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ORIGINAL PAPER

Agroecological analysis and economic benefit of organic resources and fertiliser in till and no-till sorghum production after a 6-year fallow in semi-arid West Africa

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Abstract A field experiment was conducted in Gampela (Burkina Faso) in 2000 and 2001 to assess the impact of organic and mineral sources of nutrients and combinations thereof in optimising crop production in till and no-till systems and to assess the economic benefit of these options. The study showed that under conditions of rainfall deficiency, the use of a single organic resource at an equivalent dose of 40 kg N ha^{-1} better secured crop yield than the application of an equivalent amount as urea-N, while a combination of organic resources and fertiliser was better in increasing crop yield than the application of the same N amount in the form of urea. In a year of rainfall deficiency, a mix of organic resources and fertiliser in both till and no-till systems increased crop water use efficiency, with the result that the farmer was able to purchase only half of the normal quantity of N fertiliser to obtain a higher yield that he would have done when all of the N was supplied in the form of urea. Under conditions where soil N is deficient, an economic benefit was achieved when urea was combined with easily decomposable organic material (e.g. sheep dung); mixing the urea at a dose of 40 kg N ha^{-1} with maize straw was not sufficient in alleviating the negative interaction due to the enhanced N immobilisation. The results demonstrate that the use of N fertiliser alone was risky and that a higher yield, with the accompanying economic benefit, was scarcely achieved under the prevailing rainfall conditions. The application of soil and water conservation measures can contribute greatly to increasing the economic benefit of mineral, organic or combined organic and mineral-derived nutrient application under semi-arid conditions.

Keywords Burkina Faso · Economic benefit · Fertiliser · Nitrogen use efficiency · Organic resources · Tillage · Water use efficiency

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Introduction

The application of organic resources plays a key role in West African agricultural systems where there is little or no mineral fertiliser input. In this region, continuous and intensive cropping without restitution has depleted the nutrient base of most soils, leading to negative nutrient balances (Stoorvogel and Smaling 1990; Smaling et al. 1997; Bationo et al. 1998). The mean annual losses per hectare were approximately 22 kg N, 25 kg P, and 15 kg K for the period between 1982 and 1984 (Stoorvogel and Smaling 1990). Many studies suggest that an improved management of organic resources could be a key element in the maintenance of soil fertility (Bationo and Mokwunye 1991; Mulongoy and Merckx 1993; Ouédraogo et al. 2001; Stroosnijder and Van Rheneen 2001). Agricultural systems in semi-arid West Africa face erratic rainfall conditions, and it is precisely the distribution of rainfall during the short cropping period that determines the success – or failure – of crop production. Organic resources are both the raw material and major source of plant nutrients (Sanchez et al. 1989; Janssen 1993) and function in improving the porosity, structure and water-holding capacity of the soil (Lal 1986; Mando et al. 1996) as well as possibly contributing to improved crop water use efficiency.

Although it is widely accepted that the addition of organic matter is essential to maintaining the physico-chemical health of the soil, particularly sandy soil with low clay activity, it is doubtful whether organic inputs alone will be able to compensate for the continuing removal of plant nutrients by harvested products (Vanlauwe et al. 2002). However, there are many examples from West Africa showing that the continuous application of only mineral fertiliser ultimately results in decreasing yields (Pieri 1989; Sedogo 1993) and that fertiliser recovery in sub-Saharan Africa is very low (Breman and Bationo 1999). Conversely, the application of a combination of mineral inputs and organic sources of nutrients has been shown to maintain yield levels (Pieri 1989; Kang 1993; Sedogo 1993; Bationo and Buerkert 2001) and to enhance crop water use efficiency (Breman and Bationo 1999). The sustainability of agricultural systems in West Africa would therefore seem to rely on an integrated nutrient management programme geared to land use practices that are economically viable and ecologically sound.

An important question here is whether combining the two sources of nutrients gives only additive benefits (i.e. the benefit of the combined application is equal to the sum of the benefits from the two components when applied in isolation) or truly leads to a positive or negative interaction (Iwuafor et al. 2002). More often, this issue is not taken into account in the combined organic resource and fertiliser experiments and has on occasion led to the wrong conclusions and recommendations. Therefore, the aim of the paper was to analyse the added effect (interaction) of a combined application of an organic resource and urea and the economic benefit with attention paid to nitrogen (N) use efficiency of a combined versus a single application of organic resources of different qualities and urea during two consecutive cropping seasons under till and no-till systems on the central plateau of Burkina Faso. For the economic benefit analysis, the aim is not to make a financial analysis of a cropping option but to focus on the extra-gain of a farmer following the application of a single or combined organic resource and urea under semi-arid West African conditions.

We hypothesise that a skillful combination of mineral and organic sources of nutrients may induce a positive interaction and result in an economic benefit in crop yield and N use efficiency in agricultural systems in semi-arid West Africa.

