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Influence of dry season supplementation for cattle on soil fertility and millet (*Pennisetum glaucum* L.) yield in a mixed crop/livestock production system of the Sahel

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Abstract

An experiment was conducted in 1996 and 1997 in semi-arid Niger, to determine the influence of supplementation (no supplement, supplemented with millet bran + simple superphosphate + blood meal) of cattle and mulching (0 or 3 t ha^{-1} of *Aristida sieberiana straw*) on soil fertility and millet yield. Manure was applied through corralling at a rate of 3 t faecal dry matter (FDM) ha^{-1} alone or associated to mulching. The residual effects of the treatments were measured on a second millet crop in 1997. Compared to control, the association of mulching and corralling of supplemented as well as non supplemented cattle increased soil pH (KCl) ($P < 0.01$), Bray1-P ($P < 0.05$) and NH_4-N ($P < 0.05$); grain by 136% ($P < 0.01$) stover yeild by moer than 150% ($P < 0.05$); and N and P uptake ($P < 0.01$) during the two cropping seasons. The association of mulching and corralling increased soil NH_4-N ($P < 0.01$) and soil pH ($P < 0.01$), compared to the sole corralling. The improvement of soil chemical properties resulted in grain yield increases of 54% ($P < 0.01$) and stover increases of 42% ($P < 0.01$). The effect of mulching and corralling association on grain and stover yeilds was higher when cattle were supplemented (67 and 50%) than when they were not supplemented (30 and 26%). The effects of the supplementation on grain and stover yields, and N and P uptake by millet, were restricted, when animals were corralled on bare soil (no mulching). The residual effects of supplementation were minimal.

Résumé

Cette expérience a été menée en 1996 et repétée en 1997 dans la zone semi aride du Niger, en Afrique de l'ouest. Elle visait á déterminer l'influence du parcage des bovins supplémentés en saison séche (animaux témoins, animaux supplémentés avec du son de mil + superphosphate simple ou avec du son de mil + superphosphate simple + farine de sang) associé au paillage (0 ou 3 t ha^{-1} de paille d'*Aristida sieberiana*) sur la fertilité du sol et la production de mil. Trois tonnes de matière sèche fécale par hectare (3 t MSF ha^{-1}) ont été appliquées par parcage des bovins sur le sol nu ou au préalable recouvert de paille. Les arrière-effets des traitements ont été mesurés l'année suivante sur une culture de mil. Au cours de la première saison de culture, le paillage associé au parcage des animaux supplémentés ou non supplémentés a augmenté le pH (KCl) ($P < 0.01$), le P (Brayl) ($P < 0.05$) et N-N H_4 ($P < 0.05$) du sol par rapport au témoin (sol nu sans amendement). La production de grain a augmenté de 136% ($P < 0.01$) et celle de chaume de mil de plus de 150% ($P < 0.05$). Les prelévements de N et P par le mil ont également augmenté ($P < 0.05$) par rapport au témoin au cours des deux saisons de culture. Le parcage des bovins sur la litière a augmenteé N-NH_4 ($P < 0.01$) et le pH ($P < 0.01$) du sol par rapport au parcage seul (sur sol nu). Cette amélioration des propriétés chimiques du sol a entraîné une augmentation de la production de grain 54% ($P < 0.01$) et de chaume de mil de 42% ($P < 0.01$). Comparé au parcage seul, l'association du paillage et du parcage était plus efficace sur Ia production de grain (+67%) et de chaume (+50%) lorsque les animaux étaient supplémentés, que s'ils étaient nourris exclusivement au pâturage naturel (+30 et +26%). Cependant, ces effets de la supplémentation sur la production de grain, de chaume de mil et le prelèvement de N et P étaient restreints lorsque les animaux étaient parqués méme le sol. Les effets résiduels de la supplémentation étaient assez faibles.

Introduction

Low soil organic matter (OM), nitrogen (N) and assimilable phosphorus (P) are amongst the main constraints to crop and range land production in Sahelian mixed crop/livestock systems. Continuous cropping and grazing with little or no fertilizer input resulted in nutrient mining, which in turn led to declining yields. Several studies (Mc Intire and Powell 1995; Sanchez et al. 1997; Breman 1998; Muehlig-Versen et al. 1998; Buerkert and Hiernaux 1998) concluded that the use of external input remains the only solution to equilibrate the nutrients balance.

Manure application is known to increase millet yield and enhance soil P and exchangeable bases availability as well as soil OM (Pieri 1986; Bationo and Mokwunye 1991). However, faecal and urinary N greatly depends on livestock diet quality (Powell et al. 1994; Somda et al. 1995). Thus in addition to improving livestock performance (Sangaré, personal comm.) supplementing livestock during dry season may result in improved manure quality and increased crop yields. Phosphorus is mostly excreted through faeces and is stable in the soil, whereas N is excreted via both faeces and urine and is particularly subject to volatilization (Stillwell and Woodmansee 1981; Vallis et al. 1982) and leaching. Hence procedures that improve capture of faecal and urinary N are needed to optimize the profit from enriched N content in excretions following the dry season supplementation of cattle. The objective of this study was to evaluate the influence of corralling dry season supplemented cattle, associated or not with mulching on Sahelian sandy acid soil fertility restoration and millet yield.

