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Long-term effects of fallow, tillage and manure application on soil organic matter and nitrogen fractions and on sorghum yield under Sudano-Sahelian conditions

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Abstract. Soil organic matter (SOM) controls the physical, chemical and biological properties of soil and is a key factor in soil productivity. Data on SOM quantity and quality are therefore important for agricultural sustainability. In 1990, an experiment was set up at Saria, Burkina Faso on a sandy loam Lixisol to evaluate long-term effects of tillage (hand hoeing or oxen ploughing) with or without 10 t ha^{-1} yr^{-1} of manure and fallowing on SOM and N concentrations and their distribution in particle size fractions. The field was sown annually to sorghum (*Sorghum bicolor* [L.] Moench). Ten years later, total organic C and total N, SOM fractions and their N concentrations, and sorghum yield were determined. Continuous sorghum cultivation without organic inputs caused significant losses of C and N in the hoed and ploughed plots. However, addition of manure to hoed plots was effective in maintaining similar levels of C and N to fallow plots. Without manure, SOM was mainly stored in the size-fraction <0.053 mm (fine organic matter, FOM). SOM was mainly stored in the size-fraction between 0.053 and 2 mm (particulate organic matter, POM). In plots with manure and in fallow plots, the addition of manure more than doubled POM concentrations, with levels in tilled plots exceeding those of the fallow plots, and the highest levels in manually hoed plots. Nitrogen associated with POM (POM-N) followed a similar trend to POM. Hoeing and ploughing led to a decline in sorghum grain yield. Manure application increased yields by 56% in the hoed plots and 70% in the ploughed plots. Grain yield was not correlated with total SOM but was positively correlated with total POM. This study indicated that POM was greatly affected by long-term soil management options.

Keywords: Tillage, manure, particulate organic matter, crop yield, sorghum, Lixisol, sub-Saharan Africa

INTRODUCTION

Management of soil organic matter (SOM) is important in alleviating land degradation and improving crop performance in the semiarid zones of sub-Saharan Africa (Vanlauwe *et al.* 1998). SOM is not homogeneous, but consists of organic components having widely ranging turnover times (Woomer & Swift 1994), which can be separated physically. Generally, this process can lead to two major groups of fractions: (i) particulate organic matter (POM), fractions of size >0.053 mm, and (ii) fine amorphous organic matter (FOM), consisting of fractions of particle size <0.053 mm associated with organo-silt and organo-clay material (Cambardella & Elliot 1992).

POM responds to management and is easily decomposed (Chan 2001). The organo-silt and organo-clay fractions in FOM are slow to mineralize due to physical protection, but do contribute to soil stability. Understanding the effect of soil management options on the different size fractions is believed to be key to understanding and monitoring agricultural sustainability (Vanlauwe *et al.* 1999; Chan *et al.* 2002). Indeed, only the most labile forms of SOM are believed to be involved in supplying nutrients for plant growth. However, they are also the first to be depleted as a result of cultivation or other perturbations (Bowman *et al.* 1999; Mando *et al.* 2003). The dynamics of SOM of intermediate lability, that is, fractions with a turnover time of about 15 to 20 years, are most severely affected by

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long-term physical disturbance. Therefore, increasing SOM storage through inputs to these pools may be a requirement for sustainability.

Feller & Beare (1997) suggested that the properties of POM are consistent with the theoretical characteristics of SOM pools of intermediate lability. In native grassland soils, carbon associated with POM (POM-C) accounts for up to 48% of total C, and nitrogen associated with POM (POM-N) for up to 32% of total soil organic N (Hassink 1997). POM may show promise as a short-term or early warning indicator of long-term changes in soil quality. Many research results confirm the usefulness of the POM fraction as a sensitive indicator of long-term induced changes in SOM (Hassink 1997; Vanlauwe *et al.* 1998; Mando *et al.* 2003). Research in the temperate zone found that more than 50% of POM-C and POM-N were lost between April and September under no-till corn–soybean cropping, establishing a possible link between N losses from POM and nutrient supply over the growing season (Cambardella & Elliot 1994). This was confirmed under tropical semiarid conditions (Ouédraogo *et al.* 2003). However, limited data exist on the impact of agricultural management on SOM for the semiarid zone of West Africa. Such knowledge might prove useful in selecting management practices that maintain adequate levels of appropriate forms of SOM for improved and sustainable crop performance. The objective of this research was to determine long-term effects of tillage and organic inputs on SOM fractions and crop performance in the Sudano-Sahelian savanna of West Africa and to consider implications for similar environments elsewhere.

