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Economic benefits of combining soil and water conservation measures with nutrient management in semiarid Burkina Faso

R. Zougmoré[1,2,*], A. Mando[3], L. Stroosnijder[1] and E. Ouédraogo[1,4]
*[1]Wageningen University, Department of Environmental Sciences, Erosion and Soil and Water Conservation Group, Nieuwe Kanaal 11, 6709 PA Wageningen, The Netherlands; [2]Institute for Environment and Agricultural Research (INERA), 04 BP 8645, Ouagadougou 04, Burkina Faso; [3]International Center for Soil Fertility and Agricultural Development (IFDC)-Division Afrique, BP 4483, Lomé, Togo; [4]Wageningen University, Department of Soil Quality, 67000 EC Wageningen, The Netherlands; *Author for correspondence (e-mail: rb_zougmore@hotmail.com or robert.zougmore@messrs.gov.bf; fax: (226) 340271)*

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Abstract

Nutrient limitation is the main cause of per capita decline in crop production in the Sahel, where water shortage also limits an efficient use of available nutrients. Combining soil and water conservation measures with locally available nutrient inputs may optimize crop production and economic benefit in cereal-based farming systems. A study conducted in 2001 and 2002 at Saria, Burkina Faso (annual rainfall 800 mm, PET of 2000 mm yr^{-1}) assessed the combined effects of two types of semi-permeable barriers (stone rows and grass strips of *Andropogon gayanus* Kunth *cv. Bisquamulatus* (Hochst.) Hack.) and the application of compost or urea on sorghum performance and economic benefits. The field experiment was carried out on a Ferric Lixisol, 1.5% slope and comprised 9 treatments in which the barriers were put along contours and combined with compost-N or urea-N. Installation of stone rows or grass strips without addition of nutrient inputs was not cost effective, although it induced sorghum yield increase (12–58%) particularly under poor rainfall conditions. Combining compost with stone rows or grass strips significantly increased sorghum yield that induced positive interaction effects (mean added effects of 185 kg ha^{-1} for stone rows combined with compost-N and 300 kg ha^{-1} for grass strips combined with compost-N). Economic benefits were substantial (109 480 to 138 180 FCFA ha^{-1}) when compost-N was added to both stone rows and grass strips, whereas limited economic benefits were observed with the application of urea-N (1120 to 22 120 FCFA ha^{-1}). This may provide farmers with capital to invest in soil management and may also contribute to poverty alleviation in sub-Saharan Africa.

Introduction

Soil degradation and nutrient depletion have steadily increased and have become serious threats to agricultural productivity in sub-Saharan Africa (Vanlauwe et al. 2002). Nutrient budgets of arable lands are on average negative (Smaling 1998; Henao and Baanante 1999) and fertilizer consumption is in most cases less than 10 kg ha^{-1}. According to Breman et al. (2001), only two countries in sub-Saharan Africa do not have negative nutrient balances; twelve countries in this region show an average depletion of 0–50 kg ha^{-1} of $N+P_2O_5+K_2O$, while depletions of 50–100 kg ha^{-1} were observed in 27 countries.

In the semiarid west African zone, plant nutrient use efficiency in cereal-based farming systems is often very low because of limited soil moisture conditions (Buerkert et al. 2002). The low soil quality combined with the harsh Sahelian climate leads to a low efficiency of fertilizers (Breman et al. 2001). Indeed, considering the importance of soil moisture for crop growth and for the uptake of plant nutrients in this zone, the effectiveness of soil fertility enhancing measures should be related to the rainfall regimes (FAO 1986).

In order to be effective, application of nutrient inputs in semiarid areas needs to be combined with water harvesting and water conservation schemes or where possible, with small-scale irrigation (Dudal 2002). In the Sahel, several local soil and water conservation (SWC) measures offer potential for reducing runoff, soil loss, and improving available soil moisture. This includes improved soil erosion control using stone rows, hedgerows or micro-catchments (Zougmoré et al. 2000a; Stroosnijder and van Rheenen 2001). Also, some studies have reported that the beneficial effect of SWC measures such as stone rows on soil productivity was limited under continuous non-fertilized cereal cropping (Walle and Sims 1999; Zougmoré et al. 2002). This implies that there is no effective water use efficiency without improved nutrient management.

