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Nutrient cycling practices and changes in soil properties in the crop-livestock farming systems of western Niger Republic of West Africa

F. N. Ikpe[1,*] & J. M. Powell[2]
[1]*Department of Crop, Soil Science & Forestry Rivers State University of Science & Technology, P. M. B. 5080, Port Harcourt, Nigeria;* [2]*US Dairy Forage Research Centre, 1925 Linden Drive West Madison, WI 53706-1108, USA (*Corresponding author; e-mail: iitaonne@satmail.bt.com)*

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Abstract

Pearl millet [*Pennisetum glaucum R. (Br.)* L.] is grown in West Africa on sandy, acid soils deficient in plant nutrients. In the mixed farming systems of western Niger, livestock graze millet stover by day and deposit dung and urine directly on cropland during overnight kraaling. Kraaling of livestock is perhaps the most important pathway to recycle nutrients and sustain soil fertility. Three tillage practices (immediate tillage, late tillage and no till) four amendment types (dung-plus-urine, dung alone, millet stover and millet stover ashes), and three fertilizer N rates (0, 15 and 30 kg N ha^{-1}) were factorially combined and arranged in a split plot design. Average millet grain yield in immediate till plots was 30% higher than in no-till plots and was 13% greater in plots amended with dung-plus-urine than in plots that received manure alone. The highest pH (5.8) and lowest bulk density 1.46 g/cm^3 of surface soil were measured in plots amended with dung-plus-urine. Under the less nomadic livestock management system, where animals are mostly stall-fed, technology is needed to capture and transfer nutrients in animal urine to farmers' fields for cropping.

Introduction

In western Niger, as in most parts of Sahelian West Africa, livestock and cropping small holdings are inextricably linked together. Livestock dung deposited on cropland during overnight kraaling, is perhaps the most important soil amendment material for which several contractual agreements exist for kraaling outside the villages (Quilfen and Milleville, 1983). Livestock graze millet stover and other grasses by day during the 7 months dry season. Livestock herds are made up of zebu cattle, goats and sheep and to a lesser extent camels and donkeys. However, apart from providing feed for animals millet stover is also used for cooking as fuel wood and in village industry such that its full potential as a soil amendment resource is yet to be realized (Klaij and Bationo, 1988).

The soils of western Niger have extremely low levels of organic matter (OM), total nitrogen, basic cations and effective cation exchange capacity (ECEC) (D'Hoore, 1968; Charreau and Nicou, 1971; Manu et al., 1991). Phosphorus appears to be the most limiting nutrient to millet growth as millet does not respond favorably to N fertilization until the phosphorus requirement was first met, at which point, a further yield increase might occur with the addition of N (Pichot and Roche, 1972; Pichot et al., 1981; Bationo et al., 1985; Piéri, 1986).

The inherently low soil fertility problems of these soils are aggravated by unfavorable soil physical properties. The low water holding capacity of the Shahelian sandy soil is a constraint for overcoming periods of prolonged drought. Surface soil physical properties determine largely the rainfall infiltration and the capability to store water in excess of infiltration rate (Nicou, 1974; Klaij, 1983). The sandy soils have bulk densities ranging from 1.4 to 1.7 Mg m^{-3} corresponding to a porosity of 36% to 43%. These dune soils have very high hydraulic conductivity (150–200 cm day^{-1}), and consequently a rapid internal drainage (Bationo et al., 1985).

The beneficial effects of primary tillage on millet growth and yield in the mixed farming systems of western Niger have been recognized (Nicou, 1974; Klaij and Hoogmoed, 1987; Klaij and Serafini, 1988). In these systems, tillage promotes early root development, enhances crop resistance to drought stress, a common feature of Sahelian agriculture and decreases soil bulk density (Chopart, 1983). Thus, primary tillage could be an important soil management practice among farmers in western Niger. However, this is not the case. Although farmers apply either dung-plus-urine by kraaling livestock on cropland or dung alone collected from stall-fed animals or millet stover to recycle nutrients and improve soil fertility, these materials are usually not incorporated into the soil, except in the fields immediately surrounding the villages using animal traction. Studies conducted in some villages in Western Niger on the effect of rainfall on manure availability and soil management practices showed that as one moves from the relatively wetter south to the drier north of Niger, the amount of animal dung available for cropping decreases (Williams et al., 1994). Farmers are weary of additional cost to incorporate soil amendments into soil and to purchase mineral fertilizers because of the unpredictability, unreliability and uncertainty of rainfall for cropping (Pichot, 1975; Williams et al., 1994). In years of low rainfall, millet yields are usually very low and may be nil and does not justify costs incurred to manure, till and fertilizer croplands. Several studies (Pichot, 1975; Piéri, 1989; Landais and Lhoste 1993; Powell et al., 1998) have acknowledged the beneficial effects of crop residues and livestock dung applications on soil fertility and grain yields. However, the comparative advantage of different soil management practices (kraaling. manure alone, crop residues, ashes of crop residues and complete removal of crop residues from croplands) among farmers in western Niger in a single study, is not well understood.