Materials and methods

Experimental site

The study was conducted at Boundou, (13°32′30″ N; 02°35′00″ E), 70 km East to Niamey, Niger, in semi-arid tropical Sahel. Average rainfall is 450 mm distributed from June to September. Average forage availability (DM) in October 1995 was 733 ± 24 kg ha^{-1} herbage mass on natural pasture, 172 ± 5 kg ha^{-1} weeds on croplands, 1600 ± 35 kg ha^{-1} millet stover (Hiernaux et al. 1998). At the end of the dry season in June 1996, the remaining forage mass for the different categories was 113 ± 6 kg ha^{-1}, 25 ± 1 kg ha^{-1} and 229 ± 26 kg ha^{-1} respectively. Woody plant cover was dominated by *Guiera senegalensis*, *Combretum glutinosum* and *Combretum micranthum*.

Treatments

Agronomic trials were carried out in conjunction with a feeding trial, which involved 27 steers (198.8 ± 14.8 kg per animal and 2–4 years), in 3 groups of 9 animals each (Sangaré, personal comm.). Animals were herded together on dry season natural pasture from 08h00 to 18h00. The three diets consisted of no supplement (No sup) or, supplements of millet bran (4.1 g DM kg^{-1} LW), salt (15 g NaCl per animal d^{-1}) and P (20 g simple superphosphate per animal d^{-1}) (Mb), or millet bran (4.1 g DM kg^{-1} LW), salt (15 g NaCl per animal d^{-1}), P (20 g simple superphosphate per animal d^{-1}) and blood meal (0.22 g kg^{-1} LW) (MbBm).

In the agronomic trial, manure from each supplementation group was applied at the rate of 3 t faecal dry matter (FDM) ha^{-1} by corralling of 9 animals during three nights on 8×8 m plots. For each corralling treatment the plot soil was either bare or covered with mulch of *Aristida sieberiana* at the dose of 3 t ha^{-1}. The mulch contained 3 g N and 0.2 g P kg^{-1}DM. Faecal N and P (g kg^{-1} FDM) of corralled animals were: no sup (control) 14.9 and 1.7; Mb 18 and 4.2; MbBm 18.6 and 4.9 respectively (Sangaré, personal comm.). The six treatments plus control (no manure, no mulching) were implemented in four replications (complete randomized block design).

Table 1. Treatments description

Treatments	Treatments description[a]
Pe + Pn	Corralling (3 t FDM ha^{-1}) of no supplemented cattle on mulch of *A. sieberiana* straw (3 t ha^{-1})
Pe + Sup1	Corralling (3 t FDM ha^{-1}) of cattle supplemented with Sup1 on mulch of *A. sieberiana* straw (3 t ha^{-1})
Pe + Sup2	Corralling (3 t FDM ha^{-1}) of cattle supplemented with Sup2 on mulch of *A. sieberiana* straw (3 t ha^{-1})
Pn	Corralling (3 t FDM ha^{-1}) of no supplemented cattle on bare soil
Sup1	Corralling (3 t FDM ha^{-1}) of cattle supplemented with Sup1 on bare soil
Sup2	Corralling (3 t FDM ha^{-1}) of cattle supplemented with Sup2 on bare soil
Control	No corralling, no mulching

Sup1 = millet bran + simple superphosphate; Sup2 = millet bran + simple superphosphate + blood meal; Pe = mulching

Bare and mulched replications were manured alternatively (Table 1).

Millet was planted in June 1996 following the corralling treatment in April and May 1996. After harvest, cattle were allowed to graze millet stover, and the refusal (stalks) were left on the plots. A second millet crop was planted in June 1997 to assess the residual effect of treatments. In both years, a landrace of millet was planted at a density of 10 000 pockets ha^{-1}. Soil was sampled only at the onset of 1996 rainy season in all plots, and again after harvest in October 1996. Soil pH (KCl), Bray1-P, organic C, total N, NH_4-N and NO_3-N were determined for the upper 20 cm. Thinning was carried out at twenty five days after planting to three shoots $pocket^{-1}$.

Measurements

During the first year, the growth rate of millet was determined based on plants above-ground dry matter mass (DM) at 25, 55, 65, 75 and 85 days after planting (DAP). Millet grain and stover yields were measured at harvest (118 DAP). Nitrogen (N Kjeldahl) and total P contents in grain, leaves and stalks were determined in sub-samples. Nitrogen deposited on bare plots by corralling was calculated by adding N supplied by faeces and N supplied by urine. Nitrogen deposited by mulching and corralling was calculated by adding N supplied by mulch, faeces and urine. In the calculation of P supplied by corralling, only fecal P was taken into account. Faeces deposited in each plot were weighed every morning. Urinary N deposited on the plots was calculated by subtracting faecal N and N retained as weight gain (or lost) from ingested N. N retained or lost was predicted according to Waller et al. (1982). Then, fifty percent (50%) of urinary N excreted during night corralling was presumed as lost through volatilization (Powell et al. 1998).