MATERIALS AND METHODS

Site description

The experimental field is located at the Saria Agricultural Research Station (12°16′N, 2°9′W, 300 m altitude) in Burkina Faso. The climate is Sudano-Sahelian (Fontes & Guinko 1995). Rainfall is mono-modal and irregular in time and space during a six-month rainy season (May to October). Mean annual rainfall for the last 30 years was about 800 mm. During the experiment, annual rainfall at the site ranged from 600 to 1200 mm (Figure 1). Mean daily temperatures vary from 30 °C during the rainy season to 45 °C in April and May. Potential evapotranspiration is about 2100 mm in dry years and 1700 mm in wet years (Somé 1989). The soil type is a Ferric Lixisol (FAO–UNESCO 1994) with an average slope of 1.5% and an iron pan at a depth of 50–70 cm. A survey reported by Ouattara (1994) indicated that the cation exchange capacity (CEC) was low (2–4 cmol kg^{-1}) and the base saturation ratio ranged from 70% in the topsoil to 30–50% at 80 cm depth, in line with the pH (in H_2O), which decreased from 6.4 to 4.9. The concentrations of total SOM, total N, exchangeable K and available P were very low (Table 1). Vegetation type prior to cropping was an open woody savanna (Fontes & Guinko 1995) and the main species were *Parkia biglobosa*, *Vitellaria paradoxa* and *Tamarindus indica*. The herbaceous component was dominated by *Pennisetum pedicellatum*, *Andropogon* sp. and *Loudetia togoensis*.

Experimental design

A randomized block design was established in 1990, consisting of three blocks (replications) each containing four annual treatments and one fallow treatment: hand-hoeing only (H); hand-hoeing and 10 t ha^{-1} cattle manure (H + M); oxen-ploughing (P); oxen-ploughing and 10 t ha^{-1} cattle manure (P + M); and fallow (FA). Plot size was 5 × 15 m. To avoid mixing between plots, blocks were spaced 2 m apart and individual plots 1 m apart.

Crop and soil management

Fresh cattle manure (1.1% N, 0.17% P and 19.6% C) was spread uniformly on the relevant plots each year from 1990 to 1998. After a rain event in July, hoed plots were tilled to 5 cm depth and ploughed plots to 15 cm depth using a single furrow ox-drawn plough. Fertilizer NPK (15 N-23 P_2O_5-15 K_2O) at the rate of 100 kg ha^{-1} was applied to all plots every rainy season before sowing but after ploughing or hoeing. Urea was applied at 50 kg N ha^{-1} four weeks after sowing. The ICSV 1049 sorghum (*Sorghum bicolor* [L.]) cultivar was sown each year at 96 000 seeds ha^{-1} and three seeds per hill, spaced on a 0.40 × 0.80 m grid. Plots were hand-weeded three times a year. Sorghum was harvested at maturity, usually during the last week of October. Sorghum yields reported in this paper refer to the 1999

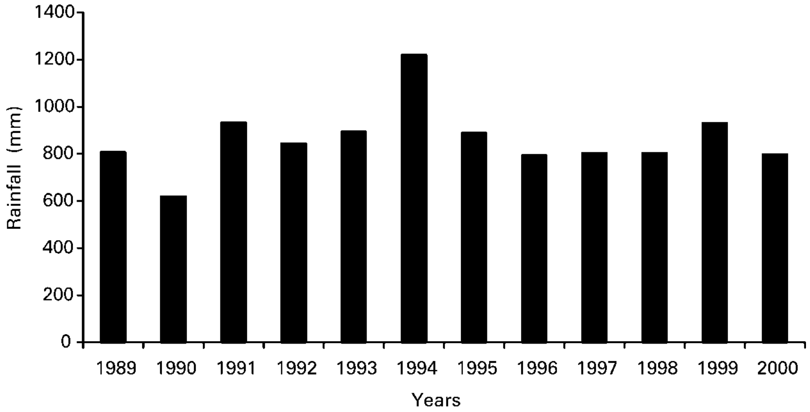

Figure 1. Annual rainfall in Saria during the experiment.