The specific objectives of this study were to (a) examine the effect of primary tillage and its timing on pearl millet grain yield (b) find out the effect of amendment type on millet grain yield and (c) assess the effects of primary tillage, soil amendment materials and mineral fertilizer N on soil properties.

Table 1. Some soil properties of the field trial site at the onset of the experiment

Soil properties		Depth (cm)		
		0–15	15–30	30–60
Soil texture%	Sand	93.0	NR	NR
	Silt	4.0	NR	NR
	Clay	3.0	NR	NR
Bulk density g/cm^3		1.65	1.67	NR
Total nitrogen (N) μg g^{-1}		174.3	141.3	108.4
Organic carbon (C)%		0.16	NR	NR
Available phosphorus (P) μg g^{-1}		9.1	8.0	2.0
Mineral N	NH_4–N μg g^{-1}	4.5	3.1	2.8
	NO_3–N μg g^{-1}	4.8	4.5	2.0
pH (H_2O)		4.9	4.6	NR
pH (KCl)		4.0	3.8	NR
Exchangeable acidity cmol kg^{-1}		0.26	0.58	NR
Available K cmol kg^{-1}		0.80	NR	NR

NR = Not recorded.

Materials and methods

Site description

The experiment was located at the ICRISAT Sahelian Centre (ISC), Sadore (13° 29′N 2° 18′E) in Niger, West Africa, approximately 45 km south of Niamey and established on acid soil, classified as Psammentic Paleustalfs (sandy, siliceous, isohyperthermic according to the USDA Soil Taxonomy (1975). These soils have a clay fraction made up of roughly equal proportions of very fine quartz and kaolintic minerals. Typical geomorphology of this area is that of sand plains slopping towards the Niger river valley and is composed of eolian sands deposited over a thick layer (2–8m) of gravel (D'Hoore, 1968).

The experimental plot was planted to millet in rotation with cowpea between 1987 and 1990. The unusually high soil available P level (9.1 μg g^{-1}) in surface soil at the beginning of the experiment was due to past applications of superphosphate fertilizer (Table 1). Annual rainfall at Sadore both study years was generally above long-term average of 560 (Sivakumar, 1986). In 1991 and 1992, the amounts of rainfall were 603 and 586 mm, respectively (Figure 1).

Experimental details

Three experimental treatments were involved: (a) Tillage practices: (i) Immediate tillage (tillage was done same day after the hand-spreading of amendments),

