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Trend and stability analyses of millet yields treated with fertilizer and crop residues in the Sahel

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Abstract

Pearl millet (*Penisetum glaucum* (L.) R.Br.) is a major food crop grown on impoverished sandy soils in the Sahel. A 9-year long-term study was undertaken in the Sahel to test the hypothesis that integrated use of millet crop residues retained on farm fields after harvest and mineral fertilizers results in greater and more sustainable yields and conserve soil fertility better than either the use of residue or fertilizer alone. The four treatments compared were: (1) control (crop residue removed and no fertilizer applied), (2) crop residue alone, (3) 30 kg N + 13 kg P ha^{-1} (fertilizer) alone and (4) crop residue + fertilizer. Use of crop residue + fertilizer increased grain yield fourfold over the control; use of fertilizer doubled millet yield relative to the control and crop residues resulted in 1.2 times more yield than the control. Crop residues significantly improved nutrient-use efficiency of the applied fertilizer. Sustainability yield index (SYI), a measure of an upward trend in yield over time, was greatest in crop residue + fertilizer plots as are soil organic carbon, available P and pH. Stability analysis indicated that crop residue + fertilizer treatment gave in greater yields and returns over fertilizer cost in the various seasons than either crop residue or fertilizer.

Keywords: Crop residue; Fertilizer use; Millet; Sahel

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1. Introduction

Integrated soil management practices involving a mixture of organic and inorganic amendments have a greater potential for improving low soil productivity than a single management option in the Sahel (Pieri, 1989; Sedego, 1981; Bukert et al., 2000). The predominant soil types, Entisols and Alfisols, are often deficient in phosphorus (P) and nitrogen (N) and low in organic carbon (Van Keulen and Breman, 1990; Bationo et al., 1991). Effective cation exchange capacity (ECEC) of the soils, which is more related to organic carbon than clay is also low (Bationo and Mokwunye, 1991). De Ridder and Van Keulen (1990) found that a decrease of 1 g kg^{-1} organic carbon resulted in a reduction of ECEC by 4.3 mmol kg^{-1}, implying a reduction of the ability of the soil to retain nutrients as the level of organic carbon falls.

Maintaining crop residues in the field after harvest is one way to stabilize soil organic carbon. Fertilization to improve total biomass yield is another indirect

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method of achieving the same objective. Crop residues applied as mulch have been used to maintain soil fertility, improve infiltration and aggregate stability (Lal, 1980; Lal et al., 1980; Maurya and Lal, 1981). In the Sahelian region, Bukert et al. (2000) associated crop residue retention in the field with increased P availability, protection of plants against erosion, decreased soil temperature as well as moisture conservation. Despite these advantages, farmers prefer to remove crop residues off the field to feed livestock, or use them as fuel or as building materials.

Breakdown and nutrient release pattern of organic materials are generally a function of the chemical composition and weather conditions. Materials with large carbon or lignin to N ratios are classified as poor quality residues and have slow rate of decomposition (Tian et al., 1995; TSBF, 2000). According to Tian et al. (1995) maize stover, which may resemble millet straw in chemical composition, had a plant residue quality index (PRQI) of 4.7, i.e. poor quality relative to *Mucuna* sp. with PRQI of 9.0 or *Leucaena* sp. with a PRQI of 14.0. Dry moisture conditions in the Sahel may further retard decomposition and mineralization of crop residues. Also, starter fertilizers speed decomposition rate of residues to facilitate proper synchrony of nutrients with crops during the growing period (Ganry et al., 1978).

The present study tested the hypothesis that integrated use of crop residues and mineral fertilizers result in more sustainable yield and soil fertility conservation than either the use of residue or fertilizer.

2. Materials and methods

A long-term study was initiated in 1983 at the International Crop Research Institute for the Semiarid Tropics (ICRISAT) Sahelian Center, Niger. Conditions at the test site, Sadore (13°15′N latitude, 2°18′E longitude), with respect to weather and soil parameters, has been described by Sivakumar (1990), Bationo and Mokwunye (1991) and Manu et al. (1991). At the beginning of the season in early June, surface (0–20 cm) soils were sampled and analyzed for pH in 1 N KCl at 2:1 solution to soil ratio (McLean, 1982), organic carbon (Walkley and Black, 1934) and available phosphorus by extraction with 0.1 N HCl and 0.03 N NH_4F at pH of 1.2.