Table 1. Properties of the Ferric Lixisol (0–25 cm depth) at Saria experimental station, Burkina Faso (± standard deviation).

Coarse sand (mg g^{-1})	220 ± 4.8
Fine sand (mg g^{-1})	310 ± 10.2
Coarse silt (mg g^{-1})	280 ± 7.5
Fine silt (mg g^{-1})	80 ± 6.5
Clay (mg g^{-1})	110 ± 13.3
Total carbon (mg g^{-1})	3.9 ± 0.54
Total nitrogen (mg g^{-1})	0.3 ± 0.08
Ca^{2+} (cmol kg^{-1})	1.99 ± 0.46
Mg^{2+} (cmol kg^{-1})	0.67 ± 0.31
Na^{+} (cmol kg^{-1})	0.00 ± 0.00
K^{+} (cmol kg^{-1})	0.09 ± 0.12
S (cmol kg^{-1})	75 ± 0.63
CEC (cmol kg^{-1})	4.96 ± 1.97
Saturation (%)	57 ± 6.80
pH (H_2O)	6.4 ± 0.19
Total phosphorus (mg kg^{-1})	67.3 ± 37.06

cropping season. In that year sorghum was sown in July and harvested in October.

Soil sampling and analyses

Soil samples were collected at 0–15 cm and 15–25 cm depths in June 1999 (two weeks after new manure had been applied) and in September 1999 using a 5 cm diameter auger. On each sampling date, three samples were taken from each plot and bulked into a composite sample. Subsamples were oven-dried and sieved to pass 2 mm (for organic C determination) and 4 mm (organic matter fractionation).

Total organic carbon (TOC) was determined from soil samples collected in June 1999 at 0–15 cm and 15–25 cm depths, using sulphuric acid oxidation with external heating (Anderson & Ingram 1993). Particulate organic matter (POM) and fine organic matter (FOM) were determined on all samples, following a procedure based on particle-size distribution with soil dispersion (Vanlauwe *et al.* 1998). A sample of 100 g of soil was dispersed in 100 mL of a sodium hexamethaphosphate–Na_2CO_3 solution mixed with 400 mL of distilled water by shaking for 16 h on a reciprocal shaker at 144 revolutions min^{-1}. After dispersion, the soil slurry was sieved on a wet-sieve shaker (Octagon 2000, Endecotts London UK) to give fractions >2 mm (F1), 2–0.25 mm (F2), and 0.25–0.053 mm (F3). In this paper the fraction <0.053 mm is referred to as FOM and the fraction >0.053 mm as POM. The fractions were oven-dried and weighed. Fractions FOM and F3 were analysed for nitrogen content and F1 and F2 were bulked before nitrogen analysis.

Nitrogen analysis was carried out using standard methods (IITA 1982).

Crop performance

Sorghum grain weight, panicle weight, grain yield and total dry matter production were determined by harvesting a 17.92 m^2 subplot within each plot, avoiding border rows.

Statistical analysis

Data were subjected to ANOVA, linear regression and Pearson's linear correlation using the SAS general linear model (GLM). Treatment interactions were identified using least significant difference (LSD) at the 0.05 probability level.

RESULTS AND DISCUSSION

Total organic carbon (TOC) and total organic nitrogen (TON)

Ten years of continuous sorghum cultivation with tillage and manure application caused significant differences in TOC between treatments at 0–15 cm depth (Table 2), but not at 15–25 cm depth (data not shown).

The date of soil sampling in June or September 1999 (at the onset and end of the cropping season) did not significantly affect organic C concentrations in the soil, and average values are used in Table 2. At 0–15 cm depth, ploughing with or without manure significantly reduced TOC compared with fallow. This reduction in TOC concentration when manure was applied can be attributed to the effect of ploughing in improving soil structure and soil moisture content, thus helping to maintain higher microbial activity (Ouattara 1994). Ploughing improved soil moisture content under the research conditions because it controls soil crusting, which is a major cause of water loss in the zone. Furthermore, tillage led to an increased decomposition rate, presumably as a result of improved moisture content (Ouattara 1994; Hoogmoed 1999) and also to the breakdown of soil macro-aggregates that exposed protected organic matter to soil organisms (Cambardella & Elliot 1994; Hassink 1997; Chan *et al.* 2002). In the present study, no attempt was made to quantify soil microbiological activity but we may speculate that the greater breakdown of soil macro-aggregates during ploughing accounted for the larger C loss from ploughed soil than from hoed plots, as soil aggregates are known to be essential for SOM storage and conservation (Buyanovsky *et al.* 1994; Hassink 1997; Chan 2001). The incorporation of manure and crop residues in the soil by tillage enhances mechanisms like fermentation and solubilization of organic substances (Fernandez *et al.* 1997), which increase decomposition rates.