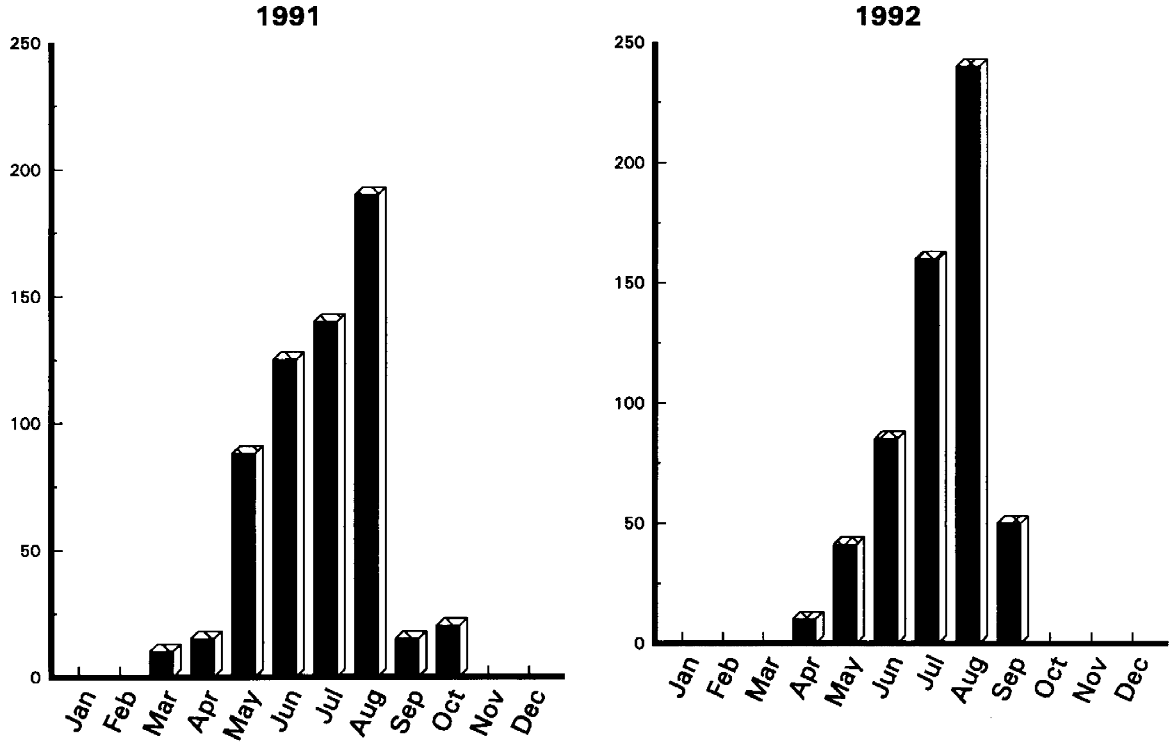

Figure 1. Rainfall mm at the ICRISAT Sahelian Centre Sadoré, in western Niger Republic.

(ii) late tillage (tillage was done two weeks after hand-spreading of amendments), and (iii) no till; (b) Soil amendments: (i) sheep dung-plus-urine, (ii) sheep dung, (iii) millet stover, (iv) millet stover ashes; and (c) Mineral N fertilizer: (i) 0, (ii) 15, (iii) 30 kg ha^{-1}.

The experimental treatments were arranged in a split-plot design. The soil amendments fertilizer N rates plus controls were factorially combined and assigned to subplots measuring 6 $\times$ 6 m in a randomized complete block design. Tillage practices formed the main plots, which were replicated four times. Tillage was accomplished with a 2-oxen drawn plough to 10 cm deep. A basal application of 10 kg P ha^{-1} as single superphosphate was applied to all plots prior to tillage. This was with the aim of meeting the optimal P requirement for the test crop, millet based on grain yield of 350 kg ha^{-1} obtained in on-farm trials in the surroundings of the ICRISAT Sahelian Centre. (Bationo et al., 1985). The amounts of sheep dung and millet stover applied (1.5 t ha^{-1} oven-dried DM, excluding earth), were determined in an earlier study on manure and crop residues application by farmers in western Niger (Powell, unpublished). However, the dung: urine ratio 1:3 on a w/w basis was based on an ILRI (International Livestock Research Institute) sheep metabolism experiment at ISC (Powell et al., 1994). Mineral fertilizer N was applied as calcium ammonium nitrate in two equal splits by banding in plots that received 15 and 30 kg N ha^{-1}, respectively. At first weeding, about three weeks after sowing millet, the first split dose of mineral fertilizer N was applied. The second split dose was given after the second and final weeding about six weeks after the first.

In the first year, millet stalks (leaf blades and sheath removed) collected from a previous year's planting were chopped to about 50 cm long and sampled for chemical analysis. For the ash treatments, the same amount of stalks applied to stalk amended plots were chopped, burnt in open half drums, and the ash stored and later sampled for chemical analysis. Dung and urine from sheep fed millet residue based diets were collected and stored in sacks and plastic containers, respectively. These were sampled for chemical analysis prior to application. Urine samples were immediately frozen until chemically analyzed. In the second year of the trial, millet stover (stalks + leaves) was retained on plots that received millet stalks the previous year. Stover from plots that received ash was collected and burnt as in the previous year and the ash applied. Sheep dung and urine were applied as per rates for 1991. Soil amendments were sampled for N, P, and K analyses.

Pearl millet cv CIVT (Composite Inter Varietal Tarna) was sown at 0.75 m spacings within rows 1 m apart to achieve a population of 13 333 stands ha^{-1}. Millet stands were thinned to 3 plants 20 days after planting to give a plant population of approximately 40 000 ha^{-1}. In 1991 millet was sown on May 30 while it was sown on 3rd June in 1992. In both years, millet panicles were harvested by the middle of September.