Several studies have shown the great importance of organic sources of nutrients in improving soil fertility. Indeed, the maintenance of soil organic matter in low-input agro-systems includes retention and storage of nutrients, increasing buffering capacity in low activity clay soils, and increasing water holding capacity (Bationo et al. 1998). However, due to the low availability of organic resources, intensive farming can only be maintained through integrated organic and fertilizer inputs (Vlek 1990).

The lack of economic motivation has been one of the major constraints to increased use of plant nutrient sources in sub-Saharan Africa (Dudal 2002). Moreover, economic evaluation of stone rows in Burkina (Zougmoré et al. 2000b; Posthumus et al. 2001) concluded that when the construction is done in teams with the aid of a project for stone transport and contour tracing, the net present value of stone rows is negative because of the high labor cost and truck rental. The performance of the agricultural sector is poor and greatly influenced by low land and labor productivity (Breman et al. 2001).

Interactions of SWC measures with organic or mineral sources of nutrients may boost crop production and therefore, could be economically profitable to farmers. This work aims to analyze the added effects of combining SWC measures with organic or inorganic fertilizer inputs during two successive cropping seasons in semiarid Burkina Faso. It is hypothesized that application of SWC measures can increase the added benefits of organic or mineral inputs in smallholder farming systems of semiarid Burkina Faso.

Materials and methods

Site description

The experimental field was located at Saria Agricultural Research Station (12°16′ N, 2°9′ W, 300 m altitude) in Burkina Faso. The climate is north-sudanian (Fontes and Guinko 1995). Average annual rainfall during the last 30 years is about 800 mm. Rainfall is mono-modal and lasts for 6 months from May to October. The seasonal distribution is irregular in time and space. Mean daily temperatures vary between 30 °C during the rainy season and may reach 35 °C in April and May. Potential evapotranspiration is 2096 mm in dry years and 1713 mm in wet years (Somé 1989).

The soil type is Ferric Lixisol with an average slope of 1.5% and with a hardpan at 70 cm depth. The textural class according to the USDA system is sandy loam in the 0–30 cm layer (62% sand, 28% silt, 10% clay) with a gravel content decreasing from 36% at the 0–5 cm layer to 30% from 10 cm depth. The rooting depth for sorghum in these soils is 80 cm. The organic C content is less than 6 g kg^{-1}, the N content is less than 0.5 g kg^{-1}, the exchangeable K content is about 46 mg kg^{-1} and the available P content is less than 15 mg kg^{-1}. The CEC is poor (2–4 cmol kg^{-1}) and we found that the base saturation ratio fell from 70% in the topsoil to 30–50% at 80 cm depth, in line with the pH (H_2O), which decreased from 5.3 to 4.9.

Experimental design

The study was conducted during two successive cropping seasons (2001–2002). The trial consisted of a randomised Fisher block design with nine treatments in two replications:

T_{sr}: stone rows, no N input
T_{src}: stone rows + compost-N
T_{sru}: stone rows + urea-N
T_u: urea-N, no SWC measures
T_0: no SWC measures, no N input
T_{gs}: grass strips, no N input
T_{gsc}: grass strips + compost-N
T_{gsu}: grass strips + urea-N
T_c: compost-N, no SWC measures

Each plot (100 m long, 25 m wide) was isolated from the surrounding area by an earth bund 0.6 m high. Stone rows and grass strips had been installed during the 1999 rainy season, spaced 33 m apart (i.e., 3 barriers per plot) along the contours. Indeed, previous studies have shown that for the more common case of farmers working with an NGO to trace contours and transport rocks, the optimal spacing that maximizes the net present value in a sorghum-based system was between 30 m and 43 m (Zougmoré et al. 2000a, b). Each stone row consisted of two rows of stones placed in a furrow. The upslope row of large stones was stabilized by the downslope row of small stones. Each stone row was about 0.2–0.3 m high. Each grass strip comprised three rows of grass, resulting in a thick barrier 0.3 m wide.

