Tropentag 2006
University of Bonn, October 11-13, 2006
Conference on International Agricultural Research for Development

Biomass production, nutrient uptake and partitioning in planted *Senna spectabilis*, *Flemingia macrophylla* and *Dactyladenia barteri* fallow systems over three fallow/cropping cycles on Ultisol and relationships with crop production

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Abstract

After 5 consecutive maize / cassava intercrops, a hedgerow intercropping trial on Ultisol in southern Cameroon was converted to a 2-year fallow, 1-year groundnut/maize/cassava intercropping system. Biomass and nutrients of all components in planted *Senna spectabilis, Dactyladenia barteri* and *Flemingia macrophylla* hedgerow fallow were determined after 3 2-year fallow phases and compared to natural fallow. Total above-ground biomass was significantly higher in the *S. spectabilis* system than any other system, due to the significantly higher biomass production of the planted tree. Total above ground biomass in the *F. macrophylla* and the *D. barteri* systems was not different from that in natural fallow. The volunteer biomass between hedgerows was only once significantly reduced by *S. spectabilis* during the first fallow phase. The amount of litter did not differ between fallow systems. The biomass of *S. spectabilis, F. macrophylla* and *D. barteri* comprised 96, 95 and 65 % wood, respectively. Relative to the total biomass, wood constituted 67% in *S. spectabilis* and about 20% in *F. macrophylla* and *D. barteri* systems. Except for Mg, the *S. spectabilis* system accumulated more nutrients in above ground biomass than any other system. The highest nutrient uptake achieved in the *S. spectabilis* system was 335 kg ha^{-1} N, 331 kg ha^{-1} Ca, 230 kg ha^{-1} K, and 39 kg ha^{-1} P. Relative to the *S. spectabilis* system, nutrient accumulation, except for Mg, was the lowest in the natural fallow control followed by the *F. macrophylla* and the *D. barteri* system. In *F. macrophylla* and *S. spectabilis,* 95% and 85% of the nutrients were accumulated in the wood. In *D. barteri* the nutrient distribution between leaves and wood was approximately equal. Export of the hedgerow wood would remove between 9 and 16 % of the nutrients accumulated in the *F. macrophylla* and *D. barteri* systems but between 27 and 53% in the *S. spectabilis* system.

Introduction

Traditional long-fallow shifting cultivation can no longer meet the food requirements in most of humid sub-Saharan Africa. Increasing population densities are posing a serious threat to the natural resource base and agricultural production because farmers' major response to higher food demands has been either an increase in cultivated area or a reduction of fallow length. The minimum fallow length to maintain crop production was estimated at 12 years (Laudelout 1990). Fallow phases in most of the humid zone of West and Central Africa are between 5 and 2 years (Gockowsky et al., 2002), reinforcing the need to seek alternative of food production systems. Planted tree fallow, often arranged in hedgerows, is one such alternative. On relatively fertile Alfisols, on-station and in maize dominated systems these fallows were shown to be productive in annual cropping. However, on West and Central African Ultisols and Oxisols and where cassava is a major staple, continuous cropping has not been as successful. Due to the long growing period of the cassava, hedgerows need to be pruned continually and can not accumulate sufficient amounts of nutrients to make a significant contribution to the nutrient supply of crops. Real fallow phases appear to be necessary on less fertile Ultisols and Oxisols. However, very little information is available on the nutrient accumulation in short fallows. Therefore this system was maintained through 3 cycles of 2 years fallow and 1 year cropping to determine if: (1) planted hedgerow fallow species produce more biomass than natural fallow; (2) planted hedgerow fallow species accumulate more nutrients in biomass than natural fallow; (3) the (hypothetical) export of wood after the fallow phase will significantly reduce the amounts of nutrients retained.

Materials and methods

The trial was established on an isohyperthermic, Typic Kandiudult at the research farm of the International Institute of Tropical Agriculture, Humid Forest Eco-regional Center, Mbalmayo, southern Cameroon, (3°51' N, 11°27' E) in May 1990. Average annual precipitation is 1513 mm with a bimodal distribution. Rains start in mid-March stop mid-July and restart end of August to stop at mid November. The trial was a randomised complete block design, replicated 3 times, with 3 hedgerow species, *S. spectabilis, F. macrophylla* and *D. barteri* versus a natural fallow control. Cropping started in April 1991. Plots measured 28 m x 6 m and had five hedgerows at 6m interrow and 0.25 m intrarow distance. All above ground biomass was sampled and separated into litter, interrow volunteers, hedgerow wood, leaves and fruit. Samples were dried ground and analyzed for N, P, K, Ca, Mg. Data were analysed in SAS release 6.12 using proc GLM. Least square means (lsmeans) and the probability of differences for pairwise comparisons (p diff) between lsmeans were calculated.