Methodology

Site description

The study was conducted at Gampela, a village located on the central plateau of Burkina Faso between 12°25′ N, 1°21′ W, during two consecutive cropping seasons (2000 and 2001). Crop and soil management was the same during the 2-year study period. The site had been under a 6-year fallow regime prior to the set-up of the experiment. All

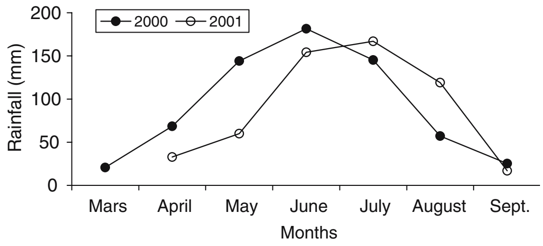


Fig. 1 Monthly rainfall distribution in 2000 and 2001 at Gampela, Burkina Faso

organic materials collected during the clearance of the site were transported outside of the plots without any burning. The climate is Soudano-Sahelian. Rainfall is monomodal and is irregularly distributed in time and space (Fig. 1). The cropping season lasts from June to October. The mean annual rainfall is about 770 mm (mean of the last 97 years), while the amount of rainfall in 2000 and 2001 was 642.2 mm and 550.2 mm (the lowest rainfall of the last 10 years), respectively. The highest annual rainfall amount of the last 10 years was 998 mm. The soil is a Ferric Lixisol, and the texture of the top soil (0–10 cm) is loamy-sand with a low soil organic matter and nutrient concentration (Table 1).

Experimental design

The experimental design was a split plot, with blocks replicated three times and tillage and no-tillage as the main treatments. The plots were 19 × 11 m and 5 m apart; the sub-plots were 5 × 4 m and separated by guard rows of 1 m. The blocks were separated by an alley of 2 m. The sub-treatments consisted of C = control (0 N), U = urea (40 kg N ha^{-1}), U80 = urea (80 kg N ha^{-1}), SD = sheep dung (40 kg N ha^{-1}), SD + U = sheep dung (40 kg N ha^{-1}) + urea (40 kg N ha^{-1}), S = maize straw (40 kg N ha^{-1}) and S+U = maize straw (40 kg N ha^{-1}) + urea (40 kg N ha^{-1}). Triple super phosphate (TSP) was applied at a dose equivalent to 15 kg P ha^{-1} every year to avoid phosphorus limitation. The chemical properties of the organic material applied during the 2 years of the study are shown in Table 2.

Table 1 Characteristics of the top soil (0–10 cm) of a Ferric Lixisol at Gampela, Burkina Faso

Soil properties	Values
Clay (%)	6 ± 1.8
Silt (%)	42 ± 2.4
Sand (%)	52 ± 3.7
Carbon (g kg^{-1})	4.7 ± 0.5
Total nitrogen (g kg^{-1})	0.4 ± 0.1
Total phosphorus (mg P kg^{-1})	55 ± 12
Total potassium (mg K kg^{-1})	304 ± 23
Exchangeable calcium (centimol kg^{-1})	0.87 ± 0.21
Exchangeable magnesium (centimol kg^{-1})	0.43 ± 0.06
Exchangeable potassium (centimol kg^{-1})	0.17 ± 0.09
Exchangeable sodium (centimol kg^{-1})	0.06 ± 0.01
pH (H_2O)	6.6 ± 0.3
pH (KCl)	4.9 ± 0.3

± Standard deviation

Crop and soil management

Improved sorghum (*Sorghum bicolor* L. Moench) variety SARIASO14 was sown in all the plots at a rate of 31,250 seedlings ha^{-1} during the two cropping seasons. Organic materials and fertilisers were applied before sowing and before tilling the plots. Animal power was used for the tillage (12 cm). In the no-till plots organic materials and urea were applied on the soil surface. During the growing period the plots were manually weeded twice. Sorghum was harvested after 4 months. Sorghum yield (grain, straw) components and harvest index (grain yield/straw yield) were measured at harvest, after drying in the sun, by weighing with an electronic balance.

Rainfall amount was recorded using a rain gauge placed in the field. Water use efficiency (WUE) was calculated as:

Table 2 Chemical properties of organic materials applied in 2000 and 2001 at Gampela, Burkina Faso

Organic resources	2000		2001	
	Maize straw	Sheep dung	Maize straw	Sheep dung
Carbon (C) (%)	45	25	54	40
Nitrogen (N) (%)	0.77	1.53	0.59	1.61
Phosphorus (P) (%)	0.18	0.33	0.08	0.19
Potassium (K) (%)	1.20	1.20	1.25	1.55
C/N ratio	59	17	91	25

$$\text{WUE} = \text{Above ground biomass } (\text{kg ha}^{-1}) / \text{Total rainfall (mm)}.$$

Soil (0–10 cm) total N was measured at flowering by a colorimetry method after digestion (Kjeldahl). Total N recovery in above-ground plant material was measured in 2001 according to the method used by Ouédraogo et al. (2006).

Apparent N use efficiency (ANUE) was calculated in 2000 and 2001 as ANUE = (Yi – Yo)/Ni, N utilisation efficiency in 2001 (NU_tE) was calculated as NU_tE = (Yi – Yo)/(NRi – NRo) and N uptake efficiency (NUpE) was calculated as NUpE = (NRi – NRo)/Ni, where Yi = yield in fertilised plots, Yo = yield in the control, NRi = N recovered in the fertilised plots, NRo = N recovered in the control and Ni = N supplied in the fertilised plots. GenStat (VSNi, Hemel Hempstead, UK) and SPSS (SPSS, Chicago, Ill.) software were used for statistical analysis. All data were subjected to ANOVA.