In relevant plots, compost was applied each year once before sowing at an equivalent dose of 50 kg N ha^{-1} (4800 kg ha^{-1} in 2001 and 5600 kg ha^{-1} in 2002). Urea was also applied at the dose of 50 kg N ha^{-1} in two splits (25 kg N ha^{-1} was applied 21 days after planting and 25 kg N ha^{-1} 56 days after planting). In all plots, a 110-day improved sorghum (*Sorghum bicolor* (L.) Moench*)* variety (Sariasso 14) was sown in rows across the slope by hand at the rate of 31250 seedlings per hectare. Prior to sowing, the plots were ploughed at 15-cm depth using oxen power in June 2001 and in July 2002, resulting in the incorporation of the applied urea or compost. The plots were weeded with hand hoes twice a year. All plots received a base dressing of 20 kg ha^{-1} P in the form of triple superphosphate to eliminate phosphorus deficiency as a factor in the experiment.

Data collection and analysis

We assume that x_1= stone rows or grass strips, x_2= application of compost-N or urea-N, x_0= control (no SWC measures, no N input), Y= yield, (x_1+x_2) = combined SWC measure (x_1) and compost-N or urea-N (x_2). From definitions of 'added effect' and 'interaction effect' given by Vanlauwe et al. (2002), Giller (2002) and Iwuafor et al. (2002), we consider that the interaction effect (IE) in crop yield is the benefit in crop yield (in comparison to the control treatment) of the combined application of both SWC measure and urea-N or compost-N ($\Delta Y(x_1+x_2)$) minus the sum of the benefits from the two components (ΔYx_1 and ΔYx_2) when applied in isolation.

$$\Delta Yx_1 = Y(x_1) - Y(x_0) \quad (1)$$

$$\Delta Yx_2 = Y(x_2) - Y(x_0) \quad (2)$$

$$\Delta Y(x_1+x_2) = Y(x_1+x_2) - Y(x_0) \quad (3)$$

$$IE = \Delta Y(x_1+x_2) - (\Delta Yx_1 + \Delta Yx_2) \quad (4)$$

There is positive interaction between x_1 and x_2 when IE $>$ 0, and negative interaction between x_1 and x_2 when IE $<$ 0.

In order to be able to determine the economic benefit of single or combined N-input and SWC measures, a minimum yield value was calculated per treatment. It corresponds to the minimum excess yield that supports the annual cost of the applied technology. To that end, the yield increase per kg N ($\Delta Y/\Delta N$) was calculated for the applied 50 kg ha^{-1} urea-N or compost-N. ΔY stands for yield increase and ΔN for applied N amount, i.e., 50 kg N ha^{-1}.

$$\Delta Y/\Delta N\ (x_2) = \Delta Y(x_2)\ /\ 50 \quad (5)$$

In 2001 and 2002, the price of 1 kg urea-N was about 544 FCFA (1 USD= 650 FCFA in 2003). The price of 1 kg of sorghum in the region of Saria fluctuated between 100 FCFA and 180 FCFA. Therefore, to be economic, sorghum yield increase ($\Delta Y/\Delta N$) should exceed 3 to 5.4 kg per unit urea-N applied. An average of 140 FCFA for 1 kg sorghum and a minimum of 3.9 kg sorghum per kg of urea-N were used in this paper. This corresponds to a minimum yield of 195 kg ha^{-1} for urea-N.

Several studies (Graaff 1996; Zougmoré et al. 2000b; Posthumus et al. 2001) have defined total costs for stone rows and grass strips installation in Burkina Faso to be 75520 CFA ha^{-1} and 33200 CFA ha^{-1}, respectively. The calculation of annual costs took into account the amortization, the opportunity cost of the capital and the repair and maintenance costs (Table 1). We assumed 300 m of bund per hectare and an amortization in 10 years for stone rows and 5 years for grass strips (Zougmoré et al. 2000b). The annual opportunity cost of capital rate, which measures the income foregone by investing in stone rows instead of livestock, small scale commerce or other activities, was fixed at 50% for Burkinabè farmers, and a repair and maintenance cost of 10 FCFA m^{-1} of bund (Lowenberg DeBoer et al. 1994). Lowenberg DeBoer et al. (1994) explained that the

Table 1. Annual costs of SWC measures and compost production in pits in Burkina Faso (in FCFA ha^{-1}).

