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On-farm evaluation of ridging and residue management options in a Sahelian millet-cowpea intercrop. 1. Soil quality changes

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Abstract. In the Sahel, promising technologies for agricultural intensification include millet stover mulching and ridging. A four year on-farm experiment was set-up in order to assess the effect of various combinations of these two technologies on soil chemical and physical quality in a millet (*Pennisetum glaucum* (L.) R. Br.) — cowpea (*Vigna unguiculata* (L.) Walp.) relay intercropping system. Treatments included bare surface, ridging, a surface applied banded millet stover mulch (2 t ha^{-1}) and a banded millet stover mulch (2 t ha^{-1}) buried in ridges. The latter three treatments were implemented exclusively in the cowpea rows, with an annual rotation between the millet and cowpea rows. Both the bare and ridge plots experienced a rapid loss of organic carbon, acidification and the development of extensive surface crusts but no increase in bulk density or penetration resistance. In the year of application, mulching improved soil quality in the cowpea row with respect to pH, organic carbon and exchangeable K^+ and Mg^{++} content, penetration resistance and bulk density, and it reduced the decline in exchangeable Ca^{++} and total N content. In the year following mulch application, a general decline in soil chemical quality was observed in the millet row, except for organic carbon content, and a positive residual effect was observed on penetration resistance and bulk density. As a rule, the effects of mulching in the year of application tended to be stronger in the ridged treatment with buried residue than in the banded surface mulch. In the year following application, this tendency was reversed. For the purpose of reducing soil degradation by nutrient mining and wind erosion, a banded surface mulch therefore appeared more effective than buried mulch.

Keywords: Sahel, tillage, mulches, soil quality, intercropping, millet, cowpeas, rotations

INTRODUCTION

In the Sahel, intensification of agricultural production is an essential requirement in the search for food security in view of the high population growth rate and limited availability of suitable cropland. In the case of Niger, where most cropland is located in the Sahelian agro-ecosystem, cereal yields average 310 kg ha^{-1} (World Resources Institute 2001). Technically suitable options for intensification of the main staple crop millet (*Pennisetum glaucum* (L.) R. Br.) and the principal legume cowpea (*Vigna unguiculata* (L.) Walp.) have been identified for the dominant sandy, low fertility soils of the Sahelian zone of Western Niger on the basis of long-term on-station experiments or on-farm trials. Promising technologies include the use of small doses of pocket-placed fertilizer, millet stover mulching, ridging, and cereal-legume rotation (Ly *et al.* 1998; Subbarao *et al.* 2000).

In western Niger, cowpea, a legume traditionally intercropped with millet, is usually produced for its value as a forage crop. Cowpea hay production requires very limited input but yields are usually low as a result of the very low planting densities. However, especially near urban markets where urban animal husbandry is a major outlet, the economic value of cowpea hay can be substantial. Intensification of cowpea production could therefore provide a means of increasing on-farm income under conditions of suitable access to markets.

Agricultural intensification requires the maintenance of soil physical, chemical and biological quality. The loss of nutrients through plant nutrient mining, erosion, leaching or volatilization, and the deterioration of soil physical properties can independently or interactively result in yield reduction. The present study aimed at investigating options for intensification of a millet-cowpea relay intercrop derived from promising existing technologies. Technologies were selected on the basis of their ability to maintain soil fertility (mulching; e.g., Bationo *et al.* 2000), to conserve the soil

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against soil losses by wind erosion (mulching or ridging; e.g. Michels *et al.* 1995), and to improve soil physical conditions in the topsoil (mulching or ridging; Babalola & Opara-Nadi 1993; Nicou *et al.* 1993). This study is based on the premise that:

(1) only low-input technologies are presently suitable for Sahelian agriculture, and

(2) adoption of known crop intensification technologies could be enhanced if directed at cash-generating crops like cowpea rather than subsistence crops like millet.

Consequently, intensification measures were directed at the cowpea. A rotation between millet and cowpea rows was introduced in the intercropping system so as to allow millet to benefit from the residual effects of the inputs applied to cowpea in the previous year.

In a previous paper, the effect of the various technologies on wind erosion was discussed (Bielders *et al.* 2000). The present paper discusses the direct and residual effects of the various technologies on soil physical and chemical properties, whereas a companion paper discusses the impact of the technologies on crop growth, yield and yield components (Bielders & Michels 2002).