Results

Total aboveground biomass was greater in the *Senna spectabilis* system in each fallow phase than in any other fallow system (Table 1). The *D. barteri*, *F. macrophylla* and the natural fallow system were not different. Biomass in the natural fallow increased over the fallow phases, yet decreased in the *S. spectabilis* system.
Biomass of volunteers was affected by fallow type only in 1998, with significantly less biomass in the interrows of the *S. spectabilis* system than in any other system. In all following years differences in volunteer biomass between systems were not significant.
Litter biomass recovered in 1998 was not affected by the fallow systems. In 2001, between 10.9 Mg ha^{-1} (*S. spectabilis*) and 15.4 Mg ha^{-1} (natural fallow) of litter were found. In 2004, litter ranged between 8.14 Mg ha^{-1} (*D. barteri*) and 12.04 Mg ha^{-1} (natural fallow); neither in 2001 nor 2004 were differences significant.
Hedgerow biomass was in all fallow phases largest in *S. spectabilis* than the other species. *Dactyladenia barteri* consistently produced more biomass than *F. macrophylla* but the difference was not significant. Leaf biomass was significantly higher in *D. barteri* (3.15 Mg ha^{-1}) than in *S. spectabilis* (1.19 Mg ha^{-1}) and *F. macrophylla* (0.20 Mg ha^{-1}) ($p<0.001$). *Senna spectabilis* produced significantly more leaves than *F. macropphylla* ($p<0.014$). Fruit biomass was negligible. In all species wood contributed the largest proportion to the biomass of the hedgerows: 95.5%, 95.1 % and 64.7 %, in *S. spectabilis, F. macrophylla* and *D. barteri,* respectively. *Senna spectabilis* hedgerow biomass declined with each fallow cycle. *Dactyladenia barteri* and *F. macrophylla* did not have a clear trend in biomass production.
Over the three fallow phases the relative contribution of the hedgerows to the total biomass declined in all hedgerow species. In the *F. macrophylla* and the *D. barteri* system this decline lead to hedgerows contributing less than the litter and the volunteers. The contribution from litter was very constant over the fallow phases except for the natural fallow where it decreased slightly. The contribution of the interrow volunteers increased.

Table 1: Total aboveground biomass (volunteers, litter, hedgerows) accumulated during three cycles of 2 years of fallow at Mbalmayo, southern Cameroon.

	1998	2001	2004	Mean
Natural fallow	19.04	23.70	23.78	22.17
Dactyladenia	27.31	31.69	21.04	26.68
Flemingia	24.74	30.82	23.22	26.26
Senna	59.94	56.08	43.57	53.20
Mean	32.76	35.57	27.90	32.08
P diff				
Senna vs Natural fallow	<0.0001	0.0002	0.0023	0.0001
Senna vs *Dactyladenia*	0.0002	0.0009	0.0012	0.0001
Senna vs *Flemingia*	0.0002	0.0007	0.0020	0.0001

Nutrient accumulation in hedgerow, volunteer and litter biomass across the three fallow phases, except for Mg, was significantly higher in the *S. spectabilis* system, than any other system (Table 2). Across the fallow phases, lowest amounts of nutrients were found in the natural fallow system. Amounts of nutrients accumulated in the *D. barteri* system did not differ from those in the *F. macrophylla* system.

Nutrients amounts in volunteers, across years, were the lowest in the *S. spectabilis* system. In 1998, the volunteer regrowth between hedgerows of *F. macrophylla* contained the highest amounts of N, Ca, Mg, and K. In 2001, the amounts of N, P, K and Ca in volunteers did not differ between the fallow systems. Magnesium content was significantly lower in volunteers between *S. spectabilis* hedges (7.9 kg ha^{-1}) than in the natural fallow control (15.6 kg ha^{-1}) and between *F. macrophylla* hedges (19.4 kg ha^{-1}). In 2001, the volunteers between *F. macrophylla* hedges contained the highest amounts of nutrients. In 2004, the amounts of nutrients in volunteers did not significantly differ between fallow systems