Statistical analyses

Variance analysis (GLM procedures, Statistical Analysis System Institute (1987)) was used to assess treatments and replicates effects on soil parameters, millet growth rates, grain and stover yields and N and P uptake by millet. Contrasts were used to compare treatment effects. The significance level was fixed at $P < 0.05$.

Results

Soil chemical properties

The corralling of cattle associated or not to mulching, increased soil pH ($P = 0.01$), NH_4-N ($P < 0.03$) and Bray1-P ($P < 0.01$) compared to control (Table 2). However soil organic C (OM) and total N were not affected significantly by corralling. Cattle supplementation resulted in increased ($P = 0.02$) soil Bray1-P, but lower pH on bare plots ($P < 0.02$). Additional effect of mulching increased soil pH ($P < 0.01$) and NH_4-N levels ($P < 0.01$) compared to corralling animals on bare soil. On comparing soil parameters before and after the first cropping season, an acidification and a slight reduction (2.6 vs 2.1) of soil Bray1-P were observed especially on control plots ($P < 0.05$).

Millet growth

Whatever the treatment, millet growth rate increased from emergence (0–65 DAP) to heading (65–85 DAP). Millet growth rate was much higher on corralled plots than on the control and was also enhanced by mulching (Figure 1).

Grain and crop residue yield

During the first cropping year, compared to control, mulching plus corralling significantly increased grain yield on average by 787 kg ha^{-1} and millet stover by 2699 kg ha^{-1} ($P < 0.01$); whereas corralling on bare soil increased grain yield by only 307 kg ha^{-1} ($P < 0.01$) and stover yield by 1353 kg ha^{-1} ($P < 0.01$)

Table 2. Effects of corralling supplemented cattle with or without mulching on soil chemical properties at 0 to 20 cm soil depth in June (onset rainy season).

Treatments[a]	Soil property						
	pH_{KCl}	P_{Bray} (ppm)	C_{org} (%)	N_{total} (ppm)	$N\text{-}NH_4^+$ (ppm N)	$N\text{-}NO_3^-$ (ppm N)	C/N
Pe + Pn	5.1	2.3	0.163	154	3.5	0.60	10.7
Pe + Sup1	5.0	3.1	0.156	156	3.2	0.58	10.1
Pe + Sup2	4.9	2.6	0.153	151	2.9	0.48	10.3
Pn	4.9	1.6	0.170	161	2.9	0.58	10.9
Sup1	4.7	3.4	0.142	129	2.2	0.43	11.1
Sup2	4.6	3.1	0.144	140	2.3	0.57	10.2
Control	4.5	1.8	0.134	138	2.1	0.45	9.8
Sem[b]	0.08	0.52	0.01	16.2	0.31	0.05	0.63
Contrast	P > F[c]						
Control vs others	0.01	0.01	0.11	0.56	0.03	0.15	0.28
Pe + Prc vs Prc	0.01	0.93	0.57	0.45	0.01	0.53	0.50
Pn vs Sup (1 + 2)	0.02	0.02	0.08	0.36	0.08	0.11	0.47
Pe + Pn vs Pe + Sup (1 + 2)	0.18	0.39	0.54	0.98	0.27	0.26	0.49

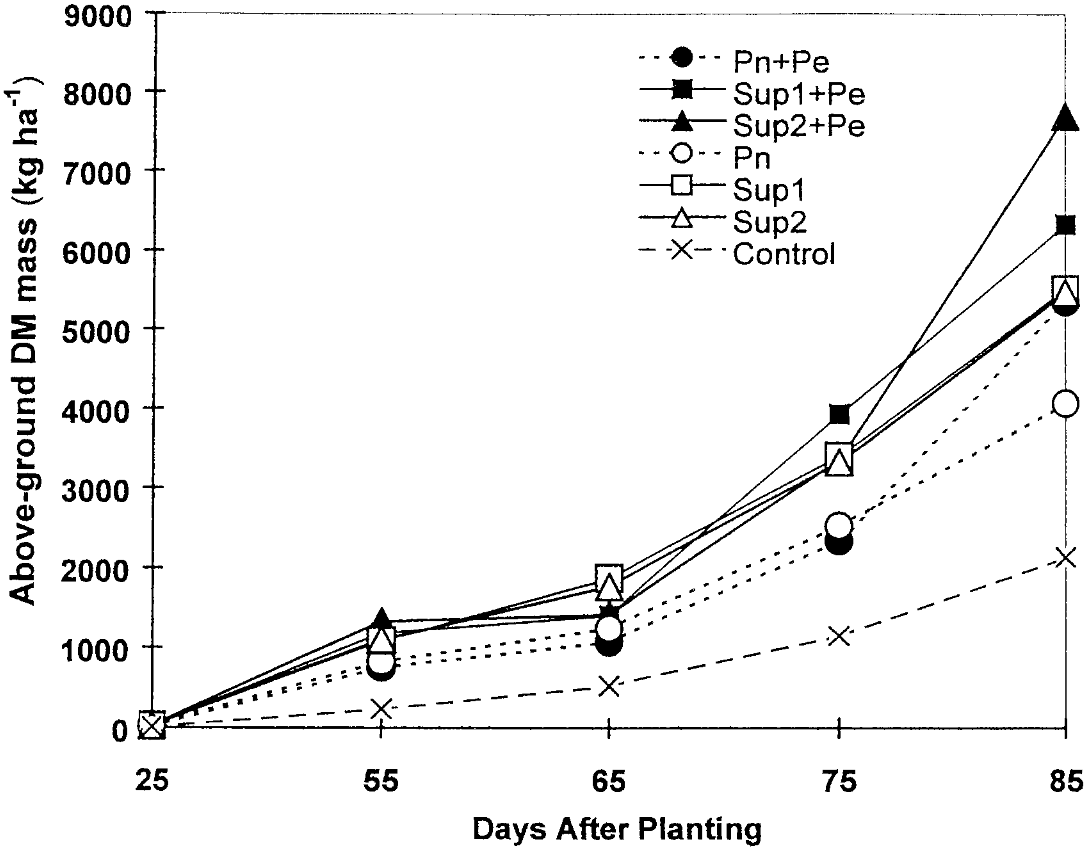
[a]Pn: corralling of unsupplemented animals; Sup 1: corralling of animals supplemented with millet bran + simple superphosphate; Sup2: corralling of animals supplemented with millet bran + simple superphosphate + blood meal; control; no mulching, no corralling; Prc: corralling; Pe: mulching;
[b]sem = Standard error of treatments means;
[c]Significance level = P < 0.05.

