Rotation and tillage effects on yield of pearl millet (*Pennisetum glaucum*) and cowpea (*Vigna unguiculata*), and aspects of crop water balance and soil fertility in a semi-arid tropical environment

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SUMMARY

A 4-year field experiment was conducted from 1986 to 1989 in Niger to determine the effects of pre- and post-harvest tillage and rotation of pearl millet (*Pennisetum glaucum* (L). R. Br.) and cowpea (*Vigna unguiculata* (L.) Walp.) on crop yield, crop water use and soil fertility on a sandy soil. Pre-sowing tillage increased grain and crop residue yields over the traditional system of no tillage. Post-harvest tillage resulted in lower yields than pre-sowing tillage during the last 2 years of the experiment. Millet–cowpea rotation increased yield and there were no important tillage × rotation interactions. Crop water use was similar for a dry and a wet year, but less water was held in the profile after the harvest of cowpea. Compared to pre-sowing tillage and no tillage, post-harvest tillage increased the amount of water conserved until the next season. In all treatment combinations, soil organic matter and total N content both declined on average by 62%, and soil pH (KCl) decreased from 4·6 to 4·3.

INTRODUCTION

Pearl millet (*Pennisetum glaucum* (L). R. Br.) and cowpea (*Vigna unguiculata* (L.) Walp.) are grown by subsistence farmers of the Sudano–Sahelian zone of the West African semi-arid tropics, an area of high-risk farming resulting from low-fertility soils and erratic rainfall. Millet is sown as soon as the rains begin, but in some years establishment is hindered by wind erosion, resulting in stand reduction or complete crop failure. Cowpea is usually sown later mostly as an intercrop, when the rains have become established. No or low inputs of fertilizers and pesticides are characteristic of the millet-based production systems in the region, which aim to produce the minimal cereal requirements of the family even in bad years, while substantial quantities of valuable cowpea hay for feeding livestock will also be produced in good years.

In the past, soil fertility was maintained by extended fallow periods (Jones & Wild 1975), and by transferred fertility by grazing animals. The increasingly intense use of the land has resulted in shorter fallow periods and in some cases the practice has disappeared.

The two crops are usually grown on sandy soils that are deficient in nutrients, particularly phosphorus (P) (Bationo & Mokwunye 1991). Response to nitrogen (N) occurs at adequate levels of P, but its effects are inconsistent due to erratic rainfall, volatilization and leaching losses (Christianson *et al.* 1988). Rotation of cereals with legumes is known to improve soil fertility due to the N-fixing ability of the legumes. Information is limited on the effects of rotation in West Africa, probably because of the predominance of intercropping cereals and legumes. Fertility deficiencies, aggravated by soil physical conditions that limit root growth, are more readily overcome when fertilization is combined with tillage (Charreau & Nicou 1971). Investigations on the effect of pre-sowing tillage showed increases in early plant stands and yield of millet on sandy non-crusting soils (Klaij & Hoogmoed 1993), and also resulted in a more efficient use of rainfall (Klaij & Vachaud 1992). Post-harvest tillage, on the other hand, reduced evaporation during the dry season (Nicou & Charreau 1985) resulting in increased water availability in the following season. Post-harvest tillage is advocated

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Table 1. *Dates of sowing for pearl millet and cowpea in Niger**

Year...	1986	1987	1988	1989
Millet	29 May	15 Jul	14 Jun	30 Jun
Cowpea	3 Jul	15 Jul	14 Jun	5 Jul

* Harvest of pearl millet 92–98 days after sowing, harvest of cowpea 75–78 days after sowing.

because draught animals are in poor condition at the beginning of the season due to lack of feed. The growing of a short duration cowpea would enable post-harvest tillage to be carried out under favourable soil moisture conditions. Research dealing with tillage within a cropping sequence is limited in West Africa. Therefore, this study was undertaken to evaluate the effects of tillage and crop rotation on crop yields, crop water use and soil fertility.

