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Nitrogen fixation and balance in burned versus mulched *Mucuna pruriens* var. *utilis* and *Pueraria phaseoloides* relay maize cropping systems

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Abstract
The contribution of the cover crops *Mucuna pruriens* var. *utilis* and *Pueraria phaseoloides* to the N balance of a sole maize relay cropping system was estimated. Over 4 consecutive years, amounts of N in 8-9 months old aboveground *M. pruriens*, *P. phaseoloides* and natural fallow biomass and litter were determined. Fallow biomass was either burned or retained as mulch. Maize aboveground N uptake and N export with grain was determined. The amount of N_2-fixed was estimated with the N difference method. In 1998, 1999, and 2000, N content in *M. pruriens* and *P. phaseoloides* biomass was higher than in natural fallow. In 2000 and 2001 biomass in previously burned plots contained less N than when biomass had been retained. Fallow-type and biomass management did not interact. Maize N uptake was higher after biomass burning in 1998, yet thereafter higher when biomass was retained. Fallow type had only in 1999 an effect, with highest maize N uptake in the *P. phaseoloides* system, followed by the *M. pruriens* system and the natural regrowth. The estimated amounts of N_2-fixed were higher in the *P. phaseoloides* system; biomass management had no effect. Nitrogen export with maize grain was highest in the *P. phaseoloides* system, followed by the *M. pruriens* system; biomass management had no effect. Maize N uptake into the aboveground biomass and N export with grains was balanced by the amount of N in fallow biomass in all systems when biomass was retained. The amount of N_2-fixed did not balance the amount taken up by the maize. In the *M. pruriens* system the N exported with grains was not balanced by N_2 fixation, the *P. phaseoloides* system had a positive balance of N export in grain versus the amount of N_2 fixed.

Introduction
Maize as a sole crop, is rapidly gaining importance in the humid forest zone of West and Central Africa because feed millers and breweries buy large quantities of dry grain and fresh cob sales are a convenient cash income source, especially in peri-urban areas. Where smallholders' access to N fertilizer is limited, maize has been the target of planted, leguminous fallows, which, through symbiotic N-fixation, appear capable to provide more N than the natural fallow, allowing sole maize crops at high plant densities. However, the most labour efficient slash & burn land preparation may cause the loss of benefits from N fixation. On the other hand, little experience has been gathered in humid Africa on the feasibility of and maize yield responses to slash & mulch versus slash & burn of cover crops. The mulch may retain most of the N_2-fixed yet may require more labour. This experiment was established to determine the effect of three fallow types: *Mucuna pruriens* var. *utilis, Pueraria phaseoloides* and natural regrowth and burning

versus retaining the biomass on maize N uptake, N export with grain and the N balance in an annually cropped relay system.

Material and methods

The trial was carried out at the IITA Humid Forest Eco-regional Centre at Mbalmayo (3°51' N, 11°27' E), southern Cameroon on an isohyperthermic typic Kandiudult. Average annual rainfall is 1513 mm in a bimodal distribution, starting mid-March to mid-July (first season) and from September to the middle of November. Cover crops were seeded in 1993. In 1994 and 1995 the trial was planted to maize as a single factor complete randomised block design with 3 replicates, comparing *M. pruriens* and *P. phaseoloides* with natural fallow. The trial was in fallow during 1996. Late February 1997 plots were slashed and split into 2 subplots where biomass was retained or burned. In 1998 to 2001, all living biomass and litter was collected in 5 squares of 0.75 x 0.75 m per plot in mid February. Maize cv. CMS 8704 (open pollinated, 90-100 days to maturity) was planted in a square configuration at 0.5 x 0.5 m distance and thinned to 4 plants m^{-2}. The cover crops were not re-seeded after the maize harvest but re-established voluntarily.
The amount of N_2-fixed by *M. pruriens* and *P. phaseoloides* was estimated by the N-difference method, using the natural fallow biomass as reference, such that:
N_2-fixed = N in biomass of cover crop plot – N in biomass of reference plot.
Four balances, based on aboveground biomass only and the assumption that fallow biomass N was completely lost by burning, were drawn between N accumulated in fallow biomass versus N accumulation in maize biomass and versus N exported with maize grains; and between N_2-fixed versus N accumulation in maize biomass and versus N exported with maize grains.
Statistical analyses were performed on untransformed data using the GLM procedure in SAS release 8, and calculating least square means (lsmeans).