	Stone rows	Grass strips	Compost pit
Installation cost	75520	33200	10000
Useful life (year)	10	5	5
Amortization cost	7552	6640	2000
Composting cost	–	–	19000
Opportunity cost of capital[a]	37760	16600	14500
Maintenance and repair costs[b]	3000	3000	2400
Discounted annual cost	48312	26240	37900

[a] Rate of opportunity cost of the capital = 50%; [b] Repair and maintenance cost for stone rows and grass strips = 10 FCFA m^{-1}.

Table 2. Effect of single or combined SWC measures and compost-N or urea-N on sorghum grain yield in 2001 and 2002 at Saria, Burkina Faso (kg ha^{-1})[a].

Treatments	2001	2002
T_{SRC}	2535 (43) a	2766 (58) a
T_{GSC}	2338 (73) ab	2536 (74) b
T_C	2278 (68) ab	2385 (79) b
T_{SRU}	1796 (50) c	1511 (39) c
T_{GSU}	1537 (22) c	1411 (30) c
T_0	1099 (76) d	1164 (75) d
T_{SR}	1226 (74) d	1308 (54) cd
T_{GS}	896 (72) d	983 (42) d
T_U	2106 (14) b	1403 (30) c
Probability	0.022	0.021

[a] Treatments with the same letter in a column are not statistically different at $p = 0.05$; Values in brackets: ± standard deviation between runoff volumes measured in pits and recorded values of runoff. T_0: no SWC measures, no nutrient supply (control plot); T_{SR}: stone rows, no nutrient supply; T_{SRC}: stone rows + compost; T_{SRM}: stone rows + manure; T_{SRU}: stone rows + urea; T_{GS}: grass strips, no nutrient supply; T_{GSC}: grass strips + compost; T_{GSM}: grass strips + manure; T_{GSU}: grass strips + urea.

high discount rate (50%) is linked to the poorly developed financial institutions and a chronic shortage of capital. The discounted average cost for stone rows using truck transport was 48312 FCFA ha^{-1} yr^{-1} while grass strips installation cost using root transplanting was 26240 FCFA ha^{-1} yr^{-1}. The minimum yield was therefore 345 kg ha^{-1} sorghum grain for stone rows and 187 kg ha^{-1} sorghum grain for grass strips (Table 3).

The production cost of 5 ton of compost in pit was determined from results of Bazié (1995) and Graaff (1996). The discounted cost for the pit establishment was about 10000 FCFA while the operational cost (pit filling, watering and emptying/pilling) was 19000 FCFA. The discounted annual cost was therefore 37900 FCFA ha^{-1} (Table 1) and the price of 1 kg of nitrogen deriving from compost was 758 FCFA. Compost cost did not include straw cost, comparable to the zero cost of the rocks that were used to construct the stone rows. Also, compost transport cost was not included, assuming that the pit was situated in the field or nearby as recommended by extension services. A minimum sorghum yield for compost-N was 5.4 kg kg^{-1}, which corresponds to a minimum yield of 271 kg ha^{-1}. This implies that for a technology to be beneficial, its excess yield, which is the difference between yield increase (ΔY) and the minimum yield, should be greater than zero.

Sorghum grain and straw yields were measured after sun drying at harvest from the 36 subplots in each plot. The STATITCF package (Gouet and Philippeau 1986) was used for statistical analyses, including ANOVA and Newman-Keuls test for significant differences between treatments at $p < 0.05$.

Results and discussion

Effects of SWC measures and nutrient management on sorghum performance

Sorghum yields were significantly different among treatments in 2001 and 2002 (Table 2). Except for T_{GS} (grass strips alone), sorghum grain yield was

Table 3. Economic benefits of single stone rows or single grass strips in 2001 and 2002.