The amounts of nutrients in the litter only differed in 1998 between fallow systems. In the *S. spectabilis* system more P (8.82 kg ha^{-1}, $P<0.008$) and more Ca (90.16 kg ha^{-1}, $P<0.005$) had accumulated in the litter than in all other systems (P: 3.39 – 5.2 kg ha^{-1}; Ca: 22.77 – 35.15 kg ha^{-1}). Nitrogen content in litter in the *S. spectabilis* system was higher (80.39 kg ha^{-1}) than in the *D. barteri* system (45.1 kg ha^{-1}) and in the control (37. 66 kg ha^{-1}; $P<0.016$) and more N in litter was accumulated in the *F. macrophylla* (65.8 kg ha-1; $P< 0.04$) than in the control system. However, in 2001, 2004 and across the three fallow phases (Table 4), no differences could be discerned between systems in litter nutrient contend.

After each fallow phase, nutrient content was highest in *S. spectabilis* hedgerow biomass and lowest in *F. macrophylla*. Across the three fallow phases *S. spectabilis* hedgerow biomass contained significantly more of all nutrients than *F. macrophylla* and more N, Ca, K and P than *D. barteri*. No differences were found between *D. barteri* and *F. macrophylla*.

With the exception of P, *S. spectabilis* accumulated substantially less nutrients during the second fallow phase, ending in 2001, than in the first fallow phase. Amounts of nutrients in fruits were negligible in all hedgerow species. Between 78% and 93% of the nutrients accumulated in *F. macrophylla* biomass were stored in the wood. In *S. spectabilis* these proportions were slightly lower ranging from 74% to 89%. In *D. barteri,* which maintained a full canopy through the dry season, about 50 % of the N, Ca and Mg, 45% of the K and 38% of the P were in the leaves.

Relative to the total amount of nutrients accumulated in all biomass, hedgerow wood of *D. barteri* and *F. macrophylla* did only contain between 9 and 16 % of any nutrient. *Senna spectabilis* wood however contained between 27% (Mg) and 53% (K) of the total nutrients.

Table 2: Total nutrient content (kg ha^{-1}) in all aboveground biomass (volunteers, litter hedgerows) in *Senna spectabilis*, *Flemingia macrophylla, Dactyladenia barteri* , and natural fallow, mean of 3 cycles of 2 years of fallow, Mbalmayo, southern Cameroon.

	Nitrogen	Calcium	Magnesium	Potassium	Phosphorus
Senna spectabilis	321.4	313.9	42.6	233.0	37.9
Dactyladenia barteri	176.5	164.0	43.5	146.4	21.6
Flemingia macrophylla	189.9	172.3	46.7	136.2	17.8
Natural fallow	135.6	139.6	42.1	124.6	16.4
P for pairwise comparison					
Senna vs *Flemingia*	0.004	<0.001	ns	<0.001	<0.001
Senna vs *Dactyladenia*	0.003	<0.001	ns	<0.001	<0.001
Senna vs natural fallow	<0.001	<0.001	ns	<0.001	<0.001
Dactyl vs natural fallow	ns	ns	ns	ns	0.032

Disussion

Planted tree hedgerow fallow does not generally produce more biomass than the natural fallow. The declining biomass production in all planted systems may indicate a lack of sustainability. This may be an indication that these tree species are not suited for long-term use in fallow-cropping cycles. Biomass production of the hedges during the cropping phases declined as well, indicating that the rigorous cutting back after two years of growth may not be a sustainable management option for the trees, yet was required to assure good crop performance. Volunteer biomass steadily increased in all systems, probably as the consequence of declining vigour of the hedgerow species or due to an increased dominance of more vigour of the volunteers such as *Chromolaena odorata*. Both factors bcontribute to reduced biomass production of hedgerow trees.

The increased biomass production in the *S. spectabilis* system was accompanied by an increased nutrient accumulation, yet *F. macrophylla* and *D. barteri* did not generally accumulate more nutrients than the natural fallow control system. Thus planted tree hedgerow fallow does not generally accumulate more nutrients than natural fallow. The export of the wood would result in a less intensive burn with potentially less negative effects on the soil. However, 75 to 90% of the nutrients accumulated by *F. macrophylla* and *S. spectabilis* would be exported, which could have negative effects on the nutrient supply to food crops. Considering that the P, Mg and K stocks in southern Cameroonian Ultisols are rather low, the export of around 15 – 30 kg ha^{-1} of P, 30 – 50 kg ha^{-1} of Mg and 100 to 150 kg ha^{-1} of K every three years, in addition to exports by food crops, will inevitably reduce stocks to critical levels for crops.

References

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