(Table 4). Thus mulching plus corralling increased grain ($P < 0.02$) and stover ($P < 0.01$) yields compared to sole corralling. With supplemented animals, differences between mulched and non mulched plots increased grain yield by 588 kg ha^{-1} and stover by 1609 kg ha^{-1}. With non-supplemented animals, mulching had less effect on grain (+264 kg ha^{-1}) and stover (+821 kg ha^{-1}) yields ($P < 0.05$). Effects of supplementation was more effective ($P < 0.05$) on grain (+318 kg ha^{-1}) and stover yields (+846 kg ha^{-1}) when corralling was associated to mulching. When animals were corralled on bare soil, effects of supplementation on millet yields were very low (Table 4).

Table 3. Effects of corralling supplemented cattle with or without mulching on soil chemical properties at 0 to 20 cm soil depth at the end of the rainy season (harvest)

Treatments[a]	Soil property						
	pH_{KCl}	P_{Bray} (ppm)	C_{org} (%)	N_{total} (ppm)	$N\text{-}NH_4^+$ (ppm N)	$N\text{-}NO_3^-$ (ppm N)	C/N
Pe + Pn	4.7	1.96	0.162	129	1.1	8.3	13
Pe + Sup1	4.5	1.73	0.136	115	1.2	7.2	12
Pe + Sup2	4.4	2.58	0.165	135	1.8	7.5	13
Pn	4.6	1.88	0.148	117	1.4	7.3	13
Sup1	4.4	2.10	0.134	104	1.1	7.1	13
Sup2	4.6	1.89	0.138	109	1.6	7.9	13
Control	4.4	1.27	0.138	114	1.0	5.3	12
sem[b]	0.11	0.29	0.01	12.7	0.25	0.86	0.7
Contrast	P > F[c]						
Control vs others	0.40	0.03	0.42	0.76	0.23	0.03	0.79
Pe + Prc vs Prc	–	0.56	0.11	0.14	0.93	0.72	0.51
Pn vs Sup (1 + 2)	0.09	0.56	0.20	0.53	0.41	0.62	0.67
Pe + Pn vs Pe + Sup (1 + 2)	0.11	0.60	0.35	0.81	0.20	0.36	0.44

[a]Pn: corralling of unsupplemented animals; Sup 1: corralling of animals supplemented with millet bran + simple superphosphate; Sup2: corralling of animals supplemented with millet bran + simple superphosphate + blood meal; control; no mulching, no corralling; Prc: corralling; Pe: mulching.
[b]sem = Standard error of treatments means.
Significance level = P < 0.05.



Pn: Corralling of unsupplemented animals;
Sup1: Corralling of animals supplemented with millet bran, simple Superphosphate; Sup2: Corralling of animals supplemented with millet bran, simple superphosphate and blood meal; Pe: mulching; Control: no mulching, no corralling;

Figure 1. Effect of mulching and/or corralling dry season supplemented cattle on millet growth

Mulching plus corralling the supplemented animals led to production levels of about 1600 kg ha^{-1} of fodder (leaves + sheath) with 7.6 g N and 1 g P kg^{-1} DM; plus 3000 kg of stalk ha^{-1} with 5.3 g N and 1 g P kg^{-1} DM recycled as mulch during the next cropping season. These yields of fodder and mulching materials were 28% and 32% higher than when unsupplemented animals were corralled on mulched plots (Table 4). On the other hand, mulching plus corralling increased fodder (369 kg ha^{-1}) and mulching material (970 kg ha^{-1}) compared to sole corralling.