MATERIALS AND METHODS

Study site

The experimental field was located in western Niger near the village of Banizoumbou (13°31′8″N, 2°39′5″E). Long-term average annual rainfall is 560 mm, which typically falls between June and mid-September (Le Barbé & Lebel 1997). The soils at the experimental site are classified as psammentic Paleustalfs (Soil Survey Staff 1990) or Luvic Arenosol (FAO 1998).

Experimental layout

The four year experiment was initiated in 1995 and consisted of 4 treatments in a randomized block design with 4 replications. The 300 m^2 plots were aligned in a single strip on the western end of a farmer's field that had been planted annually with pearl millet since 1992. During the course of the field trial, the millet field to the east of the experimental field was managed by the farmer as previously (no tillage, no fertilizer).

All experimental plots were cropped with a millet-cowpea intercrop planted in alternating rows spaced 0.75 m apart and oriented perpendicular to the mean wind direction of the erosive easterly convective storms that occur from May to August. Millet was manually sown in planting holes ('poquets') between 15 May and 21 June depending on the year and cowpea was sown in poquets a minimum of 3 weeks after millet. Both crops were harvested around mid-October each year. No mineral fertilizer was used.

The experimental treatments consisted of:

(1) 'bare' soil (no mulch, no ridging);

(2) a banded mulch (2000 kg ha^{-1} of millet stover applied as 0.3 m wide bands in the cowpea rows prior to millet sowing);

(3) ridging in the cowpea rows immediately prior to cowpea sowing; and

(4) a combined mulch-ridge treatment with 2000 kg ha^{-1} banded millet stover applied in the cowpea rows and buried in ridges, hereafter referred to as 'ridge+buried residue' treatment. This treatment was applied at the start of the rainy season (June) in 1995 and at the end of the previous growing season (Nov.–Dec.) in subsequent years. All above-ground cowpea and millet biomass was removed from the plots each year. Further details of the experimental layout have been described by Bielders *et al.* (2000).

Data collection and analysis

Prior to the implementation of the treatments, one composite soil sample (0–0.15 m depth) per plot was taken in May 1995 for chemical analysis. Additional composite samples were taken separately in the millet and cowpea rows in the second and fourth year of the experiment approximately 3 weeks after sowing of cowpea. All soil samples were analysed for pH (KCl, 1:2.5), available phosphorus (Bray–1), organic carbon (Walkley and Black), total nitrogen (Kjeldahl procedure), and NH_4AcO-exchangeable bases. In 1998 only, samples (0–0.05 m depth) were taken for soil textural analysis (<2 mm fraction) separately in the millet and cowpea rows.

Soil bulk density and volumetric water content (0–0.07 m depth, 300 cm^3 rings, 14 measurements per plot) and penetration resistance (52 measurements per plot) were measured in the cowpea (1995–1997) and millet rows (1995–1998) approximately 1 week after sowing. Penetration resistance was determined using a handheld penetrometer with a 3.14 cm^2 cone area for penetration depths of 0.025, 0.05 and 0.10 m. For both types of measurement, a sampling strategy was adopted that ensured that readings or samples were never taken twice at precisely the same location over the four year period.

Surface crusting was estimated twice on 14 July and 10 September 1997. For each plot, the dominant crust type in a 0.01 m^2 area was determined visually at 1 m intervals along two 20 m long transects per plot on the basis of the terminology proposed by Casenave & Valentin (1989). Results are reported in terms of the percentage of observations of a given crust type.

Analysis of variance and covariance for treatment effects was carried out in Genstat™ (Lawes Agricultural Trust 1996) using a randomized block structure with 4 treatments and 4 replicates. All data collected separately in the millet and cowpea row was analysed using a split plot design for crop row. Penetrometer data was analysed using a split plot structure for soil depth. In the case of soil chemical properties, a combined analysis was carried out over the two sampling years using the initial values as covariate. For penetration resistance and bulk density, a combined analysis was carried out over the last two years of the direct and residual effects. Treatment differences were regarded as significant when error probabilities were <5%.

RESULTS AND DISCUSSION

Total annual rainfall was 523, 495, 425, and 672 mm in 1995, 1996, 1997, and 1998, respectively. Both 1995 and 1996 were

Table 1. Initial soil chemical (0–0.15 m) and physical (0–0.05 m) properties of the experimental field in 1995.