Data calculation, collection and analysis

Added effect (AE) in crop yield is defined as (Giller 2002; Iwuafor et al. 2002):

$$\text{AE} = \Delta Y(x1 + x2) - (\Delta Yx1 + \Delta Yx2)$$

where $\Delta Y(x1 + x2)$ stands for the increment in yield obtained when a mineral source of nutrients ($x1$) and an organic source of nutrients ($x2$) are combined, $\Delta Yx1$ = increment in yield obtained with a single use of a mineral source of nutrients and $\Delta Yx2$ = the increment in yield with a single use of an organic source of nutrients. Positive interaction is achieved when AE > 0, and a negative interaction when AE < 0. No AE is achieved when AE = 0.

Yield increases per kilogram N ($\Delta Y/\Delta F$) in the different treatments were calculated for N doses over the intervals of 0–40 and 40–80 kg N where ΔY stands for yield increases and ΔF for N intervals. The interval 0–40 gives the yield increase per kilogram N applied at the dose of 40 kg N ha^{-1} compared to the control. The interval 40–80 gives the yield increase per unit of the supplementary 40 kg N ha^{-1} added urea-N to organic material or to fertiliser already applied at the same dose of 40 kg N ha^{-1}.

Taking into account the price of 1 kg urea and sorghum in a given year, we calculated a minimum yield value. In 2000 and 2001, the price of 1 kg urea-N was about 544 FCFA (West African currency), whereas the mean price of 1 kg of sorghum fluctuated between 67 FCFA (December–May) and 167 FCFA (June–September). Therefore, to be economic, sorghum mean yield increases should exceed 3.26 kg or 8.15 kg per unit urea-N applied or per equivalent dose of organic resource-N. The average value of 116.6 FCFA for 1 kg sorghum and an average yield increase of 4.7 kg was used for the economic calculation. As stated above, the aim was to use a simple method to assess the added benefit of a single or combined organic resource and urea application under semi-arid West African conditions.

Results

Soil N concentration

In 2000, the level of soil total N following the separate application of maize straw and urea (80 kg N ha^{-1}) treatments in tilled plots was significantly lower than that in tilled plots following urea (40 kg N ha^{-1}), S+U and SD+U treatments, respectively (Fig. 2a). No significant differences were observed among other treatments. In the no-till plots, the highest soil N concentrations were observed in plots treated with S+U and with SD+U, both of which differed significantly from the other treatments. No significant differences were observed among the other treatments.

In 2001 (Fig. 2b), soil total N concentration was lower than in 2000. No significant differences were observed between the treatments in no-till plots. In tilled plots the highest N concentration was noted in S+U, which was significantly different from other treatments.

Sorghum N use efficiency

Figure 3 indicates that in 2000, the ANUE was significantly higher in both tilled and no-till plots

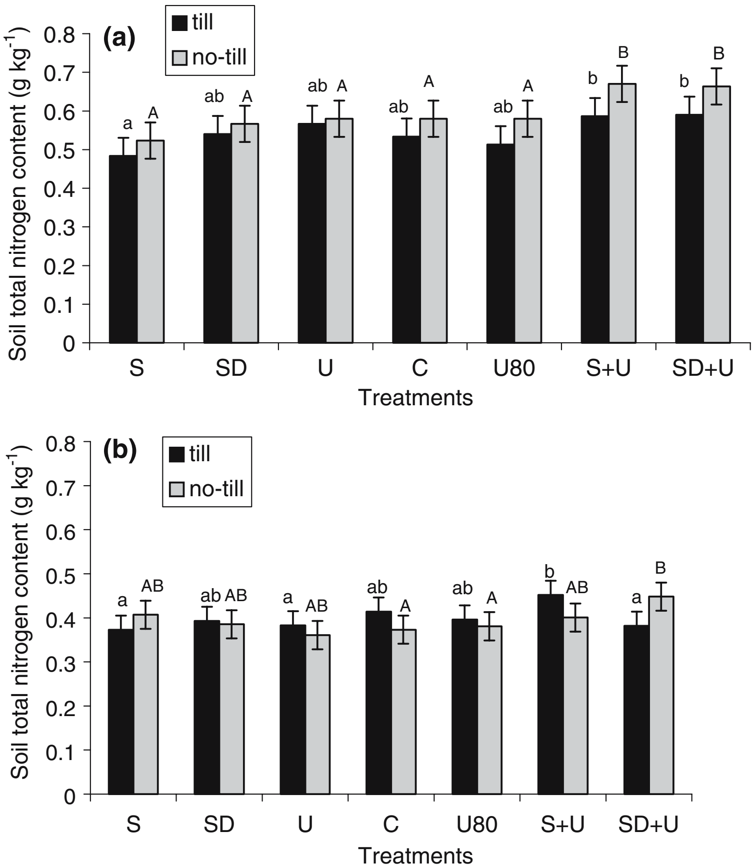


Fig. 2 Soil total N concentration (0–10 cm layer) at flowering in 2000 (**a**) and 2001 (**b**) at Gampela, Burkina Faso. *Bars* represent ± standard error of the mean. Treatments with the *same letter* are not significantly different at a level of 5%, with *lowercase lettering* indicating tilled plots and *uppercase lettering* indicating no-till plots. *S* Maize straw applied at a dose equivalent to 40 kg N ha^{-1}, *SD* sheep dung applied at a dose equivalent to 40 kg N ha^{-1}, *U* urea applied at a dose equivalent to 40 kg N ha^{-1}, *C* control plot, 0 N applied, *U80* urea applied at dose equivalent to 80 kg N ha^{-1} , *S+U* combined maize straw (40 kg N ha^{-1}) and urea (40 kg N ha^{-1}), *SD+U* combined sheep dung (40 kg N ha^{-1}) and urea (40 kg N ha^{-1})