Compared to the first year, grain and stover yields were reduced on average by 50% and 28% respectively during the second year (Table 4). Although residual effects had similar trends than effects in the first year, the residual effects of the supplementation were very reduced.

Nitrogen and phosphorus uptake

Within a cropping season, both during first and second year, treatments had little effects on N and P concentration in grain, leaves and stalks (Table 5,6). On the other hand, in all treatments, N and P contents in grain, and only P content in leaves and stalks were higher in the first year than in the second year. Corralling with or without mulching increased ($P < 0.01$) N and P uptake during both years. So did corralling plus mulching compared to sole corralling. When corralling and mulching were associated, the

Table 4. Effect (1996) and carry over effects (1997) of manuring treatments on grain and residues (leaf and stalk) yields (kg ha^{-1})

Treatments[a]	1996 harvest				1997 harvest			
	Grain	Residue	Leaf	Stalk	Gain	Residue	Leaf	Stalk
Pe + Pn	1152	3988	1261	2157	584	2755	878	1546
Pe + Sup1	1528	4628	1473	2749	623	3122	1073	1728
Pe + Sup2	1412	5039	1768	2965	613	3561	1261	1945
Pn	888	3167	1118	1748	494	2263	786	1205
Sup1	845	3240	1317	1596	481	2516	890	1328
Sup2	919	3210	1186	1618	552	2785	948	1523
Control	577	1853	646	925	271	1115	387	589
Sem[b]	120	416	–	–	65	300	–	–
Contrast	P > F							
Control vs others	0.01	0.01	–	–	0.01	0.01	–	–
Pe + Prc vs Prc	0.01	0.01	–	–	0.08	0.02	–	–
Pe + Pn vs Pe + Sup (1 + 2)	0.04	0.01	–	–	0.67	0.13	–	–

[a]Pn: corralling of unsupplemented animals; Sup 1: corralling of animals supplemented with millet bran + simple superphosphate; Sup2: corralling of animals supplemented with millet bran + simple superphosphate + blood meal; control; no mulching, no corralling; Prc: corralling; Pe: mulching.
[b]sem = Standard error of treatments means.
[c]Significance level = $P < 0.05$.

supplementation increased N uptake during the first year and both N and P uptake during the second cropping season. In contrast, without mulching, supplementation had no effect on nutrients uptake (Table 5,6).

Corralling with or without mulching provided to the soil 60 to 80 kg total N and 5 to 15 kg total P ha^{-1} (Table 7). Corralling supplemented animals provided more N and P than unsupplemented. Except in the control, N balance was positive in all treatments. In contrast, P balance was only positive in plots where supplemented animals were corralled.

Discussion

Soil pH and NH_4-N increases following urine deposition have also been reported by Stillwell and Woodmansee (1981), Vallis et al. (1982), Somda et al. (1997), Powell et al. (1998). These increases were in part due to the alkaline pH of urine from ruminants fed dry forage (Church 1975; Schlecht et al. 1998), and could also result from release of OH following enzymatic hydrolysis of urinary N, mostly in urea form (Woodmansee 1978). Such reaction can also increase gaseous losses of NH_3 (Woodmansee 1978),

Table 5. Effect of manuring treatments on N and P concentration (g kg^{-1} DM) in millet organ, and N and P uptake (kg ha^{-1}) by the millet crop

Treatment[a]	N Concentration			N uptake	P Concentration			P uptake
	Grain	Leaf	Stalk		Grain	Leaf	Stalk	
Pe + Pn	26.7	6.9	4.6	49.2	6.5	1.6	1.2	12.1
Pe + Sup1	25.3	8.4	6.1	67.9	5.5	1.0	1.1	12.7
Pe + Sup2	23.3	6.9	4.5	58.5	5.6	1.1	1.0	12.9
Pn	24.4	6.6	4.8	37.3	6.5	0.9	1.4	9.3
Sup1	24.9	5.7	4.1	35.1	5.2	1.2	0.8	7.3
Sup2	23.7	7.1	5.3	38.8	5.7	1.5	1.4	9.3
Control	25.3	8.2	4.9	24.5	6.7	1.4	1.0	5.9
Sem[b]	1.3	0.6	0.5	2.7	0.6	0.3	0.3	1.1
Contrast	P > F[c]							
Control vs others	0.67		0.96	0.01	0.20	0.54	0.67	0.01
Pe + Prc vs Prc	0.49		0.36	0.01	0.84	0.93	0.64	0.01
Pe + Pn vs Pe + Sup (1 + 2)	0.15		0.21	0.01	0.23	0.13	0.60	0.62

[a]Pn: corralling of unsupplemented animals; Sup 1: corralling of animals supplemented with millet bran + simple superphosphate; Sup2: corralling of animals supplemented with millet bran + simple superphosphate + blood meal; control: no mulching, no corralling; Prc: corralling; Pe: mulching.
[b]sem = Standard error of treatments means.
[c]Significance level = $P < 0.05$.