Property		mean	s.d.
Chemical properties[a]			
pH (H_2O)		5.1	0.14
pH (KCl)		4.3	0.15
P-Bray 1	mg kg^{-1}	2.1	0.39
Org. C	%	0.19	0.023
Total N	mg kg^{-1}	159	21
Exchangeable K^+	$cmol_+ kg^{-1}$	0.07	0.01
Exchangeable Ca^{++}	$cmol_+ kg^{-1}$	0.42	0.09
Exchangeable Mg^{++}	$cmol_+ kg^{-1}$	0.17	0.04
Exch. Acidity	$cmol_+ kg^{-1}$	0.26	0.10
Al saturation	%	21	8.7
ECEC	$cmol_+ kg^{-1}$	0.87	0.09
Physical properties[b]			
Sand content	%	95	0.7
Silt content	%	2	0.4
Clay content	%	3	0.6
Bulk density	kg m^{-3}	1620	22

[a]Average from the 16 experimental plots. [b]Average from 4 soil pits located next to the experimental plots. s.d.=Standard deviation

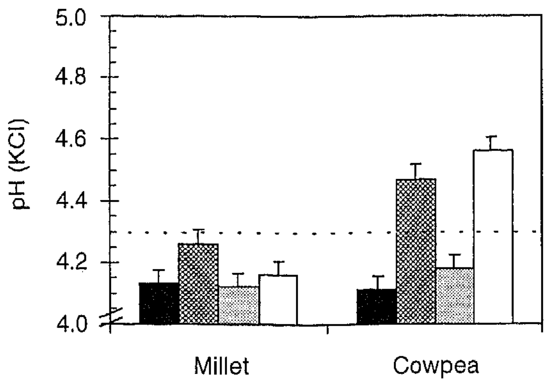

Figure 1. Effect of ridging and residue management on soil pH-KCl in the millet and cowpea row. Average values of 1996 and 1998. ■ Bare, ▩ Banded mulch, ▨ Ridge, □ Ridge+buried residue. Dashed line represents the initial average value of the experimental soil (Table 1). Bars=s.e.d.

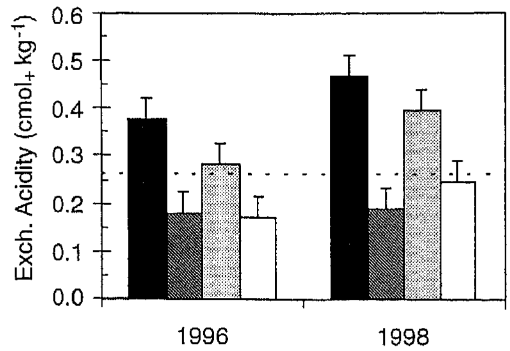

Figure 2. Effect of ridging and residue management on soil exchangeable acidity in the second (1996) and fourth year (1998) of the experiment. Average values over millet and cowpea rows. ■ Bare, ▩ Banded mulch, ▨ Ridge, □ Ridge+buried residue. Dashed line represents the initial average value for the experimental field (Table 1). Bars=s.e.d.

years with near average rainfall. In 1997, a prolonged dry spell was observed from 6 August until 1 September. In 1998, excess rainfall was observed, but this occurred mostly towards the end of the cropping season.

The soil at the experimental site was characteristic of the sandy aeolian soils of western Niger (Table 1; Bationo *et al.* 2000). Soil bulk density was high but this is not uncommon for sandy soils. At 0.19%, OC content was low but typical of cultivated land. The soil was acidic, low in exchangeable bases and poor in available P (Bationo *et al.* 1991).

Soil chemical quality

Significant crop × treatment ($P<0.001$) and year × treatment ($P=0.018$) interactions were observed for soil pH. Banded mulch, whether buried in ridges or not, significantly increased soil pH in the cowpea row in the year of application compared to the bare plots (Figure 1). This effect in the year of application was stronger in the ridge+buried residue treatment than in the banded mulch treatment, but it persisted in the millet row in the year after application only in the unburied banded mulch treatment (Figure 1).

Overall, total exchangeable acidity increased between 1996 and 1998. This increase was, however, most pronounced in the bare and ridge treatments, and to a lesser extent in the ridge+buried residue treatment (Figure 2). Significantly lower levels of exchangeable acidity were observed in the cowpea row than in the millet row for all treatments except the bare plots ($P<0.001$; not shown).