Millet yields determination

Millet was harvested manually from the interior of each plot. Panicles were separated from stover and grains were threshed manually from panicles. Two millet stands from each plot were sampled for stalk and leaf yield determinations by cutting entire plants 2 cm above soil surface and weighing to obtain total above-ground DM at 60 °C. Millet stover was divided into leaves (blades and sheaths) and stalks. Stalks and leaves were chopped into approximately 5 cm sections and sampled for dry matter determination by oven-drying for 48 hours at 60 °C.

Chemical analyses of soil amendments

Except for analyses of sheep urine and millet stover ashes, samples of intact sheep dung and millet stover were ground to pass 1 mm screen using a Cyclotec 1093 mill prior to digestion. Triplicate samples of approximately 1 ml for urine and 0.3 g of each other amendment were digested in sulphuric acid with a catalyst in an aluminum block digester for 1 h. Cooled digests were brought up to 100 ml volume with distilled water and sub-sampled for the determination of N and P contents on an autoanalyzer. The concentration of K was determination by flame emission spectrophotometry. The amounts of N, P and K in soil amendments applied to field plots at the onset of the trial were 11.0 $\pm$ 2.3 0.04 kg N ha^{-1} (standard deviation), 0.8 $\pm$ 0.01 kg P ha^{-1} and 62.3 $\pm$ 2.3 kg K ha^{-1} in millet stalks; 0.5 $\pm$ 0.01 kg N ha^{-1}, 0.8 $\pm$ 0.01 kg P ha^{-1} and 65.3 $\pm$ 3.2 kg K ha^{-1} in millet stalk ashes; 26.4 $\pm$ 0.05 kg N ha^{-1}, 4.8 $\pm$ 0.03 kg P ha^{-1} and 21.0 $\pm$ 0.06 kg K ha^{-1} in sheep dung; and 25.2 $\pm$ 0.8 kg N ha^{-1}, traces of P, and 2.1 $\pm$ 0.3 kg K ha^{-1} in sheep urine. The traces of P found in sheep urine, is in good agreement with the findings of Ternouth (1989), that only traces of P are lost endogenously from sheep through urine.

Soil sampling and analytical methods

Soil samples were taken from depths of 0–15, 15–30, 30–60 cm at the beginning (before fertilizer P and amendments applications) and at the end of each cropping season from all immediate till and no till plots for soil chemical analyses. Two cores were made per plot with an auger of 5 cm diameter. Cores were bulked, placed in plastic bags and frozen. Prior to extraction for NH_4–N and NO_3–N analyses, wet sub-samples were taken for moisture determination. Thereafter, samples were air dried and sieved to pass a 2 mm screen for further analysis. Soil cores were taken at the depth of 0–15 and 15–30cm for bulk density determination whereas soil samples were taken at the 0–15 cm depth for simplified soil particle size distribution analysis and organic carbon (c) determination.

Frozen soil samples were left at room temperature i.e. 25 °C for one hour and extracted with 2 M KCl. Extracts were kept in a refrigerator for the analysis of NH_4–N and NO_3–N on an autoanalyzer. Phosphorus was extracted from soil samples by Bray-1 method determined with an autoanalyzer. Organic carbon in surface soil (0–15 cm) was determined by the wet combustion method of Walkley-Black. Total N was extracted using an aluminum block digester on the already mentioned autoanalyzer. Soil pH was recorded in soil/water and soil/1 *M* KCl mixtures of 1/2.5 30 min after stirring. Exchangeable acidity was determine in 1 M KCl extracts by titrating with 0.01 N NaOH. The Al in the titrate was complex with NaF and back tritrated with 0.01 N HCl to determine Al levels. Available K was extracted with 0.1 N HCl (IITA, 1979) and determined by flame emission spectrophotometry. Bulk density was determined by the core method after drying the cores at 105 °C for 48 h while the hydrometer method of Bouyoucos was used to determine the soil particle size distribution.

Statistical analysis

Measured effects were regarded as significant at a probability level of $\leq$ 0.05. Differences in soil properties due to treatments were determined using the analysis of variance (ANOVA) of the general linear model GLM procedures (SAS, 1985). Linear regression analysis, was used to investigate the relationships between applied N and millet grain yield and between applied N and soil chemical properties (SAS, 1985).