	Stone rows		Grass strips	
	2001	2002	2001	2002
Annual cost (FCFA ha^{-1})	48312	48312	26240	26240
Sorghum average price (FCFA kg^{-1})	140	140	140	140
Minimum yield (kg ha^{-1})	345	345	187	187
ΔY (kg ha^{-1}) [a]	127	144	− 203	− 181
Excess yield (kg ha^{-1})	− 218	− 201	− 390	− 368
Economic benefit (FCFA ha^{-1})	− 30520	− 28140	− 54600	− 51520

[a] ΔY stands for yield increase for stone rows or grass strips treatments compared to the control treatment.

lower in the control treatment than in the water and nutrient management treatments during the two years. In 2001, sorghum yields with stone rows alone (T_{SR}) increased by 12% whereas with grass strips alone (T_{GS}) sorghum yield decreased by 18% when compared to the control (T_0). In 2002, single stone rows plots induced 12% grain yield increase whereas in single grass strips plots, grain yield decreased by 15% compared to the control. Zougmoré et al. (2003a) explained that due to their architecture, stone rows were better able to slow down runoff and to improve water infiltration compared to vegetation bunds and this may explain the better performance of sorghum with stone rows. These results indicate that during well-distributed rainfall years in the Sahel, implementing water conservation measures without adding nutrients induced little or even negative influence on crop yields. This is consistent with results of previous studies in the region (Hamer 1996; Zougmoré et al. 2003a).

In 2001, application of compost (T_C) or urea (T_U) alone greatly increased sorghum yield by respectively 107% and 92% compared to the control (T_0). Thus, applying nutrient inputs alone ($T_{C,}$ T_U) induced much higher grain yields than laying SWC barriers without nutrient inputs: 80% compared to stone rows plots (T_{SR}) and 145% compared to grass strips plots (T_{GS}). In 2002, as in 2001, single application of N-input (T_C, T_U) induced higher grain yield than single application of SWC measures: applying urea (T_U) induced 7% and 43% yield increase compared to plots with stone rows (T_{SR}) or grass strips (T_{GS}) alone, respectively, whereas application of compost alone (T_C) increased yield by 82% and 143% compared to stone row (T_{SR}) and grass strip plots (T_{GS}), respectively. As stated by Bationo et al. (1998), the productivity of most soils in their native state in the study zone is very low because of low inherent levels of plant nutrients, leading to soil mining. Thus, applying plant nutrients (50 kg N ha^{-1}) in these poor soils induced great positive reaction in crop production (Table 2), particularly during good rainfall years when soil moisture constraint is small (Figure 1). In plots with compost application, the mineralization of compost releases not only the macronutrients such as nitrogen and phosphorus, but also considerable amounts of micronutrients for plants (Velthof et al. 1998). This explains also why in 2001, combining compost with stone rows (T_{SRC}) induced a yield increase of 106% when compared to plots with stone rows alone (T_{SR}). Similarly, combining grass strips and compost (T_{GSC}) induced a grain yield increase of 160% when compared to plots with grass strips alone (T_{GS}). Also, adding urea to plots with barriers (T_{SRU}, T_{GSU}) increased grain yield by 46% and 71%, respectively, compared to plots with barriers only (T_{SR}, T_{GS}). In general, only slight differences were observed between treatments combining barriers with N-input (T_{SRC}, T_{GSC}, T_{SRU}, T_{GSU}) and receiving-N treatments without barriers (T_C, T_U). These results were confirmed in 2002: treatments combining barriers with compost (T_{SRC}, T_{GSC}) induced yield increase by respectively 138% and 118% compared to the control. Adding urea to plots with barriers (T_{SRU}, T_{GSU}) increased grain yield by 30% and 21%, respectively, when compared to control plots. The above results suggest that under Sahelian conditions, SWC in combination with nutrient management can be used to alleviate risks and to achieve production intensification. This attests that to develop new strategies of agricultural production in sub-Saharan West Africa, one should take into account local SWC technologies and improved practices of soil fertility replenishment (Dudal 2002; Schreurs et al. 2002).