Table 6. Residual-effect of manuring treatments on N and P concentration (g kg^{-1} DM) in millet organs, and N and P uptake (kg ha^{-1}) by the millet crop

Treatment[a]	N Concentration			N uptake	P Concentration			P uptake
	Grain	Leaf	Stalk		Grain	Leaf	Stalk	
Pe + Pn	20.4	6.8	4.3	24.6	3.2	0.6	0.5	3.2
Pe + Sup1	17.8	6.4	4.4	25.6	3.5	0.7	0.6	4.1
Pe + Sup	17.4	6.9	4.0	27.1	3.7	0.9	0.6	4.7
Pn	18.8	6.2	4.7	19.8	3.1	0.6	0.5	2.7
Sup1	18.0	6.3	4.2	19.9	3.6	0.7	0.6	3.1
Sup2	18.1	6.6	4.4	23.0	3.5	0.6	0.6	3.4
Control	18.0	7.2	4.4	10.2	2.7	0.6	0.5	1.3
Sem[b]	0.83	0.78	0.4	1.32	0.12	0.10	0.05	0.14
Contrast	P > F[c]							
Control vs others	0.62	0.47	0.98	0.01	0.01	0.45	0.22	0.01
Pe + Prc vs Prc	0.73	0.62	0.59	0.01	0.01	0.23	0.46	0.01
Pe + Pn vs Pe + Sup (1 + 2)	0.01	0.85	0.81	0.30	0.01	0.07	0.21	0.01

[a]Pn: corralling of unsupplemented animals; Sup 1: corralling of animals supplemented with millet bran + simple superphosphate; Sup2: corralling of animals supplemented with millet bran + simple superphosphate + blood meal; control; no mulching, no corralling; Prc: corralling; Pe: mulching.
[b]sem = Standard error of treatments means.
[c]Significance level = $P < 0.05$.

followed by accumulation of NH_4-N and NO_3-N in the soil. The observed elevated pH and NH_4-N on mulched plots, compared to bare plots, may be due to the effect of mulch on lowering of soil temperature (Buerkert et al. 1996). It is likely, therefore, that mulching promoted accumulation of NH_4-N, and perhaps reduces volatilization, that occurs usually after urine deposition at the soil surface. The observed increases of Bray1-P in response to corralling, resulted from the joint effects of pH increase (by 0.4 point on average) and additional P from faeces of corralled animals. The high level of soil P and the positive balance for P on plots where supplemented animals were corralled, could be mainly attributed to the higher faecal P (2.5 times) brought by supplemented animals. However, the low pH ($P < 0.02$; Table 2) may affect P availability and reduce the effects of additional P from supplement, on plots where supplemented animals were corralled on bare soil.

Non significant effects of treatments on soil OM was expected. Indeed, results from Sommerfeldt et al. (1988), indicate that the amount of manure applied by corralling during the present study were not sufficient to result in measurable increase of soil organic matter in the 0–20 first cm of soil.

The enhanced growth rate of millet and increased grain and stover yields that followed corralling associated or not to mulching, resulted from the additional N and P brought through faeces and urine, and from

Table 7. Calculated contributions of mulch and cattle manure to the N and P supplies (kg ha^{-1}), and potential recycling from stalks of first cropping (kg ha^{-1})

Treatment[a]	year 1: Supply		Residual		Recycled	
	N	P	N	P	N	P
Pe + Pn	66.8	5.6	17.6	−6.5	9.9	2.6
Pe + Sup1	79.4	13.2	11.5	0.5	16.8	3.0
Pe + Sup2	81.6	15.3	23.1	2.5	13.3	2.9
Pn	57.8	5.0	20.5	−4.3	8.4	2.4
Sup1	70.4	12.6	35.3	5.3	6.5	1.3
Sup2	72.6	14.7	33.8	5.4	8.6	2.3
Control	–	–	−24.5	−5.9	4.5	0.9

[a]Pn: corralling of unsupplemented animals; Sup 1: corralling of animals supplemented with millet bran + simple superphosphate; Sup2: corralling of animals supplemented with millet bran + simple superphosphate + blood meal; control no mulching, no corralling; Prc: corralling; Pe: mulching.

the positive effect of mulch and urine on soil pH and P availability (Table 2). Indeed, only when corralling of supplemented animals was associated with mulching, increase in soil Bray1-P ($P < 0.05$) was paralleled by increased grain and stover yields. It is likely, that later during the wet season, mulching (the decomposition of mulch + faeces + urine), through its influence on the pH favored the complexation of iron and aluminium by organic acids (Bationo et al. 1993; Buerkert et al. 1996), which furthered the assimilation by millet of additional P supplied in the faeces of supplemented animals. It is likely, that such reactions do not occur on bare soil, hence, the low pH on plots where supplemented animals were corralled on bare soil, and the low effect of supplementation on millet yield (Sup 1 or 2 vs Pn). Also, other factors such as: a) the positive effects of mulch on soil physical properties, water dynamic and seedling protection in the onset of rainy season; b) the provision of some limiting elements (micro-nutrients, exchangeable bases etc.) through the decomposition of mulching material, could improve millet nutrition and subsequently yields.