Results

Millet grain yield

Millet grain yield was significantly higher in 1991 than in 1992 due to more rainfall and better distributed rainfall in 1991 than in 1992 (Figure 1). In 1991, higher grain yield was obtained in plots where soil amendments were incorporated immediately than in lately tilled or no-till plots (Figure 2). The greater apparent effect of immediate tillage over late tillage in 1991 than in 1992, was likely as a result of more favourable rainfall distribution in 1991 than in 1992, particularly in the early cropping season (Figure 1). Average grain yield was highest in plots where the kraaling of sheep directly on cropland for the application of dung and urine was simulated (Figure 3).

Average grain yields in 1991 were 1600 $\pm$ 230 kg ha^{-1} in the dung-plus-urine plots, 1400 $\pm$ 230 in the manure plots, 1200 $\pm$ 230 in both stover and ash plots and 1000 $\pm$ 230 in control plots. In 1992, yields were 1100 $\pm$ 210 kg ha^{-1} in the dung-plus-urine plots, 900 $\pm$ 210 in the manure plots, 1000 $\pm$ 210 in the stover plots, 600 $\pm$ 210 in the ash plot and 500 $\pm$ 210 in the control plots. The complete return of millet stover in 1992 as opposed to millet stalks applied in 1991 may have partly led to yield increases in plots amended with millet residues over the manure and ash plots (Figure 3).

Relationship between applied mineral fertilizer N and grain yield was tested using the linear regression model. Such a relationship was found to be weak and not significant. Similarly, the expected interactions (tillage $\times$ soil amendments; tillage $\times$ soil amendments $\times$ fertilizer N) were also not significant. These results were surprising because from earlier studies (Klaij and Hoogmoed, 1987; Klaij and Bationo, 1988), under Sahelian conditions millet grain yield does not increase significantly when mineral fertilizer N is applied in excess of 30 kg N ha^{-1}.

Therefore, in our study, we considered mineral fertilizer N rates of 0, 15 and 30 kg N ha^{-1} . However, we submit that the reasons for the insignificant responses and interactions could be traced to (i) the above average rainfall in both study years: 603 vs. 560 mm in 1991 and 586 vs. 560 in 1992, could have increased the magnitude of leaching of nutrients, including N in these soils developed on wind born sands with high infiltration rates; and to (ii) the application of large quantities of N in sheep urine and dung which may have weakened the millet response to mineral fertilizer N.

Soil properties

Soil properties were measured in immediate till and no till plots. At the end of the experiment, differences in surface soil pH were due mainly to the application of soil amendments alone. Surface soil pH (H_2O) was highest (5.8) in plots where dung-plus-urine were applied, followed by manure amended plots (5.6), stover amended plots (5.5), ash amended plots (5.3), and in the control plots (5.2). As expected, the change in exchangeable acidity of the surface soil at the end of the experiment was significantly affected by soil amendment type as 0.12 $\pm$ 0.024 cmol kg^{-1} was recorded in dung–plus-urine plots, 0.16 $\pm$ 0.024 in dung plots, 0.28 $\pm$ 0.024 in ash plots and 0.29 $\pm$ 0.024 in the control plots.

Total N and organic C concentrations in surface soil (0–15 cm) were higher in tilled plots at millet harvest in 1992 than in no till plots. Mineralized N (NH_4–N and NO_3–N) followed a similar trend (Tables 2 and 3). Bray-1 P levels were not significantly affected by amendment type probably due to the increase in pH as a result of OH^- release during decomposition (Powell et al., 1998). Soil bulk density measured at the end of the experiment showed significant differences due to tillage and amendment type. At the end of the experiment, tilled plots had lower bulk densities (1.45 $\pm$ 0.03 g/cm^3) than no till plots (1.54 $\pm$ 0.03). The lowest bulk density (1.45 $\pm$ 0.03) was observed in plots amended with dung-plus-urine, followed by stover amended plots (1.47 $\pm$ 0.03), dung amended plots (1.56 $\pm$ 0.03), ash amended plots (1.48 $\pm$ 0.03) and control plots (1.54 $\pm$ 0).