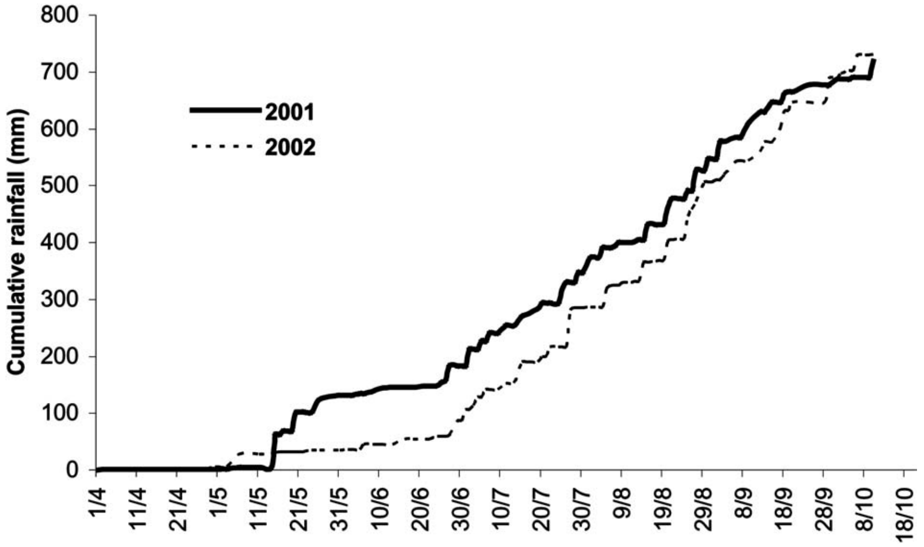

Figure 1. Cumulative rainfall for the 2001 and 2002 rainy seasons at Saria, Burkina Faso.

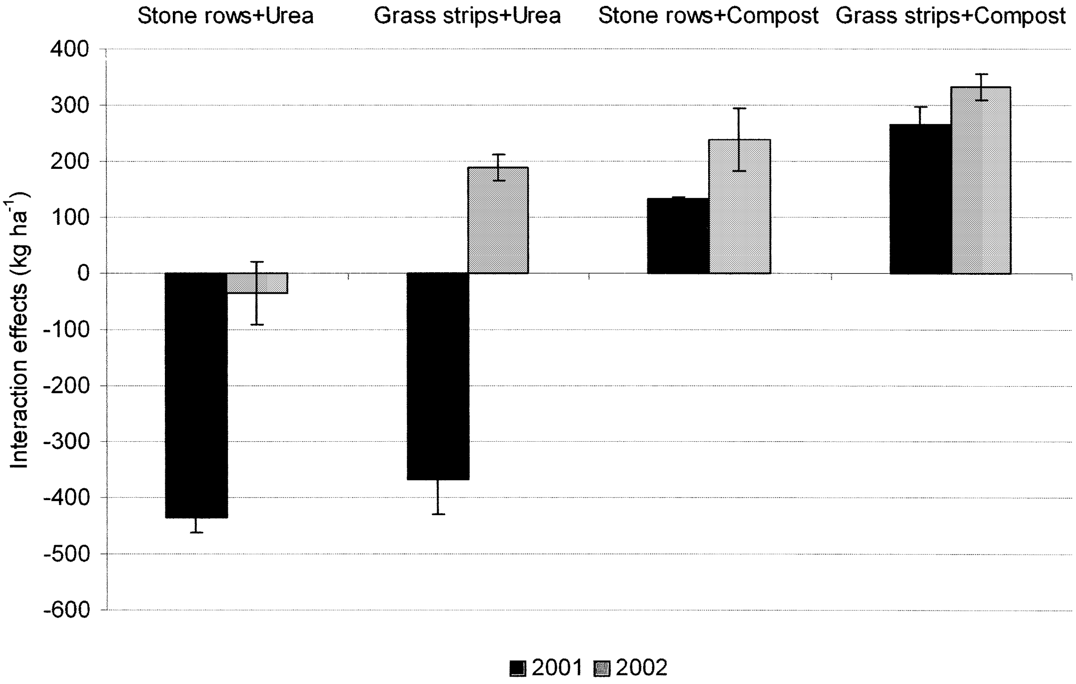

Figure 2. Interaction effects of combined SWC measures and compost or urea-N in 2001 and 2002 at Saria, Burkina Faso.