MATERIALS AND METHODS

The study was conducted from 1986 to 1989 at the ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) Sahelian Centre (13° 48′ N, 5° 15′ E; altitude 272 m), 45 km south of Niamey, Niger. Mean annual rainfall in Niamey is 560 mm (1961–90 rainfall data) with a monomodal distribution. The rainy season is short, with most of the rain received between June and September (Sivakumar 1992). The soil was a sandy Psammentic Paleustaf (West *et al.* 1984). Total sand and clay content change from 93·9 and 3·8% at the surface to 89·3 and 8·3% at 1·5 m depth. The cation exchange capacity is low (13 mmol/kg). Bulk density of the top soil is 1·58 g/cm. When wet, the topsoil is very friable, non-

Table 2. *Long-term (1961–90) mean rainfall (mm), seasonal and total rainfall received during the crop cycle of millet and cowpea in Niger*

	Long-term mean	Year 1986	1987	1988	1989
21–31 May	16·8	58·0	0·0	0·0	35·0
1–10 Jun	19·2	2·6	11·6	4·9	0·0
11–20 Jun	26·6	46·6	0·0	51·9	14·4
21–30 Jun	29·9	12·2	1·6	38·5	18·9
1–10 Jul	39·7	53·5	11·6	56·1	106·0
11–20 Jul	53·9	85·2	43·0	67·0	0·0
21–31 Jul	63·0	37·8	27·0	62·7	11·8
1–10 Aug	59·3	78·6	56·0	38·6	122·3
11–20 Aug	54·2	47·5	114·0	79·0	28·2
21–31 Aug	58·7	63·0	36·6	122·4	19·5
1–10 Sep	42·9	47·0	12·3	47·4	176·2
11–20 Sep	31·7	43·6	2·2	58·7	12·7
21–30 Sep	13·6	27·9	43·0	65·5	26·5
1–10 Oct	7·4	0·0	41·3	0·0	28·6
Total	516·9	603·5	400·2	692·7	600·1
Total received by millet crop		431	361	581	510
Total received by cowpea crop		339	319	443	437

Table 3. *Effect of tillage on cowpea grain and hay yield (t/ha), 1986–89 in Niger*

Treatment	Grain 1986	Grain 1987	Grain 1988	Grain 1989	Hay 1986	Hay 1987	Hay 1988	Hay 1989
No tillage	1·02	0·32	0·53	0·91	2·74	0·34	0·66	2·28
Pre-sowing ploughing	1·28	0·41	0·52	0·84	3·24	0·55	0·78	2·30
Pre-sowing ridging	1·10	0·32	0·46	1·07	2·57	0·35	0·69	2·89
Post-harvest ploughing	—	0·34	0·41	0·68	—	0·34	0·59	1·79
Post-harvest ridging	—	0·30	0·49	0·81	—	0·25	0·73	2·58
S.E. (D.F. 28)	0·068	0·027	0·063	0·083	0·247	0·035	0·086	0·343

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Table 4. *Effect of tillage and rotation on pearl millet grain and stover yield (t/ha), 1986–89 in Niger*

	Grain				Stover			
Treatment	1986	1987	1988	1989	1986	1987	1988	1989
Tillage								
No tillage	0·77	0·45	0·84	0·14	3·26	1·72	2·83	0·74
Pre-sowing ploughing	0·89	0·65	0·76	0·23	4·23	2·35	2·81	0·89
Pre-sowing ridging	0·91	0·60	0·81	0·21	3·56	2·20	2·94	0·80
Post-harvest ploughing	—	0·71	0·50	0·19	—	2·51	1·85	0·82
Post-harvest ridging	—	0·55	0·54	0·16	—	1·97	2·03	0·68
S.E. (D.F. 63)	0·058	0·033	0·062	0·024	0·247	0·109	0·212	0·080
Rotation								
Continuous	0·82	0·51	0·62	0·16	3·52	1·91	2·09	0·75
Rotated	—	0·68	0·77	0·22	—	2·39	2·89	0·81
S.E. (D.F. 63)	—	0·021	0·039	0·015	—	0·069	0·134	0·050

Table 5. *Seasonal evapotranspiration (ETR) and drainage (D) (mm) during the crop cycle of pearl millet and cowpea in Niger*

	1986		1987	
	ETR	D	ETR	D
Cowpea				
No tillage	276	115	265	57
Ploughing	304	104	268	60
Ridging	268	132	269	57
S.E. (D.F. 8) no tillage	5·3	6·6	6·1	8·2
S.E. tillage	9·2	11·5	4·3	5·8
Pearl millet				
No tillage	298	105	303	65
Ploughing	290	95	318	53
Ridging	270	120	304	60
S.E. (D.F. 18) no tillage	5·0	4·1	5·3	3·9
S.E. tillage	8·7	7·2	3·7	2·8

sticky, and non-plastic; attributes which greatly facilitate tillage and weeding. *In situ* field capacity of the soil is *c.* 0·10 cm³/cm³. The experimental site had not been cultivated for 5 years previous to the present study. Before planting, soil samples were taken from the top 0·15 m soil in each replication to determine chemical properties. Soil pH (KCl 1:1) was 4·6, organic matter was 0·35%, available P (Bray P_1) was 4·7 mg/kg, and total N 209 mg/kg of soil. The same soil properties were determined from composite samples of ten borings taken in all plots after harvest each year. A blanket application of 13 kg/ha of P (as triple superphosphate) was broadcast each season before sowing or land preparation.

