, 1990; Onim et al., 1990).

Interaction between grasses and shrubs

The only important interaction between grass and shrubs in productivity was the higher (P = 0.01) production of calliandra when grown with setaria than when grown alone (Table 1). This higher productivity has been reported by several authors (Mtengeti et al., 1992; Kitamura, 1985; Kusekwa et al., 1990).

A separate analysis of the crude protein (CP) content of the leafy biomass of the individual components in each grass/shrub combination was conducted during the dry season (September 1991) and the results are shown in Table 3.

Table 2. Dry matter and chemical composition of fodder components in the Buberuka highlands of Rwanda.

Species	Cutting date(s)	Dry matter (g/100 g)	Crude protein	P	K	Ca	Mg	Cellulose
			(g/100 g)					
Sesbania	13/3/89	32.0	16.9	0.23	0.11	1.75	0.28	28.81
	16/5/90	32.2	18.3	0.67	0.11	2.75	0.70	7.26
Calliandra	20/7/89	37.8	22.3	0.31	0.09	1.18	0.51	7.60
	16/5/90	38.1	23.4	0.38	0.13	1.10	0.47	11.53
Pennisetum	20/7/89	24.2	7.20	0.18	0.13	0.15	0.39	45.80
Setaria	20/7/89	23.5	8.00	0.17	0.06	0.12	0.28	45.06
	16/5/90	22.9	8.10	0.39	0.15	0.47	0.52	28.53

Table 3. Crude protein content of grasses and shrubs grown in mixtures in the Buberuka Highlands of Rwanda.

Associated species	Grass/shrub (%)			
	Calliandra	Sesbania	Pennisetum	Setaria
Calliandra	22.1	x	17.8	15.2
Sesbania	x	24.4	16.2	15.0
Pennisetum	23.3	22.3	11.3	x
Setaria	23.3	20.4	x	12.7

x indicates mixtures which did not occur.
The grasses and shrubs were cut in September 1991.

The CP content, expressed as a percentage of the dry matter, is higher in grasses grown in association with shrubs than in pure stands. The CP content of calliandra was not affected by combination with grasses. CP content of grasses associated with shrubs increased from 113 g kg^{-1} to 178 g kg^{-1} in Pennisetum and from 127 g kg^{-1} to 152 g kg^{-1} in Setaria.

Crop production adjacent to the fodder lines

Pure setaria was the least competitive fodder line and allowed the highest crop yields for beans and wheat (Table 4). Sesbania initially reduced crop yields significantly, but yields of wheat increased significantly when sesbania died. Pennisetum in pure stands or in combination with shrubs was very competitive.

During the wheat cropping season of 1991 and the bean cropping season of 1992, crop yields were measured separately above and below the fodder lines (Table 5). Yields from the upper part of the plot made up 63.5% and 60.7% of the total plot yield for wheat and beans respectively. However, there is a side by treatment interaction ($P = 0.003$ for wheat, $P < 0.001$ for beans),

Table 4. Crop yields associated with grass-shrub fodder lines in the Buberuka Highlands of Rwanda.

Treatment	1989 beans	1989 wheat	1990 beans	1990 wheat	1991 beans	1991 wheat	1992 beans	Average[a] beans	Average wheat
	(t ha^{-1})								
Calliandra	0.440	0.740	0.471	0.680	0	0.977	0.291	0.400	0.800
Sesbania	0.183	0.503	0.217	0.571	0	1.120	0.314	0.234	0.731
Setaria	0.549	0.709	0.489	0.989	0	1.017	0.300	0.446	0.906
Pennisetum	0.580	0.509	0.211	0.097	0	0.475	0.155	0.314	0.360
Call + Set	0.477	0.746	0.431	0.851	0	0.968	0.275	0.394	0.854
Call + Penn	0.460	0.771	0.340	0.246	0	0.517	0.191	0.331	0.511
Ses + Set	0.271	0.623	0.329	0.571	0	0.866	0.274	0.291	0.686
Ses + Penn	0.240	0.611	0.234	0.303	0	0.380	0.180	0.220	0.431
SED (df = 14)	0.068	0.061	0.055	0.113		0.131	0.031		

[a] Excluding failed crop.
There were two crops per year, a rotation of wheat and beans. The 1991 bean crop failed.

Table 5. Crop production above and below the fodder line in the Buberuka Highlands of Rwanda.

Treatment	Wheat 1991 (t ha^{-1})		Beans 1992 (t ha^{-1})	
	Above	Below	Above	Below
Calliandra	0.614	0.363	0.200	0.091
Sesbania	0.717	0.403	0.191	0.123
Setaria	0.637	0.380	0.200	0.100
Pennisetum	0.246	0.229	0.049	0.106
Call + Set	0.677	0.291	0.169	0.106
Call + Penn	0.320	0.197	0.114	0.077
Ses + Set	0.609	0.257	0.180	0.094
Ses + Penn	0.200	0.180	0.097	0.083
Average	0.500	0.289	0.151	0.100
SED (df = 14)*	0.099		0.028.	

* Standard error of difference between crop yields above and below the fodder line for individual treatments.

with a large difference between upper and lower sides for those treatments that do not include pennisetum, but no difference for those treatments that do. It appears that the highly competitive pennisetum does not allow the production potential of the fertility or moisture accumulated above the fodder line to be realised.