Interaction effects of combining organic-N or fertilizer-N with SWC measures

Positive interactions ($\Delta Y(x1+x2)$) of combined SWC measures and N-inputs were observed (Figure 2) apart for T_{GSU} in 2001 (–367 kg ha^{-1}) and T_{SRU} in 2001 (–437 kg ha^{-1}) and 2002 (–36 kg ha^{-1}). The negative interactions in the latter treatments were mainly explained by the higher response of sorghum yield to single N-inputs (T_C, T_U) than to single SWC measures (T_{SR}, T_{GS}), particularly during these two well-distributed rainfall years with little water stress (Figure 1). This is in accordance with results of Fatondji et al. (2001) and Zougmoré et al. (2003b), who

Table 4. Economic benefits of single urea-N or single compost-N in 2001 and 2002.

Treatment	Urea-N		Compost-N	
	2001	2002	2001	2002
N-input cost (FCFA kg^{-1} N)	544	544	758	758
Sorghum average price (FCFA kg^{-1})	140	140	140	140
Minimum yield increase (kg kg^{-1})	3.9	3.9	5.4	5.4
ΔY / ΔN (kg kg^{-1}) [a]	20.2	4.8	23.6	24.4
Excess yield increase (kg kg^{-1})	16.3	0.9	18.1	19.0
Excess yield (kg ha^{-1})	813	44	907	950
Economic benefit (FCFA ha^{-1})	113820	6160	127020	133040

[a] ΔY stands for yield increase and ΔN for applied N amount of 50 kg N ha^{-1}.

found in the same region that the supply of organic source of nutrients (manure, compost) in *zaï* and half-moon pits dug in a very degraded bare soil (locally called *zipellé*) leads to significant modifications of soil mineral status and increased crop yields. The high response of sorghum yield to added N-inputs only (T_C, T_U) suggests that nutrient supply more than water retention by the filtering barriers (T_{SR}, T_{GS}) increased the yield in combined SWC and nutrient plots.

The positive interaction of combined SWC measures with compost-N was 1.3–1.7 times greater than when combined with urea-N. In 2001, treatments T_{SRC} and T_{GSC} showed positive interaction (132 kg ha^{-1} and 265 kg ha^{-1}, respectively) whereas in 2002, treatments T_{SRC}, T_{GSC} and T_{GSU} showed higher positive interactions than in 2001 (Figure 2). This was mainly due to the cumulative and positive effect of successive application during two years of nutrient inputs particularly for compost-N. Moreover, rainfall distribution at the maturing period in 2002 was better than in 2001 (Figure 1), which may have great impact on sorghum grain production. The higher response of yield to compost than to urea suggests that soil fertilizer recovery is low and a way to improve soil productivity would consist in increasing fertilizer recovery through urea and organic resource combination and the use of fertilizers that release nitrogen slowly (e.g.: urea super granules).

An important issue is whether the positive or negative interaction results into an economic benefit, since this depends mainly on the yield level of treatments. Moreover, adoption by farmers of these technologies is only effective if they perceive a clear return on their direct investment costs (Dudal 2002).

Economic benefit of water and nutrient management

Results in Table 3 show that yield increases in 2001 and 2002 did not cover annual costs of stone rows or grass strips alone. Indeed, excess yields are negative for treatments T_{SR} (–210 kg ha^{-1}) and T_{GS} (–380 kg ha^{-1}). This confirms results of Zougmoré et al. (2000b) who found that when using truck transport under the project scenario (local people work together to gather stones and build the stone rows on a given watershed or village during community workdays), stone rows construction (not combined with application of nutrient inputs) had no economic benefit for the individual farmer, as the grain yield increase does not cover the high cost of construction. Studies by de Graaff and Spaan (2000) in the same region concluded that the cost of constructing stone rows is too high for the individual farmer, certainly for marginal semiarid Sahelian farmers. This suggests that stone row construction is only profitable if the investment costs are lowered by providing the transport of stones free of charge. Sorghum production was less in grass strips plots (particularly near the strips) than further away, probably because of the shading from the grass and competition with sorghum plants for nutrients and water. The results above indicate that under Sahelian conditions, the use of SWC measures cannot be justified on economic grounds. However, environmental and other benefits not considered in this study may still justify their application.