Yield decrease during the second cropping season could be attributed to the joint effect of soil fertility decline and rainfall deficit. However, the decrease in grain production in 1997 (288 kg ha^{-1}) as compared to 1996 (521 kg ha^{-1}) (in Banizoumbou, 7 km to Boundou) in plots receiving 3 kg P ha^{-1} of pocket placed 15-15-15 and 13 kg ha^{-1} broadcast rock phosphate (Bationo et al. 1998), could indicate that rainfall deficit was the major constraint of yield decrease.

The low N and P concentrations in grain observed during the second cropping year, could result from the interruption of translocation process following soil depletion (as compared to the first season), and an early stop of the rain distribution in 1997 (Killorn and Zourarakis 1992).

Data (Table 4) from this experiment show that the use during the first year of unpalatable roughage as mulch, and corralling of supplemented animals could induce a sustainable increase in crop production, fundamental to livestock and soil productivity in the Sahel. Because, this high crop yield in turn provides during next seasons much more forage for livestock feeding, and therefore more manure during corralling and sufficient amount of residue for mulching. However, despite the positive effect of mulching plus corralling on soil fertility and millet production, two key questions arise: Are their sufficient quantity of unpalatable roughage on the uncultivated areas (range land and fallow) of the village territory in the dry season to support the application of 2000 kg of mulch ha^{-1} (the optimal level according to Buerkert et al. (1996))? Doesn't the transfer of such quantity of OM lead to more degradation of natural pasture already under a precarious equilibrium?

Based on the remainder of millet stover litter and weeds mass on the cropland by the end of dry season 1996, and standing herbage and litter masses (53 to 61% unpalatable) in October 1995 (Hiernaux et al. 1998) minus 50% left on the ground surface to reduce wind erosion, the mulching of 1 ha of cropland requires the harvest of 8.4 ha of natural range land. In addition to unpalatable herbage of the range land and millet stover litter, the use of trees and shrub foliage litter (in February 1996) may reduce the ratio to less than 6.5 ha of range land per mulched hectare of cropland. This ratio should take into account the high variability in the productivity of natural range lands. Given this high variability in the productivity of the herbage mass in the Sahel, effects of the transfer of roughage from the natural range lands could widely vary. The availability of unpalatable roughage of the year, frequency (each 2, 3 or 4 years) and period (early, mid or late dry season) of the harvest of mulching materials are some amongst the degradation scale oriented factors. Instead of being a continuous process of phytomass removal from natural range lands, the technology proposed should aim to release a self-renewable sustainable crop/livestock production process.

Conclusion

Continuous millet cropping without amendment, contributed to exhaust Sahelian acid and sandy soil as shown by the negative N and P balances in control plots (Table 7). Application of 3 t DM ha^{-1} of manure through corralling of unsupplemented cattle was not always sufficient to overcome P deficiencies (Table 7). Mulching plus corralling of supplemented cattle (manure + urine), appeared to be instrumental in improving soil fertility, and therefore, millet yields. It could also minimize external input of inorganic fertilizer out of the reach of most smallholder farmers in the Sahel. Without mulching, the additional gain due to the supplementation was annihilated, probably because of increased urinary N losses by volatilization and the pH decrease which affects P assimilation by millet. The harvest of mulching material (unpalatable roughage) from uncultivated areas of village territory at the site of the study could be a pathway to start a sustainable crop production. Therefore, it should not be a continuous process of transfer of OM which may exhaust natural range lands and jeopardize the equilibrium of the agroecosystem.

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References

Bationo A. and Mokwunye A.U. 1991. Role of manure and crop residue in alleviating soil fertility constraints to crop production: with special reference to Sahelian and Sudanian zones of West Africa. Fertilizer Research 29: 117–125.

Bationo A., Christianson C.B. and Klaij M.C. 1993. The effects of crop residue and fertilizer use on pearl millet yields in Niger. Fertilizer Research 34: 251–258.

Bationo A., Ndjeunga J., Bielders C., Prabhakar V.R., Buerkert A. and Koala S. 1998. Soil fertility restoration options to enhance millet productivity on sandy sahelian soils in South-West Niger. In: Lawrence P., Renard G. and von Oppen M. (eds), Evaluation of technical and institutional options for small farmers in West Africa. Margraf Verlag, D-97985 Weikersheim, Germany, pp. 93–104.

Breman H. 1998. Amélioration de la fertilité des sols en Afrique de l'Ouest: Contraintes et perspectives. In: Renard G., Nef A. and von Oppen M. (eds), Soil fertility management in West African land use system. Margraf Verlag, D-97985 Weikersheim, Germany, pp. 7–20.

Buerkert A., Michel A.K., Lamers J.P.A., Marschner H. and Bationo A. 1996. Antierosive, soil physical, and nutritional effects of crop residues. In: Buerkert B., Allison B.E. and von Oppen M. (eds), Wind erosion in Niger. Implications and control measures in a millet-based farming system. Kluwer Academic publishers, Dordrecht, The Netherlands, pp. 123–138.