Organic carbon (OC) was, on average, higher in the cowpea row (0.19%) than in the millet row (0.18%; s.e.d.=0.003%). Whereas the mulch treatments maintained OC levels slightly above the initial value in both crop rows (0.21%), a reduction in OC content was observed in the ridge and bare treatments (0.17%; s.e.d.=0.01%). Similar treatment differences were observed for total N ($P=0.002$) and exchangeable Ca^{++} ($P=0.038$) except that both these properties decreased irrespective of the treatment compared to the initial values. On average, exchangeable Ca^{++} content in the cowpea row exceeded exchangeable Ca^{++} content in the millet row by 0.038 $cmol_+ kg^{-1}$ (s.e.d.=0.017 $cmol_+ kg^{-1}$).

There was a significant treatment × year × crop interaction for both K^+ ($P=0.019$) and Mg^{++} ($P=0.029$; Table 2). For the mulched treatments, K^+ and Mg^{++} levels in the cowpea row increased as a result of crop residue application compared to the initial nutrient content. This increase was stronger in the ridge+buried residue treatment than in the banded mulch treatment. In the millet row, K^+ and Mg^{++} levels were higher in the mulched treatments compared to the unmulched treatments, but nevertheless fell below the initial values irrespective of the treatment. In 1998, K^+ and Mg^{++} content in the millet row was higher or equal in the banded mulch treatment compared to the ridge+buried residue treatment.

Available P was significantly increased in the cowpea row as compared to the millet row ($P<0.001$; not shown). This

Table 2. Effect of residue management and ridging on exchangeable K^+ and Mg^{++} content in the second (1996) and fourth year (1998) of the experiment.

	Millet row				Cowpea row			
	Bare	Banded mulch	Ridge	Ridge+buried residue	Bare	Banded mulch	Ridge	Ridge+buried residue
	($cmol_+ kg^{-1}$)							
Exch. K^+								
1996	0.016	0.036	0.020	0.035	0.044	0.084	0.050	0.148
1998	0.021	0.061	0.018	0.058	0.031	0.081	0.043	0.123
s.e.d.[a] = 0.0076								
Exch. Mg^{++}								
1996	0.124	0.167	0.125	0.164	0.123	0.182	0.145	0.209
1998	0.109	0.144	0.090	0.112	0.111	0.202	0.108	0.219
s.e.d.[a] = 0.0131								

[a]standard error of the difference between means

effect was stronger in 1998 (+2 mg kg^{-1}) than in 1996 (+0.57 mg kg^{-1}; s.e.d.=0.16 mg kg^{-1}). There was no significant treatment effect on available P. The reason for this crop effect irrespective of surface management treatment is unclear given that crop production varied by almost an order of magnitude across treatments and was extremely low in the bare plots with respect to both millet and cowpea (Bielders & Michels 2002).

Over the four years of the present experiment, the topsoil in the bare and ridge treatments rapidly acidified. Such rapid decline in soil quality following continuous cropping of millet in the absence of organic amendment inputs has also been inferred by Subbarao *et al.* (2000) on the basis of the millet yield trend in a long-term experiment. The acidification in the bare and ridge treatments may be attributed to nutrient mining, the loss of buffering capacity as a result of the decline in OC content, leaching of nutrients and the loss of soil and organic matter by wind erosion (Bielders *et al.* 2000).

For the ridge treatment, the smaller rate of acidification in the cowpea rows compared to the millet rows probably resulted from ridging and cowpea growth rather than from a residual effect of millet growth in the previous year. Indeed, whereas millet dry matter production was particularly poor and not significantly different in both ridged and bare plots over the last 3 years, cowpea total dry matter production in the ridge treatment exceeded dry matter production in the bare treatment by 407% (Bielders & Michels 2002). The observed effect may be the result of complexing of Al by organic compounds released following the decomposition of small quantities of fresh organic matter as a result of cowpea leaf fall (Buerkert *et al.* 2000).