Discussion

The application of both dung and urine resulted in much higher N application than when only dung was applied. The increase in grain yield by 13% due to the application of urine in both study years (Figure 3) is attributed to (i) the additional N application in the urine and to (ii) the increase in soil pH of the acidic soil which increased P availability. In semi-arid West Africa, pearl millet production is more limited by P than by N availability (Piéri, 1985; Piéri, 1986; Manu et al., 1991). Since most P voided by sheep is in feaces (Ternouth, 1989), it was expected that dung would perhaps contribute more to plant P nutrition than urine. The results of this experiment showed that enhanced yields due to primary tillage and kraaling

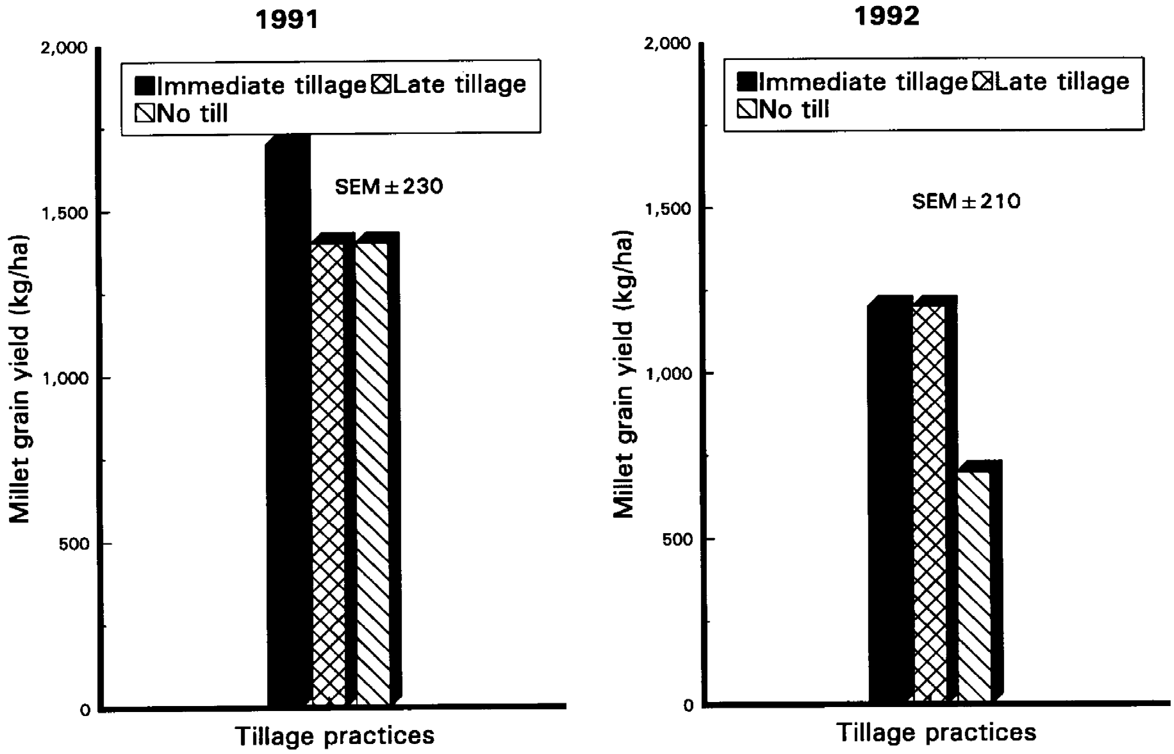

Figure 2. Effects of primary tillage on pearl millet grain yield.