At 0–15 cm depth, 10 years of manure application in manually hoed plots resulted in a significant difference in TOC, that is, 3.4 g kg^{-1} without manure and 5.5 g kg^{-1}

Table 2. Soil total organic carbon (TOC) and total organic nitrogen (TON) as affected by long-term tillage and manure management at 0–15 cm and 15–25 cm depth. Average values for soil samples taken in June and September 1999.[a]

Treatments		TOC (%)		TON (%)	
		Hoeing	Ploughing	Hoeing	Ploughing
Without manure	0–15 cm	0.335	0.348	0.027	0.028
	15–25 cm	0.36	0.316	0.028	0.028
With manure	0–15 cm	0.546	0.383	0.051	0.039
	15–25 cm	0.373	0.343	0.034	0.029
Fallow	0–15 cm	0.563		0.046	
	15–25 cm	0.426		0.036	

[a] LSD for comparison of treatments is 0.08.

with manure. The values for the ploughed plots were 3.5 g kg^{-1} without manure and 3.8 g kg^{-1} with manure; the difference between the hoed and ploughed plots receiving manure is statistically significant (Table 2). This is consistent with Fernandez *et al.* (1997) who reviewed the role of organic inputs in SOM dynamics. Organic inputs provide energy and nutrients to soil organisms that drive soil processes, which stimulate production of organic compounds essential for soil aggregate formation (Tate 1987). Moreover, annual application of cattle manure and fertilizer to the tilled plots obviously improved the physical and chemical properties of this Lixisol, leading to better crop yield and improved organic inputs through the rhizosphere (Martin & Merckx 1993; Ouattara 1994).

As for soil N, the date of soil sampling did not significantly affect the level of TON in the soil, and values in Table 2 were therefore averaged over the two sampling dates. Tillage and manure application (irrespective of soil depth) significantly reduced TON compared with the fallow plot ($P = 0.005$). TON in the topsoil (0–15 cm) was significantly greater than in the subsoil (15–25 cm) when manure was applied, but was not so without manure application (Table 2). This is a clear indication that manure, more than tillage, determined soil nitrogen distribution in manured treatments.

Fractions of soil organic matter (SOM) and nitrogen

Tillage and manure management significantly affected the composition and distribution of the SOM fractions in both 0–15 cm and 15–25 cm depths, and these differences were unchanged over the cropping season. There was a significant interaction between treatments and SOM size-distribution, as well as between date of soil sampling and POM size-fractions. Without manure application, SOM was mainly stored in the finer fraction size (FOM), irrespective of method of cultivation or depth (Figure 2). The annual manure application reversed this trend in favour of the coarse-size fraction (POM). In the absence of manure, FOM content was greatest in the ploughed plots, but not significantly different from that measured in the hand-hoed and fallow plots. However, without manure application there was a drastic decrease in POM concentration in hoed and ploughed plots. This decline in POM relative to fallow was by 75% in ploughed and 50% in hoed plots (Figure 2), which confirms that POM is the fraction that is most sensitive to soil management (Chan *et al.* 2002; Mando *et al.* 2003). Hoeing and ploughing had no effect on FOM concentration in the soil. FOM is known to be associated with and protected by soil micro-aggregates (Tisdall & Oades 1980; Oades 1984; Hassink 1997; Chan *et al.* 2002), which are probably little affected by tillage (Ouattara 1994; Ouédraogo *et al.* 2003). POM size-fractions, on the contrary, are found in soil macro-aggregates, and are therefore easily accessible to a wide range of soil organisms (Hassink 1997); they are broken down owing to the tillage operation exposing their associated organic matter to decomposition (Chan *et al.* 2002).