The application of millet stover, either in bands or buried in ridges, was able to significantly improve the soil fertility status in the cowpea rows for the duration of the experiment with respect to pH (Figure1), exchangeable K^+ and Mg^{2+} content (Table 2), OC and exchangeable Al^{3+}. Since no other amendments were added to the soil but millet stover, the observed increase in pH and decrease in exchangeable Al^{3+} in the cowpea row of the mulched plots may be attributed to the addition of basic cations, mostly K^+ and Ca^{++}, released during crop residue decomposition (Buerkert *et al.* 2000). In the case of K^+, the addition of small quantities through dust deposition on mulched plots may also have contributed (Herrmann *et al.* 1996). However, in contrast to K^+ and Mg^{2+}, mulching was not able to prevent a general decline in Ca^{2+} in the cowpea row compared to the initial values but only to reduce this decline as compared to the bare plots. This agrees with the straw/grain nutrient content ratio which, for unfertilized millet, decreased in the order: $K^+ > Mg^{++} > Ca^{++}$ (Bationo & Mokwunye 1991). Indeed, since in the mulched treatments large quantities of nutrients are recycled, overall nutrient decline is expected to occur faster for those elements which have the lowest ratios, i.e. for which a larger proportion of the nutrient uptake is stored in grain rather than straw.

Significant residual effects on soil pH (Figure 1), K^+ and Mg^{++} contents (Table 2) and OC were apparent in the millet row following crop residue application. However, only in the case of OC did the residual content in the millet row exceed the initial content. For the three other properties, mulching resulted only in a reduction of the acidification and nutrient depletion process compared to the bare and ridge treatments. Despite the relatively high mulching rate and low productivity levels, additional input of nutrients would be required to maintain soil fertility levels.

Except for OC and Ca^{++}, the effects of mulching on soil chemical properties in the cowpea row in the year of application tended to be stronger in the ridge+buried residue treatment compared to the banded mulch treatment. In contrast, the residual effects in the millet row tended to be stronger (OC, N, Mg^{++} and K^+) or non significant (Ca^{++}, pH, Al^{3+}) in the banded mulch plots as compared to the ridge+buried residue treatments. This difference may result from a more rapid decomposition of buried stover compared to mulching, leading to a larger treatment effect in the first year of the ridge+buried residue treatment compared to the surface mulch. The slower decomposition of the surface applied mulch in the first year ensures a larger residual effect in the second year compared to the ridge+buried residue treatment. For similar soils, Bationo *et al.* (1995) have reported decomposition rates of the order of 50% after a single rainy season following surface application of 2 t ha^{-1} of millet stover. The difference in the timing of application of the residue in the ridges in 1995 compared with subsequent years did not have a significant

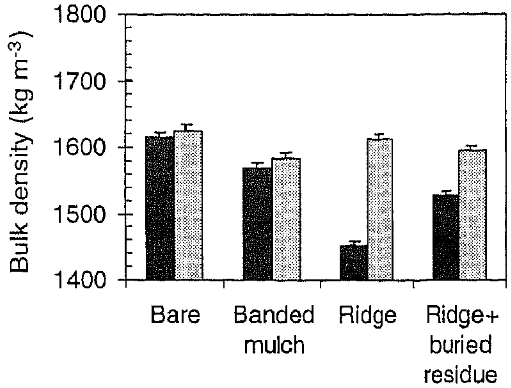

Figure 3. Direct (cowpea row; black bars) and residual (millet row; dotted bars) effect of ridging and residue management on soil bulk density. Average value over the last 2 years of measurement. Bars=s.e.d.