treated with a single organic resource or combined organic resource with urea than in those given single urea treatments. In tilled plots in 2001, the highest ANUE was obtained in plots treated with SD+U and with S and SD, while the lowest ANUE was observed in plots treated with urea and with S+U. In the no-till plots in 2001, the highest ANUE was obtained in plots treated with maize straw, but the difference was not significant from the ANUE obtained in plots treated with S+U and with SD+U; the lowest ANUE was found in plots treated with urea and sheep dung.

Figure 4a shows that in tilled plots in 2001, the NUpE was significantly lower in plots treated with U80, maize straw and sheep dung, while it was significantly higher in plots treated with SD+U compared with other treatments. No significant differences were observed between maize straw and S+U. In the no-till plots, the highest NUpE was found in plots treated with maize straw and the lowest in those treated with sheep dung and urea; these differences were significant compared to other treatments. No significant differences in NUpE were observed between U80, S+U and SD+U in the no-till plots. With the exception of the maize straw treatment, there was a general trend towards a lower NUpE in the no-till plots as compared to tilled plots.

In the tilled plots, sorghum NU_tE was significantly higher following the maize straw, sheep dung and SD+U treatments (Fig. 4b), while it was the lowest following treatments with U80, urea and S+U. In no-till plots, NU_tE was highest following the SD+U treatment and the lowest following the urea U, U80 and sheep dung treatments; these differences were significant compared to other treatments.

Sorghum water use efficiency

In both 2000 and 2001, rainfall was lower than the average annual rainfall, but it was much lower in

Fig. 3 Apparent N use efficiency (*ANUE*) in 2000 (**a**) and 2001 (**b**) at Gampela, Burkina Faso. *Bars* represent standard errors of the means. Abbreviations are as defined in Fig. 2

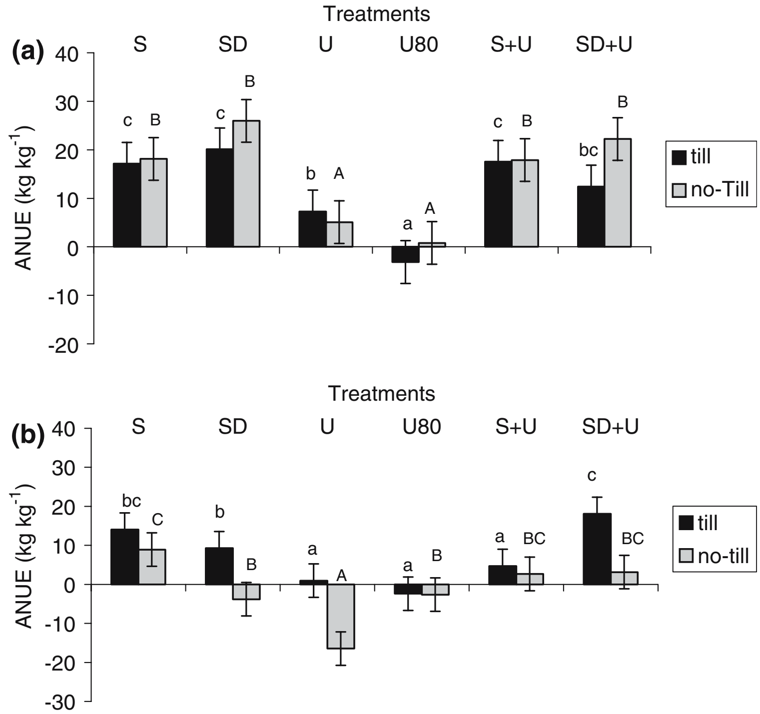
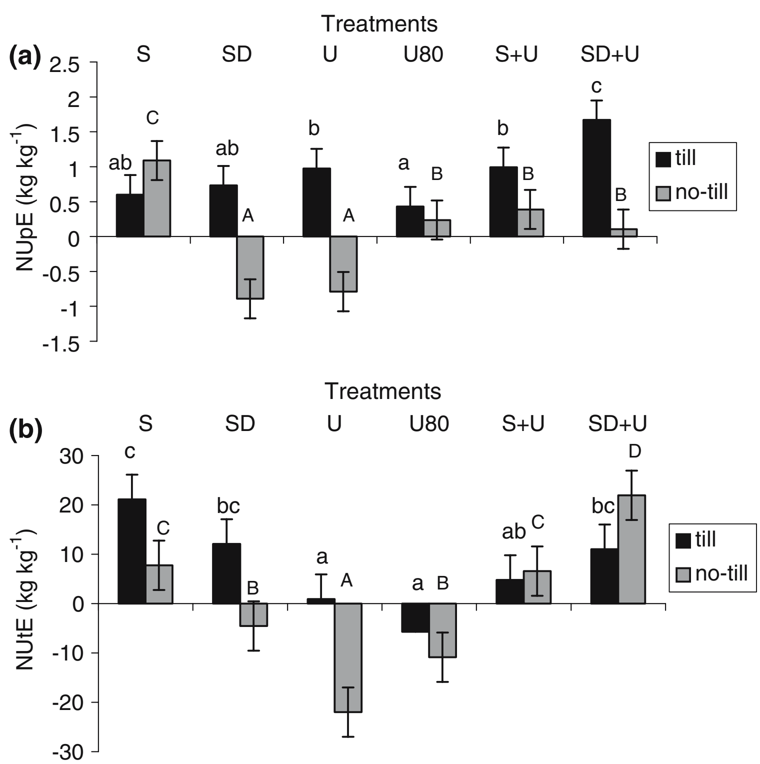