Conversely, economic benefits of treatments in Table 4 show that single application of compost-N or urea-N were cost-effective but supply of urea-N was less beneficial (6160 FCFA) in 2002 compared to compost-N (133040 FCFA).

The combination of SWC measures with urea-N (T_{SRU}, T_{GSU}) or compost-N (T_{SRC}, T_{GSC}) induced

Table 5. Economic benefits of combining stone rows or grass strips with compost-N or urea-N in 2001 and 2002 at Saria, Burkina Faso[a].

	2001				2002			
	T_{SRU}	T_{GSU}	T_{SRC}	T_{GSC}	T_{SRU}	T_{GSU}	T_{SRC}	T_{GSC}
Minimum yield for N inputs (kg ha^{-1})	195	195	271	271	195	195	271	271
Minimum yield for SWC measures (kg ha^{-1})	345	187	345	187	345	187	345	187
Minimum yield for SWC + N input (kg ha^{-1})	540	382	615	457	540	382	615	457
Excess yield (kg ha^{-1})	158	54	821	782	− 193	− 135	987	915
Economic benefit (FCFA ha^{-1})	22120	7560	114940	109480	− 27020	− 18900	138180	128100

[a] T_{src}: stone rows + compost-N; T_{gsc}: grass strips + compost-N; T_{sru}: stone rows + urea-N; T_{gsu}: grass strips + urea-N.

positive economic benefits in 2001 (Table 5), indicating that at least the annual costs for implementing SWC measures and applying compost-N or urea-N were covered by the excess yields in the combined SWC measure and N-input treatments. However, in 2002, compared to the results of 2001, economic benefits for treatments with SWC measures and compost-N increased on average by 16% while economic benefits for combined SWC measures and urea-N treatments decreased by 200% and even showed negative values.

Ganry and Badiane (1998) noted that in cultivated sandy soils of dry tropical zones, organic matter becomes more important in the soil surface layer, because of its effects on the water balance and the mobility of mineral elements. Easily decomposable organic material like compost may well make available plant nutrients at a crucial time of sorghum production (maturing phase), which, in combination with better water availability thanks to SWC measures, have improved sorghum productivity. Moreover, organic matter maintains a soil physical, chemical and biological balance that would accelerate crop root formation in the soil profile (Piéri 1989). The best sorghum production resulting from this positive interaction effect of SWC measures and N-inputs explains their greatest economic benefits. Loss of available urea-N through runoff or leaching could explain the lower interactive effect of urea-N that has resulted in lower economic benefits in comparison to organic-N (Ouédraogo et al. 2004, in press).

Conclusions

Results of this study suggest that:

When annual rainfall is well distributed in time (as was the case in 2001 and 2002 at Saria, Burkina Faso), installation of stone rows only induced very limited sorghum yield increase while *Andropogon gayanus* grass strips induced sorghum yield decrease. These yields were not enough to support installation costs due to high labor, transport and material inputs.

Application of the sole compost-N or urea-N induced significant greater sorghum yield increase than SWC measures only.

Stone rows or grass strips combined with compost-N induced positive interaction effects while stone rows combined with urea-N showed negative interactions. A positive interaction of grass strips combined with urea-N was observed only after two years.

Economic benefits when combining compost-N to both stone rows and grass strips were substantial (109 000 to 138 000 FCFA ha^{-1}) while the greatest amounts observed with added urea-N were small (7560 to 22 120 FCFA ha^{-1}).

These results indicate that in the Sahel, opportunities do exist for making more efficient use of local sources of nutrients such as compost in combination with locally accepted SWC measures. This may empower farmers to invest for sufficient nutrient supply in the sub-Saharan soils characterized by poor fertility.

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