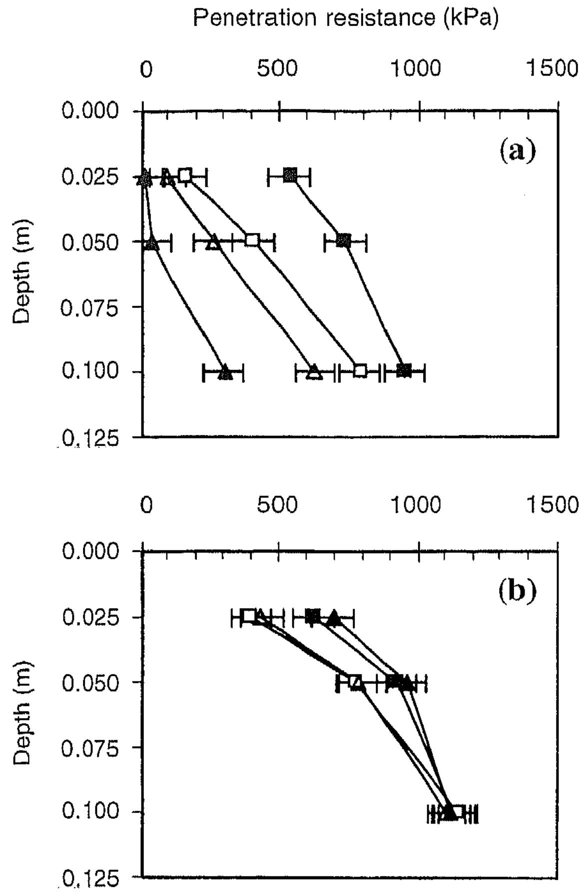

Figure 4. (a) Direct (cowpea row) and (b) residual (millet row) effect of ridging and residue management on soil penetration resistance to 0.1 m depth. Average value over the last 2 years of measurement. ■ Bare, □ Banded mulch, △ Ridge, ▲ Ridge+buried residue. Bars=s.e.d.

effect on the soil chemical properties, most likely because microbiological activity during the dry season is minimal.

Soil physical quality

In any single year, volumetric water content (VWC) differences between treatments never exceeded 2.2%, and no overall correlation could be identified between VWC and penetration resistance. Treatment differences in penetration resistance therefore reflect differences in intrinsic soil properties (cohesion, bulk density) rather than treatment differences in VWC at the time of measurement. This is confirmed by the significant positive correlation that was observed between penetration resistance at 5 cm depth and bulk density ($R^2 = 0.61$; not shown).

In the bare treatment, average bulk density ranged between 1600 and 1630 kg m^{-3} across crop rows and years. Similarly, penetration resistance in the same treatment varied by less than 15% over the four years, with an average of 562, 890 and 1308 kPa at 0.025, 0.05 and 0.1 m depth, respectively. This shows that soil physical quality did not decline significantly over time in the bare plots with respect to bulk density and penetration resistance.

Ridging and banded mulching reduced bulk density in the cowpea row on average by 160 and 50 kg m^{-3}, respectively (Figure 3). In 1995 when ridges were built immediately prior to sowing, burial of residue in ridges reduced bulk density in the cowpea row by an amount comparable to plain ridges (170 kg m^{-3}; not shown). In the following two years, this treatment reduced bulk density by 90 kg m^{-3} on average when the ridges had been built at the start of the previous dry season (Figure 3).

Except for the millet rows in 1995, the impact of surface management practices on penetration resistance decreased with depth in all years and crop rows ($P<0.001$). Ridging and mulching significantly reduced penetration resistance up to 0.1 m depth in the cowpea row compared to the bare treatment (Figure 4a). This reduction was least for the banded mulch treatment and greatest for the ridge+buried residue and ridge treatments.

Ridging without residue resulted in lower penetration resistance in the cowpea row than the ridge+buried residue treatment except in 1995 when the opposite was observed. However, despite the partial collapse of ridges during the dry season as a result of wind erosion and trampling by livestock, the burial of residue in ridges still led to an average absolute increase in soil porosity of the cowpea row of 3.5% over the last 2 years and a reduction in penetration resistance by 87, 64 and 34% at 2.5, 5 and 10 cm depth, respectively. For the ridge+buried residue treatment, the porosity of the stems themselves may be largely responsible for the observed reduction in soil bulk density. In the case of the banded mulch treatment, the accumulation of loose sediment within the millet stover bands may also have contributed (Bielders *et al.* 2000).

Residual effects on bulk density in the millet row were apparent only for the banded mulch and ridge+buried residue treatments and only in 1996 and 1998. This amounted to an average reduction in bulk density of 40 and 30 kg m^{-3} in the banded mulch and ridge+buried residue treatments, respectively, over the last two years. This corresponds to a change in porosity of 2 to 2.5%. Nicou *et al.* (1993) reported a strong positive correlation between soil porosity and root growth of various crops on

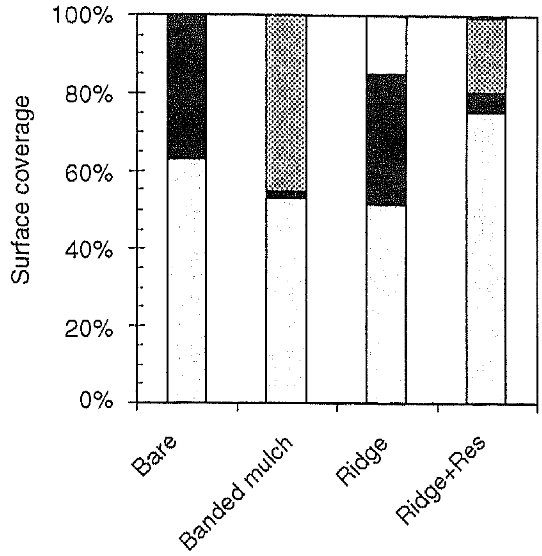

Figure 5. Effect of ridging and residue management on surface coverage of different soil surface crust types in 1997. Average of 2 observation dates. ▒ Structural crust, ■ Erosion and discontinuous structural crusts, ▒ Loose sand deposits, □ Runoff crusts. Ri+Res = Ridge + buried residue.