Fig. 4 Nitrogen uptake efficiency (NUpE) **(a)** and utilisation efficiency (NU_tE) **(b)** in 2001 at Gampela, Burkina Faso. *Bars* represent standard errors of the mean. Treatments with the *same letter* are not significantly different at a level of 5%, with *lowercase lettering* indicating tilled plots and *uppercase lettering* indicating no-till plots. Abbreviations are as defined in Fig. 2



2001 (550 mm) than in 2000 (642 mm). However, the rainfall was better distributed in 2001 than 2000. For example, in 2000, July received more rainfall than August, which is usually the rainiest month in semi-arid West Africa. The rainfall in 2000 did not extend to the maturing period of crop growth.

In tilled plots, the WUE in 2000 was significantly higher following the SD+U and S+U treatments compared to the other treatments (Table 3). In the plots treated with S+U and SD+U, the WUE increased significantly compared to maize straw and sheep dung treatments, whereas no significant differences in WUE were observed between the urea, U80 and the control treatments. In no-till plots, with the single application of organic resource and urea, the highest WUE was noted with sheep dung, which was significantly different from that of the control and the urea treatment but did not differ from that with maize straw. A significant WUE increase was observed in the no-till plots treated with S+U and with SD+U compared, respectively, to those treated with maize straw and sheep dung. No significant increase in WUE was observed in the no-tillplots when the urea dose was increased.

In the tilled plots in 2001, with single urea and organic resource application, WUE was higher in the maize straw treatment and significantly different from the urea treatment and the control but did not differ from sheep dung (Table 3). In the combined organic resource and urea treatments, the highest significant WUE was observed in the SD+U treatment followed by the S+U and was significantly different from the U80 treatment and the control. In the no-till plots, WUE was significantly higher in the maize straw treatment than in the other treatments, while it was significantly lower in the sheep dung and urea treatments compared to other treatments. The addition of urea did not significantly affect WUE in the S+U treatment relative to the maize straw treatment, but WUE did increase in the SD+U treatment compared to the sheep dung treatment. No significant difference was observed for WUE in the plots treated with U80 compared to the control in the no-till plots. These results show that, in general, WUE was higher in 2001 than in 2000, although total rainfall was higher in 2000 than in 2001.

ANOVA showed that tillage ($P<0.05$) and fertilisation ($P<0.001$) significantly affected WUE in 2000. In 2001, WUE was significantly influenced by tillage ($P<0.01$), fertilisation ($P<0.001$) as well as by the interaction between tillage and fertilisation ($P<0.001$).

Table 3 Sorghum water use efficiency (WUE) (kg mm^{-1}) for total above-ground plant biomass production in 2000 and 2001 at Gampela, Burkina Faso

Treatments[a]	WUE[b]			
	2000		2001	
	Tillage	No-till	Tillage	No-till
S	9.2 a	8.3 b,c	12.3 c,d	12.3 d
SD	11.6 b	9.1 c	11.3 b,c	5.8 a
U	8.7 a	6.9 a,b	10.1 a,b	5.2 a
C	8.0 a	5.5 a	8.8 a	8.3 b
U80	8.5 a	7.5 b	9.4 a	7.6 b
S+U	16.7 c	11.5 d	14.4 d	10.3 c
SD+U	15.7 c	14.2 e	20.0 e	9.4 b,c

[a] S, Maize straw (40 kg N ha^{-1}); SD, sheep dung (40 kg N ha^{-1}); U, urea (40 kg N ha^{-1}); C, control (0 N); U80, urea (80 kg N ha^{-1}); T, till; NT, no-till

[b] Treatments with the same letter within a column are not significantly different at a level of 5%

Added effect

Table 4 shows that, in the tilled plots in 2000, the added effects of combined organic resources and urea were highest in the S+U treatment (+745 kg ha^{-1}), indicating a positive interaction between maize straw and urea. In the SD+U treatment, however, the added effect was –101 kg ha^{-1}, indicating a negative interaction between sheep dung and urea. In the no-till plots, positive added effects were recorded in the S+U (+502 kg ha^{-1}) and SD+U (+534 kg ha^{-1}) treatments (Fig. 5a). In 2001, the highest added effects were observed in the SD+U treatment, whereas in the S+U treatment, a negative added effect occurred in the tilled plots (Fig. 5b).