Buerkert A. and Hiernaux P. 1998. Nutrients in West African Sudano-Sahelian zone: losses, transfers and role of external inputs. Zeitschrift Pflanzenernähr. Bodenk 161: 365–383.

Church D.C. 1975. Digestive physiology and digestion of ruminants. Vol. 1. In: Digestive physiology. 2nd edn. O&B Books, Corvallis, Oregon, USA, pp. 115–132.

Hiernaux P., Fernández-Rivera S., Schlecht E., Turner M.D. and Williams T.O. 1998. Livestock-mediated nutrient transfers in Sahelian agro-ecosystems. In: Renard G., Net A. and von Oppen M. (eds), Soil fertility management in West African land use system. Margraf Verlag, D-97985 Weikersheim, Germany, pp. 339–347.

Killorn R. and Zourarakis D. 1992. Nitrogen fertilizer management effects on corn grain yield and nitrogen uptake. Journal Production Agriculture 5: 142–148.

Mc Intire J. and Powell J.M. 1995. African semi-arid tropical agriculture cannot grow without external outputs. In: Powell J.M., Fernández-Rivera S., Williams T.O. and Renard C. (eds), Livestock and sustainable nutrient cycling in mixed farming systems of sub-Saharan Africa. ILCA, Addis Ababa, Ethiopia, pp. 539–554.

Muehlig-Versen B., Buerkert A., Bationo A. and Marschner H. 1998. Crop residue and phosphorus management in millet based cropping systems on sandy soils of Sahel. In: Renard G., Nef A. and von Oppen M. (eds), Soil fertility management in West African land use system. Margraf Verlag, D-97985 Weikersheim, Germany, pp. 31–40.

Pieri C. 1986. Fertilisation des cultures vivriéres et fertilité des sols en agriculture paysanne subsaharienne. L'Agronomie Tropicale 41: 1–20.

Powell J.M., Fernández-Rivera S. and Höfs S. 1994. Effects of sheep diet on nutrient cycling in mixed farming systems of semi-arid West Africa. Agriculture, Ecosystems and Environment 48: 263–271.

Powell J.M., Ikpe F.N., Somda Z.C. and Fernández-Rivera S. 1998. Urine effects on soil chemical properties and the impact of urine and dung on pearl millet yield. Experimental Agriculture 34: 259–276.

Sanchez P.A., Shepherd K.D., Soule M.J., Place F.M., Buresh R.J. and Izac A.-M.N. 1997. Soil fertility replenishment in Africa: An investment in natural resource capital. In: Buresh J.R., Sanchez P.A. and Calhoun F. (eds), Replenishing soil fertility in Africa. American Society of Agronomy and Soil Science Society of America. SSSA Special Publication 51. SSSA, Madison, WI, USA, pp. 1–46.

Schlecht E., Fernández-Rivera S. and Hiernaux P. 1998. Timing, size and N-concentration of faecal and urinary excretions in cattle, sheep and goats: can they be exploited for better manuring cropland? In: Renard G., Nef A. and von Oppen M. (eds), Soil fertility management in West African land use system. Margraf Verlag, D-97985 Weikersheim, Germany, pp. 361–367.

Somda Z.C., Powell J.M., Fernández-Rivera S. and Reed J. 1995. Feed factors affecting nutrient excretion by ruminants and fate of nutrients when applied to soil. In: Powell J.M., Fernández-Rivera S., Williams T.O. and Renard C. (eds), Livestock and sustainable nutrient cycling in mixed farming systems of sub-Saharan Africa. ILCA, Addis Ababa, Ethiopia, pp. 227–243.

Somda Z.C., Powell J.M. and Bationo A. 1997. Soil pH and nitrogen changes following cattle and sheep urine deposition. Commun. Soil Sci. Plant Anal. 28: 1253–1268.

Sommerfeldt T.G., Chang C. and Entz T. 1988. Long-term manure applications increase soil organic matter and nitrogen, and decrease carbon to nitrogen ratio. Soil Science Society American Journal 52: 1668–1672.

Statistical Analysis System Institute 1987. SAS/STAT for personal computers. SAS Institute, Cary, NC, USA.

Stillwell M.A. and Woodmansee R.G. 1981. Chemical transformation of urea-nitrogen and movement of nitrogen in shortgrass prairie soil. Soil Science Society American Journal 45: 893–898.

Vallis I., Harper L.A., Catchpoole R. and Weier K.L. 1982. Volatilization of ammonia from urine patches in a subtropical pasture. Australian Journal of Agricultural Research 33: 97–107.

Waller J.C., Black J.R., Bergen W.G. and Johnson D.E. 1982. Michigan protein systems. In: Owen F.N. (ed.), Protein requirements for cattle. Oklahoma State University, pp. 323–351.

Woodmansee R.G. 1978. Additions and losses of nitrogen in grassland ecosystems. Bioscience 28: 448–453.