sandy soils from Senegal. There was no significant residual effect of ridging on bulk density and penetration resistance in the millet row, which reflects the rapid collapse of ridges under the influence of rainfall and wind erosion (Bielders *et al.* 2000) and trampling by livestock during the dry season. Residual effects of the management practices on penetration resistance in the millet row were observed in the top 0.05 m in the banded mulch and ridge+buried residue treatments (Figure 4b). These two treatments reduced penetration resistance in the millet row by 38 and 20% on average at 2.5 and 5 cm depth, respectively, compared to the bare treatment. Given the absence of residual effect of ridging on soil physical properties, the beneficial residual effect of the ridge+buried residue treatment on bulk density and penetration resistance can therefore be attributed to the incorporation of millet stover rather than to ridging *per se*.

Ridging and residue management practices significantly affected the surface coverage of loose sand and erosion crusts ($P<0.001$) on both observation dates in 1997 (Figure 5). On banded mulch plots, loose sand deposits occupied on average 45% of the soil surface. This agreed with the large sediment deposition rates measured on these treatments (Bielders *et al.* 2000). In contrast to the mulched plots, low permeability erosion crusts and discontinuous structural crusts with partially exposed clay skins covered 50% of the surface on the bare plots on 14 July, and was still as high as 24% on 10 September. On ridged plots without residue, such crusts occupied 30 and 37% of the soil surface on 14 July and 10 September, respectively. The presence of erosion crusts and discontinuous structural crusts is indicative of the removal of material by wind and water erosion (Casenave & Valentin 1989) and is consistent with the large soil losses reported for the bare and ridged treatments (Bielders *et al.* 2000). Runoff crusts, which reflect the redistribution of soil by runoff, were restricted to ridged plots without residue, covering between 13 and 16% of the soil surface on both dates (Figure 5). Such runoff crusts were always located in-between ridges.

Clay+silt content in the top 0.05 m remained below 6% in all treatments and crop rows. The bare and ridge treatments nevertheless saw their clay+fine silt content increased by 1.4% in absolute value on average compared with the banded mulch treatments (s.e.d.=0.46%; not shown). This probably reflects the large soil losses measured on the bare and ridged plots (Bielders *et al.* 2000) which may have led to exposure at the soil surface of deeper soil material slightly enriched in clay as well as from the presence of the clay skin of the erosion crusts.

Compared to all other treatments, banded mulch application resulted in an increase in fine sand content of 6.5%. Similar findings were reported by Michels *et al.* (1995). Within the sand class, fine sand is most readily eroded and transported. The greater fine sand content in the banded mulch treatment therefore probably reflects trapping by the banded mulch of fine sand eroded from the adjoining millet field. Bielders *et al.* (2000) have shown that the banded mulch treatment was the only one to experience a net deposition of sediment, the three other treatments experiencing a net loss.

CONCLUSIONS

Under the present experimental conditions, the bare and ridge treatments underwent a rapid loss of organic C and strong acidification, most likely as a result of a negative nutrient balance and extensive soil loss by wind erosion. However, except for the development of extensive erosion and discontinuous structural crusts, these treatments did not experience a loss in physical quality over the four year period, implying that any reduction in crop yield on these treatments should not be correlated with a deterioration of the soil physical properties.

Because it is better able to control soil acidification and nutrient depletion in the year following application, banded surface mulch appears to be a more sustainable technical option than the banded residue buried in ridges from the point of view of soil chemical and physical quality. However, surface mulching requires temporary protection of millet stover during the dry season against free-ranging livestock, which may be a drawback.