The four treatments compared were: (1) control (crop residues removed and no fertilizer applied), (2) millet crop residues retained on the field after harvest, (3) application of $30\,\mathrm{kg\,N\,ha^{-1}} + 13\,\mathrm{kg\,P\,ha^{-1}}$ (fertilizer) alone, and (4) a combination of crop residues and fertilizer. Sources of fertilizers were urea for N (46–0–0) and single superphosphate (0–20–0) for P and both were broadcast and incorporated. Nitrogen was applied in two equal amounts at planting and 6 weeks later while phosphorus was broadcast and incorporated only at planting. The design of the experiment was a randomized complete block with four replications. Millet cultivar CIVT (110 days) was planted at a spacing of 1 m × 1 m to attain a plant population of 10,000 hills $\mathrm{ha^{-1}}$. Crops were planted in June and harvested in October. Plot size was 50 $\mathrm{m^2}$.

Statistical analysis with Statview software (SAS, 1998) included analysis of variance and regression. Regression models for yield (Y) trends ($Y = a + bT$, where T is time in years) and stability ($Y = a + be$, where e is the environmental index) analyses followed the methods previously used by Yadav et al. (2000) and Hildebrand and Russell (1996), respectively. The *t*-test with the pooled residual mean square was employed for the pairwise comparison of intercepts and slopes (Gomez and Gomez, 1984). Monthly rainfall and temperatures were recorded and used as input variables in the Newhall simulation model (NSM) to determine evapotranspiration (ET) (Van Wambeke et al., 1992). Water-use efficiency (WUE) was computed as the ratio of grain and stover yields to ET, adjusted using millet crop coefficient (Doorenbos et al., 1979). Fertilizer-use efficiency (FUE) was calculated as (yield (in fertilized plots) − yield (in control plots)/(applied fertilizer in kg $\mathrm{ha^{-1}}$)) (Cassman et al., 1996). Sustainability yield index (SYI) was assessed using the formula of Singh et al. (1990) as

$$\mathrm{SYI} = \left(-\frac{1}{y} - \mathrm{S.D.}_{\cdot n-1}\right) Y^{-1}$$

where $-1/y$ is the mean yield, $\mathrm{S.D.}_{\cdot n-1}$ the standard deviation and Y the maximum yield. Returns over fertilizer cost were computed as (yield of millet × average price for that year) − cost of fertilizer for the year. The study was conducted from 1984 to 1996 but data from 1986 to 1991 were excluded in the present analysis as a student partly involved in the project took them overseas.

3. Results and discussion

3.1. Seasonal and treatments effects on yield

The growing seasons, June–August, for the years 1984 and 1992 were dry following the 80% confidence limit rainfall classification previously used by Peterson et al. (1990). The 1994 growing season was wet and the rest were considered average (Table 1). Millet, a drought tolerant crop, was indifferent to growing seasons' moisture conditions as reflected in the poor correlation between yield and mean rainfall in June–August ($r = 0.40$, $p > 0.05$). In the dry years of 1984 and 1992, millet yields were comparable or greater than some average years. It is interesting to note that millet plots treated with a combination of crop residues and fertilizer yielded as much as 2160 kg ha^{-1} in 1992 (dry) whereas the control (210 kg ha^{-1}) and the other treatments produced less than 1000 kg ha^{-1} of grain.

Weather variability is primarily responsible for year-to-year variability of crop yield while soil and crop management practices such as varieties, fertilization and type of cropping systems determine yield differences within seasons (Hien et al., 1997). Other scientists contend that uncertain patterns of rainfall in the Sahel may result in large yields in some dry years because rains came at the critical stages of the crop. Conversely, poor yields have been recorded in years with large amounts of rainfall, which was unevenly distributed (Sivakumar, 1990; Shapiro et al., 1993; Hien et al., 1997). Integrated use of crop residues and mineral fertilizes (Table 1), may therefore appear to be an appropriate technology to sustain crop yields regardless of weather conditions. In Niger, Bukert et al. (2000) ascribed positive effects of crop residue on improved soil and crop productivity to enhanced P availability, decreased soil temperature and increased soil moisture conservation.