Economic benefit of applied urea-N in a single application or mixed to organic resources

Negative or positive added value does not mean economic benefits as this depends on the yield

Table 4 Sorghum yield (kg ha^{-1}) response to the application of single and combined N doses of urea with an organic resource in 2000 and 2001, Gampela, Burkina Faso

Treatments		Sorghum yield[b] (kg ha^{-1})					
		2000			2001		
Fertilisation[a]	Tillage	Grain	Straw	Harvest index	Grain	Straw	Harvest index
S	T	1395 a	4341 a	0.32 b	1714 c	5050 b	0.34 b
	NT	1120 B	3691 A	0.30 B	1350 C	5416 D	0.26 B
SD	T	1833 b	5065 a	0.36 b	1524 b,c	4716 b	0.33 b
	NT	1434 B,C	4618 A	0.31 B	842 B	2363 A	0.37 C
U	T	1320 a	4051 a	0.33 b	1191 a,b	4363 a,b	0.27 b
	NT	598A	4206 A	0.14 A	336 A	2499 A	0.13 A
C	T	1029 a	4326 a	0.24 a	1153 a,b	3690 a	0.31 b
	NT	395 A	3556 A	0.11 A	994 B	3597 B,C	0.28 B,C
U80	T	778 a	4692 a	0.17 a	962 a	4184 a,b	0.23 a
	NT	458 A	4382 A	0.10 A	783 A,B	3404 B	0.23 A,B
S+U	T	2432 c	7764 b	0.31 b	1530 b	6373 c	0.24 a
	NT	1826 C	4986 A	0.37 B	1208 B,C	4463 C,D	0.27 B
SD+U	T	2023 b,c	8068 b	0.25 a,b	2598 d	8365 d	0.31 b
	NT	2173 D	6962 B	0.31 B	1245 B,C	3903 B,C	0.32 B
Mean		1344	5051	0.27	1188	4312	0.28

[a] Legend as in Table 3

[b] Treatments with the same letter within a column are not significantly different. $LSD_{0.05}$ test: Lowercase letters indicate treatments in tilled plots; uppercase letters indicate treatments in no-till plots

level following the treatments. A single application of organic-N and urea-N at a dose of 40 kg N ha^{-1} gave positive returns on the investment in 2000 (Table 5). However, a single urea application was not economically interesting. In both the till and no-till systems, the best results were obtained with the sheep dung treatment, with economic benefits of €109 and €150 in the till and no-till plots, respectively.

In Table 6 it can be seen that supplementing 40 kg N ha^{-1} urea-N to organic-N in the tilled plots resulted in a yield excess per extra urea-N applied that was only interesting in the S+U treatment (€151). In the no-till plots, comparable results were obtained with straw (€92) and sheep dung (€98). When the urea dose was increased to 80 kg N ha^{-1}, a tremendous loss in benefit was observed (–€130 in tilled plots and –€58 in the no-till plots), indicating that the use of urea alone, especially at a high dose, was not economically viable under the prevailing conditions.

In 2001, a single application of organic-N to both the tilled and no-till plots had a positive economic benefit for maize straw; in tilled plots, the positive effect was for sheep dung (Table 7). Supplementing urea-N to organic resources in 2001 only gave positive results with sheep dung (€158 in tilled plots; €38 in no-till plots) (Table 8). In the other treatments, the economic benefits were negative whatever the soil management (tilled or no-till).

Discussion

Synergy between organic-N and mineral-N in crop performance

In 2000, the positive interaction of the S+U treatment in the tilled plots suggests a synergistic effect as sorghum did not significantly respond to maize straw or urea applied separately. Moreover, the plants may have lacked the nutrients to use the available water (lowest soil total N was noted in the maize straw treatment; Fig. 2), as also indicated by the low water use efficiency in this treatment (Table 3). In the urea treatment, the nutrients may have been easily released but the water shortage may have limited nutrient use by plants, as characterised by low WUE. The positive interaction observed may be due to increased nutrient and water use efficiencies

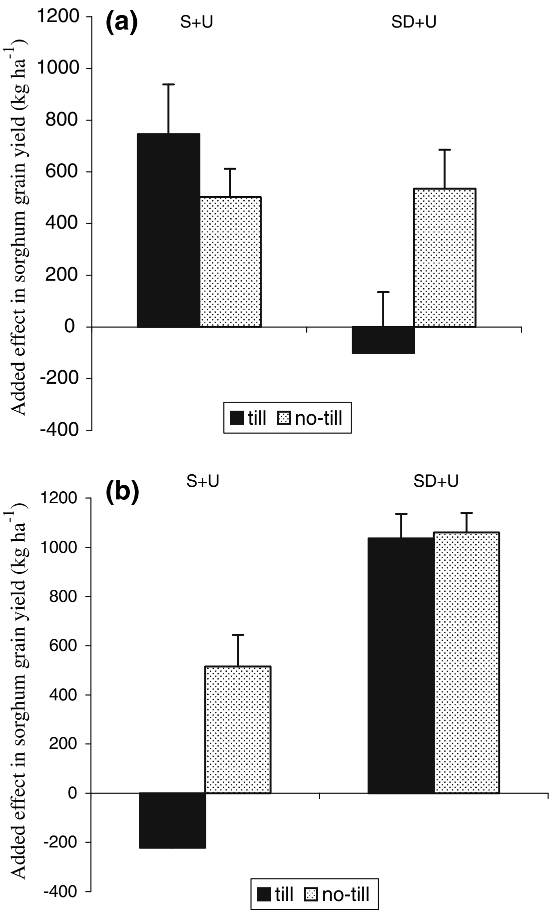


Fig. 5 Added effect in 2000 (**a**) and 2001 (**b**) at Gampela, Burkina Faso. *Bars* represent standard deviation. Abbreviations are as defined in Fig. 2

(WUE was highest in S+U), and tillage may have also reduced nutrient loss.