Results

Nitrogen in fallow biomass

The mean amount of N in the fallow biomass over the four years was the lowest in natural fallow (Table 1). *Pueraria phaseoloides* fallow accumulated more N than *M. pruriens* fallow. Burning biomass before planting maize reduced the amount of N in biomass in two of the following years and on average over the four-year period. There was no fallow type x biomass management interaction in any year or across the years.

Amount of N_2-fixed by Mucuna and Pueraria

Pueraria phaseoloides fixed more N_2 than *M. pruriens* in 2001 and across the four years (Table 2). Biomass burning had no effect on the amounts of N_2 fixed. There was no fallow type x biomass management interaction.

Nitrogen content in aboveground maize biomass and N export with maize grain

Burning had a positive effect on maize N uptake in 1998, yet reduced maize N accumulation in the following years. In 1999 maize N uptake was larger in *P. phaseoloides* fallow compared with both other fallows. In *M. pruriens* fallow maize N uptake was higher than in the natural fallow. Nitrogen exports with maize grains were not different between fallow types in 1998, but higher after both leguminous fallows than after natural fallow in 1999 and 2000. Biomass management had no effects from 1998 to 2000, yet in 2001, maize grain N export was more than 50% higher in biomass retained treatments than in biomass burned treatments.

Nitrogen balances

Due to the complete loss of biomass N in burned plots, N balances are the negative equivalent of the amounts of N accumulated in the maize biomass or the grain exported.

Table 1: Nitrogen content (kg ha^{-1}) of *Mucuna pruriens, Pueraria phaseoloides* and naturalfallow biomass, at slashing in 1998 to 2001, Mbalmayo, Cameroon.

Fallow type	Biomass management	Nitrogen content (kg ha^{-1})				
		1998	1999	2000	2001	Mean
Natural		105.6	110.0	115.2	105.5	109.1
Mucuna		141.4	152.0	172.2	111.9	144.4
Pueraria		142.9	209.6	234.7	153.0	185.0
	Retained	138.1	162.5	206.7	149.1	164.1
	Burned	121.8	151.9	141.3	97.8	128.2
		Pairwise comparison				
Natural vs. *Mucuna*		0.030	ns	ns	ns	0.018
Natural vs. *Pueraria*		0.026	0.019	0.003	ns	<0.001
Mucuna vs. *Pueraria*		ns	ns	0.041	ns	0.010
Burned vs. retained		ns	ns	0.016	0.011	0.007

Table 2: Estimated amounts of nitrogen fixed (kg ha^{-1}) by *Mucuna pruriens* var. *utilis* and *Pueraria phaseoloides* fallow, in 1998 to 2001, Mbalmayo, Cameroon.

Fallow type	Biomass management	Nitrogen fixed (kg ha^{-1})				
		1998	1999	2000	2001	Mean
Mucuna		35.8	42.0	57.0	6.4	35.3
Pueraria		37.2	99.6	119.5	47.5	76.0
	Retained	10.7	57.6	90.1	25.9	46.1
	Burned*	62.3	84.0	86.4	28.0	65.2
		Pairwise comparison				
Mucuna vs. *Pueraria*		ns	ns	0.095	0.002	0.033
Burned vs. retained		ns	ns	ns	ns	ns

* Note: estimates made before burning, the N fixed in aboveground biomass was lost in the burn.

N in fallow biomass – N in maize biomass and maize grains

In mulched plots the amount of N in the fallow biomass was larger that the N uptake by the maize in all years. Accordingly, N export with maize grain was lower than the N amounts in fallow biomass. In all cases the balance was the lowest in the natural fallow. In 1999 both legume fallows had more positive N balances than natural fallow. In 2000, all three fallow types were different, in the order Pueraria > Mucuna > natural fallow. On average across all four years, Pueraria had a more positive balance than both Mucuna and natural fallow.