Matching fodder production with fodder needs

The different fodder systems have trades-off in terms of quantity and quality of fodder and therefore the choice of a particular system will be influenced

Table 6. Average annual yields and estimated annual crop losses of different fodder combinations in the Buberuka Highlands of Rwanda.

Treatment	Beans			Wheat			Annual total	Loss
	Average production ($t\ ha^{-1}$)	Gross production (US \$ ha^{-1})	Loss (US \$ ha^{-1})	Average production ($t\ ha^{-1}$)	Gross production (US \$ ha^{-1})	Loss (US \$ ha^{-1})	(US \$ ha^{-1})	(US \$ m^{-1})
Calliandra	0.400	138	31	0.800	221	45	76	0.039
Setaria	0.446	154	15	0.906	250	16	31	0.016
Pennisetum	0.314	108	61	0.360	99	167	228	0.113
Call + Set	0.394	136	33	0.854	236	30	63	0.034
Call + Penn	0.331	114	55	0.511	141	25	80	0.090
Average yield	0.377	130		0.686	189			
Control yield (estimated)	0.491	169		0.962	266			

by the requirements of the livestock system for which the fodder is being produced. Two types of livestock are considered here, the local Ankole cattle, with little or no milk production, and the improved breed, with an average daily milk production of 8 l day^{-1}.

Average daily feed requirements are 6.30 kg dry matter (DM) and 0.44 kg crude protein (CP) for the Ankole breed and 10.70 kg DM and 0.96 kg CP for the improved breed. The average daily contribution towards the production of dry matter and crude protein from the different fodder species mixtures can be computed from the data presented in Tables 1 and 2. Data presented in Table 3 are not used because of their preliminary nature. In the following analysis, data from treatments that include sesbania are not considered because of its poor survival.

To match dry matter and crude protein production from the fodder systems with the requirements of the two livestock breeds, linear programming was used. The objective function to minimize in order to optimize land use is the length of the linear planting needed to feed one Ankole or one improved cow.

Hence we have to minimize $X_1 + X_2 + X_3 + X_4 + X_5$, in which:

X_1 = Length (m) of a double row of pure of calliandra
X_2 = Length of a double row of pure of pennisetum
X_3 = Length of a double row of pure of setaria
X_4 = Length of a row of calliandra and pennisetum
X_5 = Length of a row of calliandra and setaria

subject to the following constraints:

Dry matter:

$$3.98X_1 + 17.71X_2 + 4.31X_3 + 10.29X_4 + 5.24X_5$$
$$= 6300 \text{ for Ankole}$$
$$= 10700 \text{ for improved breed}$$

Crude protein:

$$0.918X_1 + 1.270X_2 + 0.347X_3 + 1.119X_4 + 0.830X_5$$
$$> 440 \text{ for Ankole}$$
$$> 960 \text{ for improved breed}$$

The optimum length for the Ankole breed was 356 m of pure pennisetum and for the improved breed 310 m of pure pennisetum plus 506 m of calliandra and pennisetum in association.

The above calculation is a first approximation since the actual digestibility of the crude protein of the calliandra should be considered as well as the seasonal variation in fodder production and animal feeding requirements over the lactation period. However, the computation does indicate that the optimum length can vary depending on the breed of cattle, and can include the tree components.

The linear programming model may be further refined by taking into consideration the cost of producing the fodder. Three cost components should be considered: i) cost of establishing a unit length of fodder planting, ii) the cost of harvesting a unit length of fodder, and iii) the cost in terms of crop losses per unit length of fodder planting. For this linear programming model, only the crop losses will be considered, since no data were collected on the other cost items. However, other costs are small in comparison with crop losses and therefore differences in these costs between treatments will not dramatically alter the solutions. This refined model is still only concerned with the fodder production options tested in the trial, and can not compare these with other sources of cattle fodder. Nor can it account for benefits that have not been assessed such as erosion control.

No control treatment of a plot without fodder was included in this experiment. However, it is also possible to estimate the performance of crops in the absence of fodder lines by considering performance in the pure sesbania plots during the last year, because the shrubs had died by that time. The wheat and bean yields in these pure sesbania treatments were 41% and 30% higher respectively than the mean of the other plots. These figures enabled the average crop losses to be determined by subtracting the gross production values of the 'control' treatment from the gross production values of the different fodder treatments. Gross production values were then computed by multiplying the average wheat and bean yields by their respective farm gate prices (276 and 345 US dollars t^{-1} for wheat and beans, respectively).

Using the crop losses incurred by the different fodder models, the objective function was rewritten as follows:

$$\text{Minimize: } 5.529X_1 + 16.443X_2 + 2.286X_3 + 12.986X_4 + 4.929X_5$$

The optimum solution for the Ankole breed was 1462 m of pure setaria, which results in an annual crop loss of US dollars 23, while the improved breed cattle requires 2189 m of pure setaria plus 241 m of calliandra and setaria in association. The latter combination results in a crop loss of US dollars 42.70.

Conclusions

The experiment has shown that pennisetum and setaria can be grown with calliandra in mixtures or separately on contour lines but that high mortality makes sesbania unsustainable. Inclusion of the shrubs increases the overall quality of the fodder and also increases the quality of the grass component. The high production of the pennisetum-based systems is at the expense of adjacent crops. Economic evaluation shows that the optimal grass/shrub combination will depend on both fodder production objectives and on the relative importance of production of fodder and crop. However it is clear that the leguminous shrubs can be part of the solution. Other benefits of the contour plantings, such as erosion control, were not assessed in this study.

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