Two tillage methods (ploughing to a depth of 0·15 m and ridging without prior tillage) were compared with the traditional system which involves no primary tillage. Ridges were 0·15 m high and spaced 0·75 m apart. Tillage was executed yearly, either pre-sowing after the first rain in May or June that exceeded 8 mm, or immediately after harvest, thus resulting in five tillage treatments. The tillage treatments were permanently assigned to plots. Rotation treatments were continuous pearl millet, and pearl millet followed by cowpea, with each plot carrying just one crop per year. The two phases of the rotation (Preece 1986) were grown in each year, providing 15 treatments. Treatments were arranged in randomized complete blocks with eight replications. The plot size was 6 × 10 m.

An early maturing pearl millet cultivar, CIVT (90 days) and an early maturing cowpea cultivar, Suvita 2 (75 days), both recommended in Niger, were sown in 0·75 m-spaced rows in hills. In ridged plots the crops were sown on top of the ridge. Within-row spacing was 1·1 m for millet and 0·33 m for cowpea. Sowing dates depended on sufficient moisture received for each crop (Table 1). Stands were thinned to three plants per hill for millet and two plants per hill for cowpea. Cowpea was protected against insects by spraying cypermethrin (Cymbush Super Electrodyn®). Weeding was done as required, using a local hand hoe.

Soil water was measured in three replications at 0·3 m depth and from 0·4 m to a depth of 2·6 m at 0·2 m intervals using a Troxler model 3322 neutron probe (Troxler Electronic Laboratories Inc, Research Triangle Park, NC 27709, USA), which was field calibrated. For the 1986 and 1987 seasons, seasonal crop evapotranspiration (ETR) and drainage (D) were calculated from weekly soil water profile measurements following Klaij & Vachaud (1992), assuming the depth of drainage at 1·4 m. Infrequent measurements in the last 2 years precluded water balance calculations.

Table 6. *Total soil water (mm) in the 0·3–1·4 m profile at the beginning and end of the rainy season, as a function of tillage and rotation in Niger*

	Tillage						Rotation		
	Pre-sowing		Post-harvest						
Date	Ploughing	Ridging	Ploughing	Ridging	No tillage	S.E. (D.F. 28)	Millet	Cowpea	S.E. (D.F. 28)
25 Sep 86	96·2	102·2	97·6	98·9	96·7	2·98	103·0	87·4	2·31
21 Jun 87	53·2	52·8	62·2	64·5	52·8	2·70	57·7	56·2	2·09
24 Sep 87	49·1	56·2	53·4	59·5	55·6	2·59	56·5	51·3	2·01
8 Jun 88	35·7	38·3	42·3	40·9	36·4	1·38	39·7	36·7	1·07
17 Sep 88	88·9	93·1	88·2	91·7	93·7	1·79	94·7	84·3	1·39
7 Jun 89	60·7	64·3	79·9	74·9	62·4	1·76	67·6	70·3	1·36
29 Aug 89	101·0	102·9	103·1	107·3	105·4	1·61	106·3	99·3	1·25