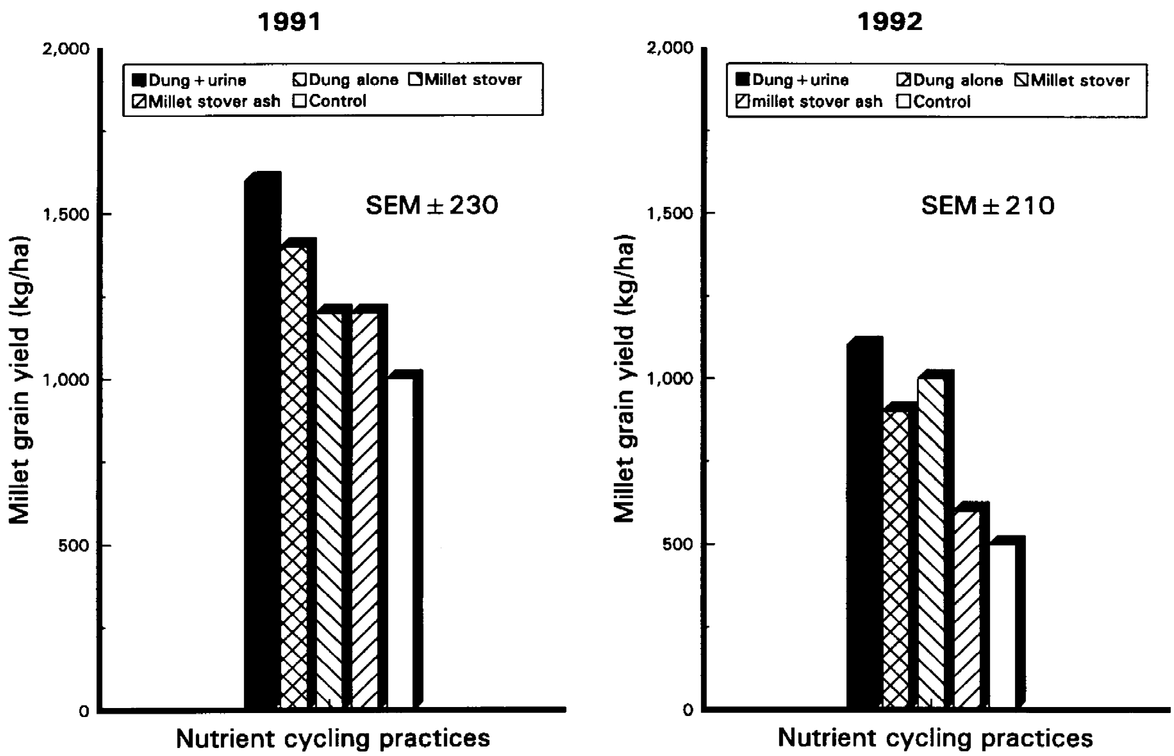

Figure 3. Effects of nutrient cycling practices on pearl millet grain yield.

Table 2. Soil chemical properties at the end of the experiment in tilled plots, supplied with soil amendments and fertilizer N rates

Soil amendments	Depth (cm)	Organic C %	Total N	Bray-1 P	Av. K^+ (μg g^{-1})	NH_4^+	NO_3^-	pH (KCl)	pH (H_20)
Dung + urine	0–15	0.22	237.2	10.5	74.7	5.6	2.1	4.2	5.5
Dung		0.21	236.7	10.2	57.4	5.6	1.7	4.1	5.3
Millet stover		0.21	229.4	10.3	67.4	5.3	1.3	4.3	5.5
Millet stover ash		0.18	224.9	8.9	70.9	3.0	1.6	4.1	5.3
Control		0.17	205.6	9.4	31.1	3.1	1.6	4.1	5.3
S. E. ±		0.012	20.86	1.73	3.21	0.41	0.55	0.15	0.14
Dung + urine	15–30		188.0	7.6	66.3	4.8	1.0	4.1	5.3
Dung			168.3	7.4	93.1	4.6	1.1	4.1	5.1
Millet stover			170.6	8.8	69.3	4.3	1.5	4.0	5.3
Millet stover ash			164.3	9.1	47.7	3.4	0.9	4.0	5.1
Control			156.5	4.4	33.2	3.3	0.8	4.0	5.0
S. E. ±			20.56	2.98	6.45	0.47	0.27	0.05	0.08
Dung + Urine	30–60		163.3	3.5	27.3	3.0	0.2	4.0	4.9
Dung			150.7	2.8	30.3	2.9	0.4	3.9	4.8
Millet stover			159.1	3.2	31.9	2.9	0.4	4.0	5.0
Millet stover ash			170.5	4.6	31.3	3.4	0.2	3.9	4.8
Control			105.0	1.9	30.0	3.5	0.2	4.0	5.0
S. E. ±			10.54	1.10	1.02	0.43	0.12	0.05	0.13

Table 3. Soil chemical properties at the end of the experiment in no tilled plots, supplied with soil amendments and fertilizer N rates