3.2. Crop residue and fertilizer effects on production indices

Effect of crop residue and fertilizer on grain and stover yields, WUE, FUE and SYI averaged over the nine growing seasons are shown in Table 2. Both average grain and stover yields increased with increasing soil fertility management. Grain yields in crop residue + fertilizer plots increased almost fourfold over the control; yield in plots treated with fertilizer alone were nearly twice over the control and yields from the crop residue plots were 1.2 times more than the control. WUE and SYI followed a similar pattern as yields. Retention of crop residues on the field

Table 1
Long-term yield of millet as affected by crop residue treatments and moisture conditions in nine growing seasons in the Sahel[a]

Year	Rainfall (mm)	Yield				
		Moisture condition	Control (kg ha^{-1})	Crop residue (kg ha^{-1})	Fertilizer (kg ha^{-1})	Crop residue + fertilizer
1984	52.0	Dry	270	410	1080	1250
1985	130.2	Average	160	770	1030	1940
1986	134.8	Average	70	740	820	1530
1991	138.1	Average	270	560	510	1350
1992	101.0	Dry	210	710	930	2160
1993	123.6	Average	220	310	350	420
1994	201.4	Wet	490	730	980	1350
1995	130.6	Average	540	1130	830	1340
1996	145.2	Average	660	950	1590	2500

Source	*F*-value	*p*-Value
Analysis of variance		
Year (Y)	21.1	<0.0001
Treatment (Trt)	147.5	<0.0001
Y × Trt	4.9	<0.0001

[a] Mean rainfall: 128.55; 80% confidence limit of rainfall: 18.30 mm; standard error of yield: 118.68 kg ha^{-1}.

Table 2
Crop residue effect on millet grain and stover (Y) yields, water use-efficiency (WUE), fertilizer-use efficiency (FUE), and sustainability yield index (SYI) averaged over a 9-year period in the Sahel[a]

Treatment	Y (kg ha^{-1})	WUE (kg ha^{-1}/mm)	FUE (kg ha^{-1}/kg ha^{-1})	SYI
Grain				
Control	320	0.78	NA	0.19
Crop residue (CR)	700	1.69	NA	0.40
N + P fertilizer (F)	900	2.17	13.5	0.35
CR + F	1510	3.61	27.6	0.42
F-value and probability	22.5, $p < 0.01$	32.4, $p < 0.01$	24.3, $p < 0.01$	CI = 0.16
Stover				
Control	1390	3.31	NA	0.45
Crop residue (CR)	2560	6.22	NA	0.62
N + P fertilizer (F)	3060	7.56	41.3	0.66
CR + F	5400	13.65	100.5	0.56
F-value and probability	$p < 0.01$	$p < 0.01$	$p < 0.0003$	CI = 0.14

[a] NA: not applicable; CI: confidence interval at the 95% probability level.

significantly $(p < 0.01)$ improved efficiency of the applied fertilizer. The respective efficiencies of crop residue + fertilizer and fertilizer alone were 27.6 and 13.47 kg ha^{-1}/kg ha^{-1}. This demonstrates that greater yields are attainable with a limited amount of fertilizer, if crop residues are retained on the farm fields in the Sahel.

Increased WUE of millet due to fertilizer application has been documented by Payne (1997), who further argued that high plant density together with improved soil fertility are not detrimental to crop yields in semiarid environment. Millet grain WUEs of the present study using ET values generated by the new simulation model (Van Wambeke et al., 1992) tallied with those of Payne (1997) using empirical methods. The SYI (Singh et al., 1990) is based on variance of yield dispersion, therefore, it is useful for assessing relative performance of sustainability of individual treatments and does not consider levels of production. The confidence intervals show that, in terms of sustainability of grain yields (Table 2), the control treatment $(\mathrm{SYI} = 0.19)$ was less sustainable but not different from the fertilizer treatment $(\mathrm{SYI} = 0.35)$. However, the crop residues with SYI values of 0.40 differed from the control treatments. Thus, besides the control, the other three treatments could be regarded as sustainable, though at varying levels. The results of this study are similar to SYI obtained for rice and wheat by (Yadav et al. (2000) and it showed that crop residue + fertilizer sustained millet grain yields better than the three treatments.