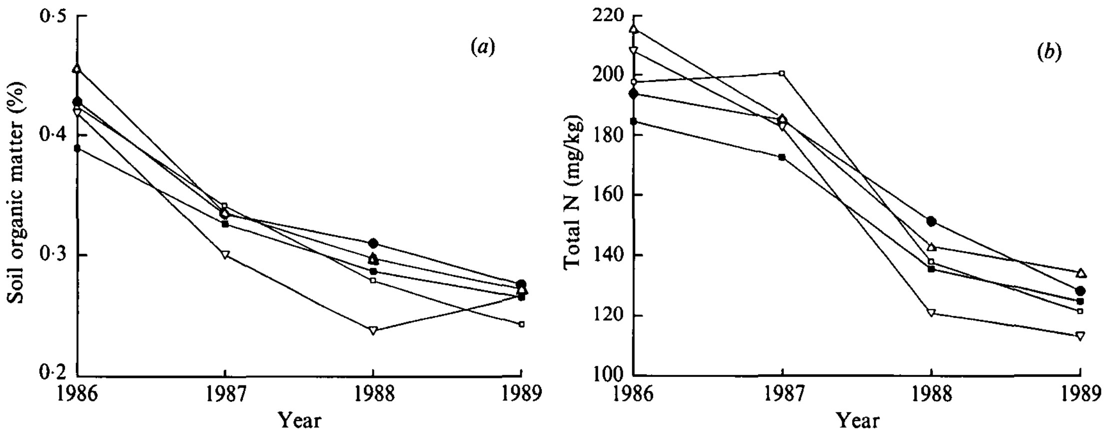

Fig. 1. The effect of tillage on (*a*) soil organic matter content (%) and (*b*) total N (mg/kg), sampled in the top 0·15 m soil: no tillage (●), pre-sowing ridging (△), post-harvest ridging (▽), pre-sowing ploughing (■), post-harvest ploughing (□). Vertical bars represent S.E. (D.F. error = 24).

The rainfall distribution during each crop cycle is shown in Table 2. Initial crop stands, stands at harvest, millet grain and stover (stem and leaves) yields, and cowpea grain and hay yields were measured in 30 m^2 plots for millet and 60 m^2 plots for cowpea. Millet stover and cowpea hay were removed each year following traditional practice. The data for the 4 years were analysed both separately and combined, using analysis of variance.

RESULTS AND DISCUSSION

Crop yields

Cowpea grain and hay yields were significantly affected by tillage method and year, with a significant year × tillage interaction for grain yield. Therefore, yield data are presented for individual years (Table 3). Pre-sowing tillage increased cowpea grain yields significantly, compared to the other treatments, in 1986 and 1987. This increase was not consistent in the subsequent years. Grain and hay yields were low in 1987 and 1988, when cowpea was sown either in mid-July or mid-June, respectively. The year 1987 was dry, characterized by dry spells after sowing and before harvest which may have severely affected seed and hay yields. In 1988, on the other hand, there were no dry spells and low grain yields could have resulted from poor insect control due to early sowing. The optimum date for sowing cowpea in the West African semi-arid tropics has been reported to be in early July (Muleba *et al.* 1991).

For millet, a significant tillage × rotation interaction was observed only in 1987. Tillage × year and rotation × year interactions were found for grain and stover yields (Table 4). Pre-sowing tillage increased both grain and stover yields over no tillage in all years except 1988. Post-harvest tillage was much less effective than pre-sowing tillage. It increased grain

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and stover yields over no tillage in 1987 only, whereas in 1988 and 1989 yields were significantly depressed compared to pre-sowing tillage, for unknown reasons. The low yields in all treatments in 1989 were due to infestation by raghuva (*Heiliocheilus* (*Raghuva*) *albipunctella*), a millet head insect pest. After the first year, millet grain and stover yields from rotated plots were significantly greater than those of the continuous millet. Yield advantages due to rotation were, however, modest. Much greater yield increases of 70–100% were reported by Klaij *et al.* (1994), in a similar but less acid soil. The numbers of heads/ha reflect the millet yields. In the first 3 years the number of heads was stable (40300, 46800, and 39700 heads/ha respectively), but this number dropped to 17200 in 1989 (S.E. = 1060). Pre-sowing tillage produced 39700, post-harvest 33500, and no tillage 34200 heads/ha (S.E. = 1190). Continuous millet had 34500 with rotation increasing this number to 37800 heads/ha (S.E. = 750).

Crop water balance

In 1986 total rainfall was above the long-term average and fairly well distributed during the crop cycle (Table 2). In 1987, rains started late with a relatively dry period in the first 20 days of September. In 1987, the first year allowing a comparison of pre- and post-harvest tillage, no differences in ETR or D were found. Hence, results are presented comparing no tillage, ploughing, and ridging (Table 5). Only for millet in 1987 was the seasonal ETR significantly different due to tillage, with ploughing resulting in the highest ETR, which is reflected in the high stover yields. ETRs of millet for 1986 and 1987 were quite similar; obviously more drainage occurred during the relatively water-abundant season of 1986. Noteworthy, is the similar ETR of cowpea and millet, but the cowpea, being a 75-day maturity variety, exhibited high evapotranspiration rates (as much as 6 mm/day for a weekly period, data not shown) during its shorter period of maximum vegetative cover.

Effect of tillage on soil moisture conservation

Compared to no tillage and pre-sowing tillage, post-harvest tillage conserved water through the extended dry season in the 0·3–1·4 m profile by *c.* 10–12 mm before sowing in 1987, 4–6 mm in 1988, and 12–15 mm in 1989 (Table 6). The water conservation effect probably due to weed control was small, and would benefit the next crop in case of drought stress, provided the roots had penetrated sufficiently deep to tap the conserved water. Generally, less water was found at harvest in plots sown with cowpea than with millet, because more water is extracted by cowpea up to harvest due to the actively transpiring full canopy. This, combined with the delayed sowing, resulted in a drier soil to tillage depth, thus making post-harvest tillage conditions less favourable than for millet plots.