There were no significant differences in FOM content between hoed and ploughed soil when manure was applied (Figure 2). This may be an indication that the capacity of soil to preserve SOM in association with clay was exceeded. In the topsoil H + M plot, POM concentration was about three times greater than FOM, and significantly greater than the POM fraction in the P + M and FA plots (Figure 2). POM was greater than FOM in FA, H + M and P + M treatments Furthermore, POM concentrations in H + M and P + M were greater than POM in the FA plot. The addition of manure resulted in an increase of the POM fraction not only due to the incorporation of manure into SOM, but also to the increased input of sorghum residues (roots + stubble) (Table 3). The application of manure did not modify

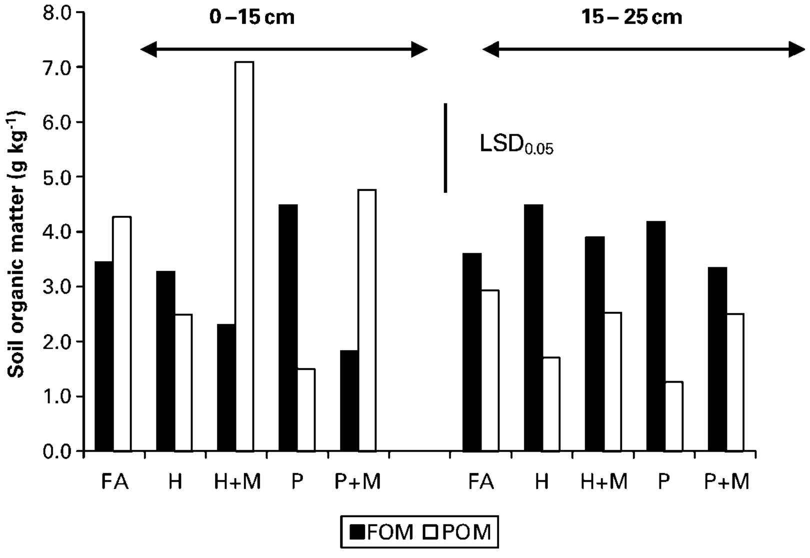

Figure 2. Long-term effects of tillage and manure application on particulate organic matter (POM) and fine organic matter (FOM) at 0–15 cm and 15–25 cm soil depths. Data are averages over two sampling dates (June and September 1999). FA = fallow; H = hand-hoed; H + M = hand-hoed + manure; P = oxen-ploughed; P + M = oxen-ploughed + manure.

Table 3. Sorghum grain yield as affected by long-term tillage and manure management.[a]

	Grain yield (t ha^{-1})	
	Hoeing	Ploughing
Without manure	1.12	0.87
With manure	2.53	2.94

[a] LSD for comparison of treatments is 0.7.

SOM composition and distribution in the untilled soil horizon (15–25 cm).

The different fractions of SOM significantly responded to tillage and manure management (Figure 3). The difference in POM concentration between plots with and without manure was greater in the two smaller size-fractions than in the larger size-fraction (Figure 3). This indicates that long-term accumulation of POM occurs in finer fractions. Soil of treatment H + M accumulated more POM in all fractions than the other treatments. Ploughing without manure resulted in the smallest POM concentrations. The magnitude of the differences significantly decreased with depth, but remained unchanged over the cropping season (June–September 1999). There was a highly significant interaction effect between fraction size, soil depth and treatment ($P < 0.01$). With hoeing or ploughing, POM decreased compared with fallow. Addition of manure to either hoed or ploughed land resulted in the 0.25–2 mm and 0.053–0.25 mm POM fractions at 0–15 cm depth increasing significantly to levels comparable to or significantly greater than that of the fallow (Figure 3). Finer fractions of SOM are more biologically active than coarse fractions (Feller & Beare 1997; Vanlauwe *et al.* 1998). In the deeper soil layer (15–25 cm), such effects were not significant (Figure 3).

Tillage and manure significantly influenced N concentrations in SOM fractions (Figure 4). FOM-N concentration was greater than POM-N in all treatments. Averaged over the date of soil sampling and depth, N concentration was 0.3 g kg^{-1} (FOM) and 0.05 g kg^{-1} (POM).

We anticipate that POM originating from fresh organic inputs was less processed by microbial activity than FOM. It is known that the transfer of organic resources to a lower hierarchical level of the food web is accompanied by an increase in N concentration (Heal *et al.* 1997). Nitrogen concentration in the FOM fraction was significantly greater in tilled plots without manure as a result of continuous mineralization of organic N without organic input. FOM-N concentrations were similar in the H + M, P + M and FA treatments. The difference in soil POM-N concentrations between H + M and P + M treatments can be attributed to greater mineralization rates in the latter. Soil sampling date had no effect on N concentration of SOM fractions.