Despite being built on dry soil, the burial of residue in ridges proved to be an effective means of stabilizing the ridges during the dry season, with beneficial effects on soil physical properties both in the first and second year following burial. The improvement in soil porosity and penetration resistance is small, however, and it is difficult to assert whether such changes could by themselves result in significantly improved crop growth. In addition, although no storage of millet stover is required, ridging may constitute a constraint for this technique. The development of simple, low cost animal-drawn ridging implements may help alleviate this constraint. Animal strength is usually limited following the long dry season when pre-sowing tillage is required. This constraint does not apply to the ridge+buried residue treatment since only post-harvest tillage is performed.

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REFERENCES

Babalola O & Opara-Nadi OA 1993. Tillage systems and soil properties in West Africa. Soil and Tillage Research 27, 147–174.

Bationo A Baethgen WE Christianson CB & Mokwunye AU 1991. Comparison of five soil testing methods to establish phosphorus sufficiency levels in soil fertilized with water-soluble and sparingly soluble-P sources. Fertilizer Research 28, 271–279.

Bationo A Buerkert A Sedogo MP Christianson BC & Mokwunye AU 1995. A critical review of crop residue use as soil amendment in the West African semi-arid tropics. In: Livestock and sustainable nutrient cycling in mixed farming systems of Sub-Saharan Africa, eds. JM Powell S Fernandes-Riverra TO Williams & C Renard, Vol. 2, International Livestock Center for Africa (ILCA), Addis Ababa, pp 305–322.

Bationo A & Mokwunye AU 1991. The role of manures and crop residues in alleviating soil fertility constraints to crop production: with special reference to the Sahelian and Sudanian zones of West Africa. Fertilizer Research 29, 117–125.

Bationo A Wani S Bielders CL Vlek PLG & Mokwunye AU 2000. Crop residue and fertilizer management to improve soil organic carbon content, soil quality and productivity in the Desert Margins of West Africa. In: Global climate change and tropical ecosystems, eds R Lal JM Kimble & BA Stewart, CRC Press, Boca Raton, pp 117–145.

Bielders CL & Michels K 2002. On-farm evaluation of ridging and residue management options in a Sahelian millet-cowpea intercrop. 2. Crop development. Soil Use and Management 18, (in press).

Bielders CL Michels K & Rajot J-L 2000. On-farm evaluation of ridging and residue management practices to reduce wind erosion in Niger. Soil Science Society of America Journal 64, 1776–1785.

Buerkert A Bationo A & Dossa K 2000. Mechanisms of residue mulch-induced cereal growth increases in West Africa. Soil Science Society of America Journal 64, 346–358.

Casenave A & Valentin C 1989. Les états de surface de la zone sahélienne. Influence sur l'infiltration. Editions de l'ORSTOM, Paris, France.

FAO 1998. World reference base for soil resources. ISSS/ISRIC/FAO, Rome.

Herrmann L Jahn R & Starh K 1996. Identification and quantification of dust additions in peri-saharan soils. In: The impact of desert dust across the mediterranean, eds. S Guerzoni & R Chester, Kluwer Academic Publ., Dordrecht, pp 173–182.

Lawes Agricultural Trust 1996. Genstat 5, release 3.2. Oxford Science Publications, Clarendon Press, Oxford.

Le Barbé L & Lebel T 1997. Rainfall climatology of the HAPEX-Sahel region during the years 1960–1990. Journal of Hydrology 188/189, 14–43.

Ly SA Bielders CL van Duivenbooden N Tassiou A Gouro AS & Anand Kumar K 1998. Technologies diffusables et transférables aux producteurs. 1ère partie. Dossiers techniques. International Crops Research Institute for the Semi-Arid Tropics/Institut national de la recherche agronomique du Niger.

Michels K Sivakumar MVK & Allison BE 1995. Wind erosion control using crop residue. I. Effects on soil flux and soil properties. Field Crops Research 40, 101–110.

Nicou R Charreau C & Chopart J-L 1993. Tillage and soil physical properties in semi-arid West Africa. Soil and Tillage Research 27, 125–147.

Soil Survey Staff 1990. Keys to Soil Taxonomy. 4th edition/Ed., Blacksburg, Virginia.

Subbarao GV Renard C Payne WA & Bationo A 2000. Long-term effects of tillage, phosphorus fertilization and crop rotation on pearl millet-cowpea productivity in the West-African Sahel. Experimental Agriculture 36, 243–264.

World Resources Institute 2001. Niger at a glance. http://www.wri.org/facts/cs-pdf/niger.pdf.

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