In the no-till plots, surface-applied urea may be lost with intensive rainfall as no significant difference in soil total N was observed between the urea treatment and the control, which reduced the ANUE. Surface-placed straw reduces run-off (Mando et al. 1996; Mando 1997) and therefore reduces surface-placed nutrient loss and enhances soil moisture. This may explain the positive AE of combined surface-placed maize straw and urea (S+U). The negative interaction observed may be attributed to low nutrient utilisation efficiency, as characterised by the low harvest index based on a high total biomass production. It is more obvious that the water stress at the maturing period may limit nutrient transfer from the straw and leaves to grains, which in turn reduce nutrient utilisation efficiency (Lawson and Sivakumar 1991). In no-till plots, soil total N was higher in the SD+U treatment compared to the application of the total amount (80 kg N) as urea-N only, indicating a reduction in nutrient loss when urea is combined with sheep dung. In addition, both ANUE and WUE improved with the SD+U treatment compared

Table 5 Economic benefit of single organic-N and urea-N treatment in 2000. Values are based on a sorghum price of 117 CFA kg^{-1} and a minimum $\Delta Y/\Delta F$ (to cover N-costs) of 4.7

	Tillage[a]	Treatments[b] ($kg\ N\ ha^{-1}$)		
		S40	SD40	U40
$\Delta Y/\Delta F$ ($kg\ kg^{-1}$)	T	9.2	20.1	7.3
	NT	18.1	25.1	5.1
Yield excess ($kg\ kg^{-1}$)	T	4.5	15.4	2.6
	NT	13.4	21.3	0.4
Yield excess ($kg\ ha^{-1}$)	T	178.8	615.9	103.3
	NT	536.9	851.8	15.8
Economic benefit	T	20,843	71,824	12,040
(FCFA ha^{-1})	NT	62,603	99,323	1,847
Economic benefit	T	32	109	18
(€ ha^{-1})	NT	95	150	3

[a] T, Tillage; NT, no-till

[b] S, Maize straw; SD, sheep dung; u, urea; all applied at a dose equivalent to 40 kg N ha^{-1}

Table 6 Economic benefit of the added 40 kg N ha^{-1} urea to treatments with 40 kg N ha^{-1} organic-N and urea-N in 2000. Values are based on a sorghum price of 117 CFA kg^{-1} and a minimum $\Delta Y/\Delta F$ (to cover N-costs) of 4.7

	Tillage[a]	Treatments[b] ($kg\ N\ ha^{-1}$)		
		S+U40	SD+U40	U80
$\Delta Y/\Delta F$ ($kg\ kg^{-1}$)	T	25.9	4.8	–13.5
	NT	17.7	18.5	–3.5
Yield excess	T	21.2	0.05	–18.2
($kg\ kg^{-1}$)	NT	12.9	13.8	–8.2
Yield excess	T	848.8	1.9	–729.7
($kg\ ha^{-1}$)	NT	518.1	550.7	–328.5
Economic benefit	T	98,973	226	–85,079
(FCFA ha^{-1})	NT	60,407	64,216	–38,306
Economic benefit	T	151	0.3	–130
(€ ha^{-1})	NT	92	98	–58

[a] T, Tillage; NT, no-till

[b] S+U, Maize straw + urea; SD+U, sheep dung + urea; U80,urea applied at dose equivalent to 80 kg N ha^{-1}

Table 7 Economic benefit of single organic-N and urea-N in 2001. Based on a sorghum price of 117 CFA kg^{-1} and a minimum $\Delta Y/\Delta F$ (to cover N-costs) of 4.7

	[a]Tillage	Treatments[b] (kg N ha^{-1})		
		S40	SD40	U40
$\Delta Y/\Delta F$ (kg kg^{-1})	T	14.0	9.3	0.9
	NT	8.9	–3.8	–16.4
Yield excess (kg kg^{-1})	T	9.3	4.6	–3.8
	NT	4.2	–8.5	–21.1
Yield excess (kg ha^{-1})	T	372.6	182.9	–149.9
	NT	168.2	–339.8	–845.4
Economic benefit (FCFA ha^{-1})	T	43,443	21,333	–17,488
	NT	19,607	–39,625	–98,571
Economic benefit (€ ha^{-1})	T	66	33	–27
	NT	30	–60	–150

[a] T, Tillage; NT, no-till

[b] S, Maize straw; SD, sheep dung; u, urea; all applied at a dose equivalent to 40 kg N ha^{-1}

to a single urea application; this had a positive impact on crop performance and explains the positive AE when sheep dung and urea were combined.