Crop performance

Grain yield of sorghum was 1.12 and 0.87 t ha^{-1} in the hoed and ploughed plots without manure, respectively, a difference that was not significant (Table 3). These relatively low yields can be explained by the decline in SOM fractions, mainly POM in these plots (Figure 2 and Table 2), leading to a suboptimal supply of N to the crop, despite the application of mineral fertilizer NPK and urea. Addition of manure significantly increased grain yield by a factor of 2.3 (hoed) and 3.5 (ploughed) to 2.53 and 2.94 t ha^{-1}, respectively. The increase in yield was associated with the increase in nutrient availability due to the decomposition of the applied manure. The addition of manure may also have improved soil water status and soil

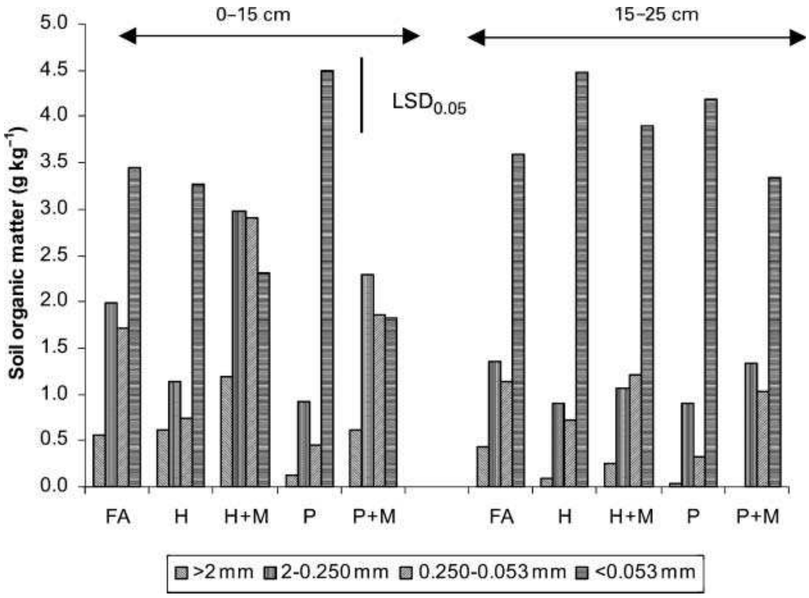

Figure 3. Long-term effects of tillage and manure application on composition and size of soil organic matter physical fractions at 0–15 cm and 15–25 cm depths. Data are averages over two sampling dates (June and September 1999). FA = fallow; H = hand-hoed; H + M = hand-hoed + manure; P = oxen-ploughed; P + M = oxen-ploughed +manure.

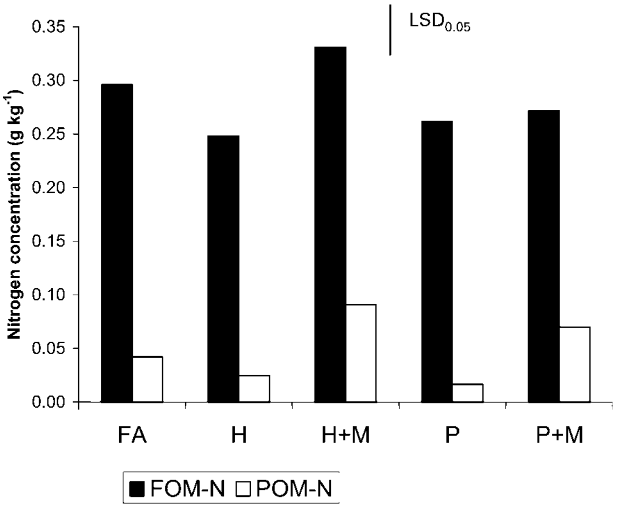

Figure 4. Long-term effects of tillage and manure application on soil organic nitrogen fractions associated with fine organic matter (FOM-N) and particulate organic matter (POM-N). Data are averages over two sampling dates (June and September 1999). FA = fallow; H = hand-hoed; H + M = hand-hoed + manure; P = oxen-ploughed; P + M = oxen-ploughed + manure.

structure (Ouattara 1994), leading to a greater water availability for crops and to improved efficiency of use of the applied fertilizer (Bationo & Buerkert 2001; Mando *et al.* 2003). This was confirmed by the poor crop response to NPK and urea in plots without manure.