Soil amendments	Depth (cm)	Organic C %	Total N	Bray-1 P	Av. K^+ (μg g^{-1})	NH_4^+	NO_3^-	pH (KCl)	pH (H_20)
Dung + Urine	0–15	0.19	182.2	12.1	64.0	3.5	1.4	4.3	5.6
Dung		0.18	181.6	11.3	33.4	3.1	1.6	4.1	5.4
Millet stover		0.19	174.6	12.4	58.5	3.4	0.9	4.1	5.5
Millet stover ash		0.18	173.4	9.2	33.8	3.4	1.6	4.0	5.3
Control		0.16	170.4	9.2	35.3	3.0	1.0	4.3	5.2
S. E. ±		0.012	20.86	1.73	7.31	0.41	0.55	0.15	0.14
Dung + Urine	15–30		175.6	8.0	78.2	3.7	0.6	4.0	5.2
Dung			163.3	5.2	87.3	3.0	0.7	4.0	5.2
Millet stover			165.7	6.9	42.2	3.7	0.5	4.0	5.3
Millet stover ash			169.7	9.2	39.6	3.3	0.6	4.0	5.1
Control			127.2	42.7	43.8	3.3	0.4	4.0	5.1
S. E. ±			20.56	2.98	4.11	0.47	0.27	0.05	0.08
Dung + Urine	30–60		146.9	2.4	60.5	3.3	0.31	4.0	5.0
Dung			145.9	2.2	32.8	3.4	0.30	4.0	4.9
Millet stover			133.6	3.4	37.5	3.3	0.30	3.9	4.8
Millet stover ash			132.8	2.0	30.2	2.8	0.20	3.9	4.9
Control			137.6	1.6	26.4	2.9	0.30	4.0	4.9
S. E. ±			10.64	1.10	12.23	0.43	0.12	0.05	0.13

likely resulted from the combined effects of (i) immediate incorporation and minimum N loss through volatilization, (ii) urine application by increasing soil pH and P availability (Powell et al., 1998), as well as (iii) the additional N applied in the form of urine.

The incorporation of dung-plus-urine, dung alone and millet stover by primary tillage 10 cm deep into the soil, minimized N loss by volatilization, particularly from urine and enhanced faster decomposition of dung and stover. This might have synchronized nutrient release from these amendments with millet plant demands and thus resulted in greater grain yield in tilled than in no-till plots.

The sandy soil under study is very low in organic matter content and essential bases, has predominantly kaolinitic clays and is poorly buffered (D'Hoore, 1968). Consequently, urine application may have resulted in increases in soil pH, particularly in the first weeks after urine application. In this study, such increases in soil pH persisted till millet harvest 3–4 months after urine application (Tables 2 and 3). This increase in soil pH of acidic soil likely increased Bray-1P due to the dissolution of P from iron and aluminum compounds. In another publication of the same trial, we (Ikpe et al., 1999) showed that significantly higher P (6.3 ± 0.70 kg ha-1 in 1991 and 4.5 ± 0.70 in 1992) was taken up in millet grains from the dung-plus-urine amended plots compared with 4.7 ± 0.70 in 1991 and 3.7 ± 0.70 in 1992 in plots where dung alone was applied.

The higher concentration of total N in tilled plots than in untilled plots was due to the incorporation of applied soil amendments, especially dung and urine. Incorporation of urine immediately after application minimized N loss and at the end of the experiment more NH_4–N was present in tilled plots than in no-tilled plots.

Reduction in soil bulk density in soils of Sahelian West Africa due to tillage as was observed in our study has been found to enhance early rooting, greater access to soil moisture, increased nutrient uptake hence more secured and higher yield (Chopart, 1983; Klaij, 1983). Nicou (1974); Klaij and Hoogmoed (1987) and Chopart (1983) observed that primary tillage was responsible for lower bulk density and thus seems particularly advantageous in this semi arid environment where early rains are usually preceded by extremely strong winds, which cause sandblasting, burying and cutting of millet seedlings. The comparatively lower soil bulk densities measured in the dung-plus-urine and millet stover amended plots, were as a result of higher millet below-ground DM biomass following higher above-ground millet yields obtained in these plots both study years.

Conclusions

The incorporation of soil amendments applied to soil has far-reaching implications for the crop-livestock systems of Sahelian West Africa. The extensive livestock management system of kraaling livestock overnight on fields outside the villages between cropping seasons results in much higher yields and more nutrients are recycled. Overnight kraaling of livestock directly on cropland needs little or no labour, while labour is required for the transportation of millet stover, often on animal-drawn carts, from farmers' fields to homesteads where animals are kept and feed in stalls. Also, labour is needed for the collection, storage, transportation and hand spreading of dung on fields prior to planting of millet. Although immediate incorporation of amendments into soil resulted in higher yields than no till, this may prove impracticable as manuring of fields by kraaling of livestock may take several nights and even weeks depending on the size of herds and the type of livestock (small or large ruminants), the size of the field and the number of fields a farmer may choose to manure in a cropping season (Williams et al., 1994). Other constraints to kraaling are (i) the necessity to have a guard during the nights and (ii) a well for drinking water. Under the intensive livestock management system (stall-feeding of livestock), technology to capture and transfer nutrients in animal urine to farmers' fields for cropping is needed.

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