N_2-fixed - N in maize biomass and maize grain

With the exception of the Pueraria biomass retained system in 1999 and 2000, N_2-fixation did not balance the N uptake into maize aboveground biomass. On average across the years, maize N-uptake was not balanced by N_2-fixation of any of the legumes. In all years but 2000, the balance was not different between the legume species. In 2000 there was a significant interaction, such that both burned legume treatments had a more negative balance than the mulched treatments and the difference within *P. phaseoloides* being larger than within *M. pruriens* fallow. The legume species had no effect on the balance of N_2-fixed versus the N export in grain in any year and on average across years. In 1998, N_2-fixation did not balance the N export with maize grains in any of the fallow types and biomass management systems (Table 3). In 1999, biomass retention had a

more positive balance compared with biomass burned ($P = 0.07$). In 2000, and on average across the four years, biomass retention had a significantly more positive balance compared to biomass burned.

Table 3: Nitrogen balance of amounts of N fixed versus N export with the maize grain harvest (kg ha^{-1}) after *Mucuna pruriens* var. *utilis* and *Pueraria phaseoloides* fallow, in 1998 to 2001, Mbalmayo, Cameroon.

Fallow type	Biomass management	Nitrogen balance (kg ha^{-1})				
		1998	1999	2000	2001	Mean
Mucuna		-28.6	-16.0	-1.8	-24.0	-17.6
Pueraria		-31.8	7.2	20.7	-5.6	-2.4
	Retained	-24.0	22.3	53.7	-5.8	11.5
	Burned	-36.5	-31.1	-34.7	-23.9	-31.5
		Pairwise comparison				
Mucuna vs. *Pueraria*		ns	ns	ns	ns	ns
Burned vs. retained		ns	ns	0.007	ns	0.031

Relationships

The amount of N in fallow biomass was not correlated with the N uptake into aboveground maize biomass in 1998 irrespectively of biomass management. For the years 1999 to 2001, weak, yet significant correlations were found (Figure 1), depending on biomass management. Across years, legume species and biomass management, N uptake into maize biomass was not correlated with the amount of N_2-fixed. Neither within any year, nor within the different biomass management treatments or within the two legume species was N_2-fixation correlated with maize N uptake or with the grain yield.

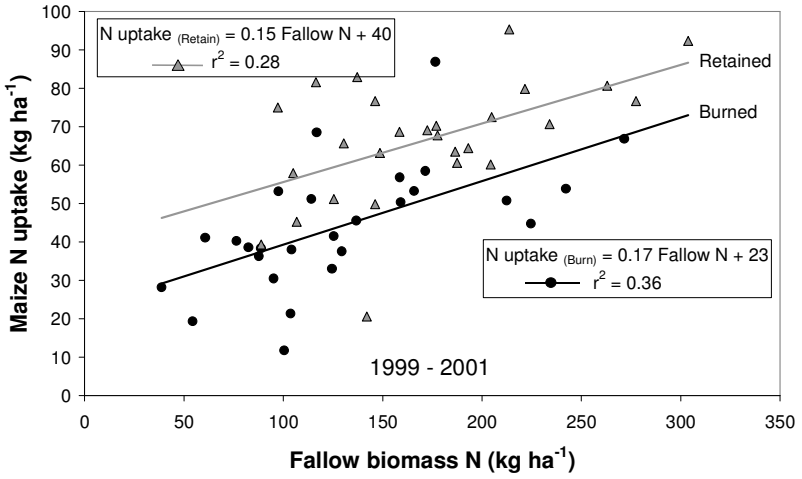

Figure 1: Relationships between N content in the fallow biomass and N uptake into maize aboveground biomass in biomass retained and biomass burned treatments. Mbalmayo, 1999 – 2001, southern Cameroon.

Note: in biomass burned the N of the fallow biomass was lost in the burn before maize planting.

Conclusion

The amounts of N_2 fixed did not cover exports. However, the method to estimate N_2-fixed is not free of errors, which were likely to have caused underestimation of amounts of N_2 fixed due to differential losses from legume versus natural fallow biomass to the soil. Estimates of N_2 fixed were relatively low, yet the legume systems produced maize grain yields higher than in natural fallow for some years. Burning biomass did not have a negative effect on the amounts of N_2 fixed, yet had obviously strong negative N balances. The systems need to be monitored for longer time to assess if the legumes and the different biomass managements can sustain production.