Linear regression (Table 4) showed that only 31% of the variation in sorghum grain yield was explained by changes in total soil organic carbon (TOC) ($P = 0.062$). The same analysis showed a significant relationship ($r^2 = 0.56$, $P = 0.005$) between grain yield and POM, indicating that POM is closely related to nitrogen availability (Cambardella & Elliot 1992; Chan 2001). No significant effects on sorghum grain yield were found for the fraction-size >2 mm, probably because this fraction contains mainly fresh organic inputs (mostly sorghum leaves), which contain little N (data not shown) and are slow to decompose (Vanlauwe *et al.* 1998). In contrast, the fraction-size 2–0.25 mm accounted for 78% ($P = 0.0001$) of the total variation in grain yield, of which 70% ($P = 0.0006$) was associated with the 0.25–0.053 mm fraction. The FOM fraction accounted for 41% of the variation in grain yield. The contribution of the FOM fraction was most likely due to its contribution to cation exchange capacity (CEC) and, therefore, to fertilizer recovery rather than a direct contribution to N availability. This was corroborated by the correlation analysis, which indicated no significant relationship between FOM-N and yield (Table 4). Oorts (2002) found that organic fractions ranging from 0.0053 mm to 0.0020 mm in particle size (i.e. a fraction of FOM) accounted for much organic-matter related CEC. Sorghum grain yield was correlated with POM-N ($r^2 = 0.63$, $P = 0.0021$) and with N in the 0.25–2 mm fraction ($r^2 = 0.53$, $P = 0.0074$). The highest correlation was observed between grain yield and N content in the 0.25–0.053 mm SOM fraction ($r^2 = 0.69$, $P = 0.0009$) (Table 4), because this fraction was the richest in N.

Table 4. Correlations between sorghum grain yield and soil total organic carbon (TOC), soil total organic nitrogen (TON) and soil organic matter (SOM) fractions.

Independent variables	r^2	P
TOC	0.305	0.062
SOM fraction (F1) >2 mm	0.0010	0.923
SOM fraction (F2) 2–0.25 mm	0.779	0.0001
SOM fraction (F3) 0.25–0.053 mm	0.704	0.0006
POM fraction (F1 + F2 + F3)	0.561	0.0050
FOM (SOM fraction <0.053 mm)	0.410	0.0249
TON	0.499	0.00 101
POM-N	0.627	0.0021
FOM-N	0.335	0.00 483
N053 (N concentration in F3)	0.686	0.0009
N2-25 (N concentration in F1 + F2)	0.528	0.0074

CONCLUSIONS

Organic resources and fertilizer additions are prerequisites to sustainable production under Sudano-Sahelian conditions. However, the amount of manure used in this study (10 t ha^{-1}) will usually be out of reach to most farmers. Therefore, research should focus on the more efficient use of organic resources internal to the production system, and the means to increase biomass availability for soil management. This research also showed that variation in sorghum yield was best explained by the concentration of POM and POM-N, and that these concentrations decline with tillage but by less when manure is applied. Most of the changes in SOM concentrations were accounted for by changes in POM, and POM was related to crop yield. These results show that in Sudano-Sahelian conditions POM is an indicator of soil quality.

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REFERENCES

Anderson JM & Ingram JSI 1993. Tropical soil biology and fertility: a handbook of methods. CAB International Wallingford UK.

Bationo A & Buerkert A 2001. Soil organic carbon management for sustainable land use in Sudano-Sahelian West Africa. Nutrient Cycles in Agroecosystems 61, 131–142.

Bowman RA Vigil MF Nielsen DC & Anderson RL 1999. Soil organic matter changes in intensively cropped dryland systems. Soil Science Society of America Journal 63, 186–191.

Buyanovsky GA Aslam M & Wagner GH 1994. Carbon turnover in soil physical fractions. Soil Science Society of America Journal 58, 1167–1173.

Cambardella CA & Eliott ET 1992. Particulate organic-matter changes across a grassland cultivation sequence. Soil Science Society of America Journal 56, 777–783.