In 2001, a negative AE was observed in tilled plots treated with S+U. A previous study indicated that in tilled plots treated with maize straw the addition of 40 kg N ha^{-1} enhanced N immobilisation (Ouédraogo et al. 2006). This may explain the highest soil N concentration in the S+U plot at flowering and the lack of a significant difference in NUpE between the maize straw and S+U plots as well as the low ANUE. The data suggest that yield reduction was also due to a low NU_tE (Fig. 4). In the no-till plots, the positive AE was not due to an increase in crop yield following the addition of urea to the sheep dung but resulted from a buffering effect due to higher NU_tE of the S+U treatment compared to urea (Fig. 4): the former avoids the yield depression that occurs in a single urea application for which the lowest harvest index and NU_tE were noted. The same trend was observed in SD+U treatments in the no-till plots. In tilled plots, the positive interaction in the SD+U treatment induced the highest crop performance. The presence of sheep dung as easily decomposable organic material increased nutrient availability and thereby improved crop nutrition (NUpE was the highest in the SD+U treatment), while tillage may reduce nutrient loss through run-off and volatilisation. As reported by Fernandes et al. (1997), in the semi-arid conditions of West Africa characterised by a short-term rainy season (3–4 months), the success of crops depends on rapid crop growth with the initial rains. If sufficient nutrients are not present at that critical time, then crops have a greater risk of failure.

Table 8 Economic benefit of the added 40 kg N ha^{-1} urea to treatments with 40 kg N ha^{-1} organic-N and urea-N in 2001. Values are based on a sorghum price of 117 CFA kg^{-1} and a minimum $\Delta Y/\Delta F$ (to cover N-costs) of 4.7

	Tillage[a]	Treatments[b] (kg N ha^{-1})		
		S+U40	SD+U40	U80
$\Delta Y/\Delta F$ (kg kg^{-1})	T	–4.6	26.9	–5.7
	NT	–3.6	10.1	3.5
Yield excess (kg kg^{-1})	T	–9.3	22.2	–10.4
	NT	–8.3	5.4	–1.2
Yield excess (kg ha^{-1})	T	–371.8	886.1	–417.3
	NT	–330.3	215.12	–49.0
Economic benefit (FCFA ha^{-1})	T	–43,354	103,326	–48,651
	NT	–38,507	25,083	–5,718
Economic benefit (€ ha^{-1})	T	–66	158	–74
	NT	–59	38	–9

[a] T, Tillage; NT, no-till

[b] S+U, Maize straw + urea; SD+U, sheep dung + urea; U80, urea applied at dose equivalent to 80 kg N ha^{-1}

Economic benefit of combining organic resources and fertilisers

What counts for farmers is that with the mixed treatment and a given soil management option (till or no-till), one needs to purchase only half the quantity of N fertiliser and still get the same yield as when all of the N is supplied with urea.

In 2000, N may not have been the limiting factor for crop growth as the site had been under 6 years of fallow prior to the set-up of the experiment (ANUE was the same in easily and slowly decomposable organic material). This may account for the low economic benefit following a single N application. Moreover, Bationo et al. (1996) indicated that in the semi-arid zone, the rainfall characteristics (in time and space) largely determine the efficiency with which fertilisers can be used. Dry periods during the growing season may result in low fertiliser use efficiency, which further increases drought stress in the crops and has a subsequent negative effect on crop yield. A single application of sheep dung was enough to achieve the best economic benefit under these conditions, and supplementary added N was not efficiently used in this sandy soil. Surface-applied N may be lost through volatilisation or run-off, resulting in a low economic benefit of combined organic-N and mineral-N or a single application of a high dose of urea. Recent studies suggest that applying soil and water conservation measures may bring about the best fertiliser use efficiency and best economic benefit (Zougmoré et al. 2004). The application of maize straw, which is a slowly decomposable organic material, may induce soil moisture conservation, but N immobilisation may also occur and the crop will best respond to supplementary applied N under these conditions.

In 2001, the second year of cultivation, mixing only 40 kg N ha^{-1} to organic resources was economically justified in the sheep dung treatment but it was not enough to alleviate N limitation in the maize straw treatment. Rainfall distribution in 2001 covered the sorghum maturing period, and the application of an easily decomposable organic material improved the supply of N to the crop and subsequent crop production.

The adaptation of an animal production system, such as an animal fattening system versus an extensive animal production system, the best integration between crop and animal production and composting techniques can positively contribute to an improvement in organic resource availability and quality and in their subsequent effects on the efficiency of crop nutrient use.

Conclusion

The results of this study show that under irregular rainfall distribution, the use of a single organic resource at an equivalent dose of 40 kg N ha^{-1} better secured crop yield than the application of an equivalent amount as urea-N. Combining organic resources and fertiliser was found to increase crop yield better than applying the same N amount in the form of urea. In a year of rainfall deficiency, mixing organic resources and fertiliser in till or no-till systems will increase crop water use efficiency, thus enabling the farmer to purchase only half the normal quantity of N fertiliser and still obtain a higher yield than when all the N is supplied with urea. Under conditions where soil N is deficient, economic benefit is achieved when urea is combined with an easily decomposable organic material (e.g. sheep dung). Mixing urea at a dose of 40 kg N ha^{-1} with maize straw is not sufficient in itself to alleviate the negative interaction due to enhanced N immobilisation.

Based on these result, we conclude that the use of N fertiliser alone may be risky and that increases in yield, thereby resulting in economic benefit, was scarcely achieved under the prevailing rainfall conditions. The application of soil and water conservation measures can contribute greatly towards increasing the economic benefit of mineral, organic or combined organic and mineral-derived nutrient applications under semi-arid conditions. Under such conditions, a skillful combination of mineral and organic sources of nutrients may induce a positive interaction and, consequently, result in an economic benefit with respect to crop yield in semi-arid West Africa.

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