Soil chemical properties

There was a significant decline in soil organic matter and total N content over the 4-year study period (Fig. 1). This was probably due to the annual removal of the crop residues. The effect of tillage on the annual levels of these soil properties was small but statistically significant. For instance, post-harvest ridging had the lowest total N levels in 1988 and 1989, which corresponded with the lower crop yields. In 1989, soil organic matter content of no tillage plots was the highest at 0·28%, and the lowest at 0·24% for post-harvest ploughed plots (S.E. = 0·006). Crop rotation did not help in maintaining soil organic matter levels. Soil pH declined from the initial level of 4·6 to 4·3 (S.E. = 0·01), while each year the soil was slightly more acid in the rotated plots compared to the continuous millet. With the annual application of P, the level of P-Bray$_1$ after harvest was 6·4 in 1986, 10·1 in 1987, 9·2 in 1988, and 13·1 in 1989, exceeding the level of 7·9 mg P/kg deemed to produce at least 90% of the potential production of millet in a similar soil environment (Bationo & Mokwunye 1991). The study reports a single experiment of only 4 years, and it may be important to ascertain longer-term effects of tillage in various rotation systems on crop yields as well as on soil physical and chemical properties.

Mention of trade names does not constitute endorsement of or discrimination against any product by the Institute.

REFERENCES

BATIONO, A. & MOKWUNYE, A. U. (1991). Alleviating soil fertility constraints to increased crop production in West Africa: the experience in the Sahel. *Fertilizer Research* **29**, 95–115.

CHARREAU, C. & NICOU, R. (1971). L'amélioration du profil cultural dans les sols sableux et sablo-argileux de la zone tropicale sèche Ouest-africaine et ses incidences agronomiques (d'après les travaux des chercheurs de l'IRAT en Afrique de l'Ouest). *L'Agronomie Tropicale* **26**, 209–255, 565–631, 903–978, 1183–1237.

CHRISTIANSON, C. B., BATIONO, A., HENAO, J. & VLEK, P. L. G. (1988). Fate and efficiency of N fertilizers applied to pearl millet in Niger. *Plant and Soil* **125**, 221–231.

JONES, M. J. & WILD, A. (1975). *Soils of the West African Savanna: The Maintenance and Improvement of their Fertility. Commonwealth Bureau of Soils, Technical Communication No. 55*. Slough: Commonwealth Agricultural Bureaux.

KLAIJ, M. C. & HOOGMOED, W. B. (1993). Soil management for crop production in the West African Sahel. II.

Emergence, establishment, and yield of pearl millet. *Soil & Tillage Research* **25**, 301–315.

KLAIJ, M. C. & VACHAUD, G. (1992). Seasonal water balance of a sandy soil in Niger cropped with pearl millet, based on profile moisture measurements. *Agricultural Water Management* **21**, 313–330.

KLAIJ, M. C., RENARD, C. & REDDY, K. C. (1994). Low-input technology options for millet-based cropping systems in the Sahel. *Experimental Agriculture* **30**, 77–82.

MULEBA, N., MWANKE, M. & DRABO, I. (1991). Use of successional sowing in evaluating cowpea (*Vigna unguiculata*) adaption to drought in the Sudan savannah zone. 1. Seed yield response. *Journal of Agricultural Science, Cambridge* **116**, 73–81.

NICOU, R. & CHARREAU, C. (1985). Soil tillage and water conservation in semi-arid west Africa. In *Appropriate Technologies for Farmers in Semi-arid West Africa* (Eds H. W. Ohm & J. G. Nagy), pp. 9–32. West Lafayette, Indiana, USA: Purdue University.

PREECE, D. A. (1986). Some general principles of crop rotation experiments. *Experimental Agriculture* **22**, 187–198.

SIVAKUMAR, M. V. K. (1992). Climate change and implications to agriculture in Niger. *Climatic Change* **20**, 297–312.

WEST, L. T., WILDING, L. P., LANDECK, J. K. & CALHOUN, F. G. (1984). *Soil Survey of the ICRISAT Sahelian Center, Niger, West Africa*. Soil and Crop Sciences Department/Tropsoils, Texas A&M University System, College Station, Texas, USA.

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