Cambardella CA & Elliot ET 1994. Carbon and nitrogen dynamics of soil organic matter fractions from cultivated grasslands soils. Soil Science Society of America Journal 58, 123–130.

Chan KY 2001. Soil particulate organic carbon under different land use management. Soil Use and Management 17, 217–221.

Chan KY Heenan DP & Oates A 2002. Soil carbon fractions and relationship to soil quality under different tillage and stubble management. Soil and Tillage Research 63, 133–139.

FAO-UNESCO 1994. Soil map of the world. ISRIC Wageningen Netherlands.

Fernandez ECM Motovalli PP Castilla C & Mukurumbira L 1997. Management of soil organic matter dynamics in tropical land use systems. Geoderma 79, 49–67.

Feller C & Beare MH 1997. Physical control of soil organic matter dynamics in the tropics. Geoderma 79, 69–116.

Fontes J & Guinko S 1995. Carte de la végétation et de l'occupation du sol du Burkina Faso. Note explicative. Ministère de la coopération française Toulouse France.

Hassink J 1997. A model of the physical protection of organic matter in soils. Soil Science Society of America Journal 61, 131–139.

Heal OW Anderson JM & Swift MJ 1997. Plant litter quality and decomposition: an historical overview. In: Driven by nature: plant litter quality and decomposition, eds G Cadish & KE Giller, CAB International & Cambridge University Press Cambridge UK pp 283–296.

Hoogmoed WB 1999. Tillage for soil and water conservation in the semi-arid tropics. Tropical Resource Management Paper 24. Wageningen University Wageningen Netherlands.

IITA 1982. Automated and semi-automated methods for soil and plant analysis. Manual series 7. International Institute of Tropical Agriculture Ibadan Nigeria.

Mando A Ouattara B Sédogo MP Stroosnijder L Ouattara K Brussaard L & Vanlauwe B 2003. Long term effects of tillage and organic input on Ferric Lixisol organic matter and crop performance under Sudano-Sahelian conditions. Soil and Tillage Research 80, 95–101.

Martin JK & Merckx R 1993. The partitioning of root-derived carbon with the rhizosphere of arable crops. In: Soil organic matter and sustainability of tropical agriculture, eds K Mulongoy & R Merckx, John Wiley Chichester UK pp 101–107.

Oades JM 1984. Soil organic matter and structural stability: mechanisms and implications for management. Plant and Soil 76, 319–337.

Oorts K 2002. Charge characteristics and organic matter dynamics in weathered soils of the tropics. Doctoraatsproefschrift No. 539. Katholic Universiteit Leuven Belgium.

Ouattara B 1994. Contribution à l'étude de l'évolution des propriétés physiques d'un sol ferrugineux tropical sous culture: pratiques culturales et états structuraux du sol. Thèse de doctorat, Université National de Côte d'Ivoire Abidjan.

Ouédraogo E Mando A Brussaard L & Stroosnijder L 2003. Organic resources and fertilisers management for soil carbon build-up and crop performance improvement in semi-arid West Africa. Agriculture Ecosystems and Environment 00, 000–000.

Somé L 1989. Diagnostique agro-pédologique du risque climatique de sécheresse au Burkina Faso. Etude de quelques techniques améliorant la résistance pour les cultures de sorgho, de mil et de maïs. Thèse doctorat Université des Sciences et Techniques du Languedoc (USTL) Montpellier France.

Tate RL 1987. Soil organic matter, biological and ecological effects. John Wiley and Sons New York.

Tisdall JM & Oades JM 1980. The effect of crop rotation on aggregates in soils. Journal of Soil Science 33, 141–163.

Vanlauwe B Sanginga N & Merckx R 1998. Soil organic matter dynamics after addition of nitrogen-15 labelled *Leucaena* and *Dactyladenia* residues. Soil Science Society of America Journal 62, 461–466.

Vanlauwe B Aman S Aihou K Tossah BK Adebiyi K Sanginga N Lyasse O Diels J & Merckx R 1999. Alley cropping in the moist savanna of West-Africa: III. Soil organic matter fractionation and soil productivity. Agroforestry Systems 42, 245–264.

Woomer PL & Swift MJ 1994. The biological management of tropical soil fertility. Wiley-Sayce Chichester and Exeter UK.

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