Studies by Hafner et al. (1993a) in the Sahel and others elsewhere in the savanna agroecological zones have claimed similar advantages of residue mulch and fertilizers on crop yield improvement (Lal et al., 1980; Bukert et al., 2000; Rebafka et al., 1994). Furthermore, (Rebafka et al., 1994; Andreas et al., 2000) attributed crop residue application to enhanced P uptake and subsequent increased yields, through the promotion of well-developed millet root system. The availability of crop residues, however, is constrained by other uses for the residues (e.g. livestock feeding, and fuel for cooking) in the household (Nicou and Charreau, 1985).

3.3. Trends of grain and stover yields

Both grain and stover yields in the various treatments had positive slopes (slope), indicative of increasing yields over years during the experimental period (Table 3). The International Institute of Tropical Agriculture (IITA, 1992) medium-term plan describes systems that generate upward long-term yield trends as being sustainable, regardless of the magnitude of yield. In our view, the levels of yields in favorable and adverse years that signify robustness of technologies, are equally important as the slope, and the two should be used to judge sustainability of technologies. In the present study, apart from the control, none of the slopes of the treatments was significantly different from zero but the intercepts

Table 3
Trend analysis of millet grain and stover yields over a 9-year period in Niger

Treatment	Intercept	Slope	S.E.	*p*-Value	R^2
Grain					
Control	34.35NS	57.6[*]	15.8	0.008	0.65
Crop residue (CR)	455.15[**]	49.0	29.3	0.138	0.28
N + P fertilizer (F)	772.12[**]	25.9	47.8	0.605	0.04
CR + F	1435.36[**]	14.8	77.1	0.853	<0.05
Stover					
Control	1180.75[**]	39.6	68.3	0.581	0.05
Crop residue (CR)	2203.67[***]	77.6	76.0	0.341	0.13
N + P fertilizer (F)	2655.14[***]	99.7	78.1	0.243	0.19
CR + F	3871.69[***]	365.7[*]	163.8	0.061	0.42

[*] Denote intercepts and slopes are significantly different from zero at the 10% probability level.

[**] Denote intercepts and slopes are significantly different from zero at the 5% probability level.

[***] Denote intercepts and slopes are significantly different from zero at the 1% probability level.

were different from zero and greater than that of the control as well (Tables 3 and 4). The slopes were inversely related to the intercepts for the grain $(r = -0.96, p = 0.04)$, indicating that treatments with large mean grain yield did not increase significantly over time under the Sahelian conditions.

The standard errors of the slopes were greater for the systems with fertilizer than those without, implying a greater variability in yields with the top management option, i.e. a combination of fertilizer and crop residues. This does not portray inconsistency, since large mean yields of treatments over years, irrespective of pests and moisture stress, is the overriding deciding factor (Flinn et al., 1982). Intercepts and slopes of stover yields increased with soil management. The above study conducted in the Sahel, partly supports the results of Dirks and Bolton (1981) in Canada, who found that fluctuation in maize yields

Table 4
Pairwise comparison of slopes and intercepts of millet grain and stover yields over an 8-year period in Niger

Treatments	Slope		Intercept	
	|Difference|	*T*-statistic[*]	|Difference|	*T*-statistic[*]
Grain				
Control vs. crop residue	8.57	0.26	420.80	12.3[***]
Control vs. fertilizer	31.7	0.63	687.77	13.7[***]
Control vs. crop residue + fertilizer	42.8	0.54	1401.01	17.8[***]
Crop residue vs. fertilizer	23.1	0.29	316.97	4.0[**]
Crop residue vs. crop residue + fertilizer	34.2	0.42	980.21	11.9[***]
Fertilizer vs. crop residue + fertilizer	15.1	0.17	663.24	7.3[***]
Stover				
Control vs. crop residue	38.0	0.37	1022.92	10.0[***]
Control vs. fertilizer	60.1	0.58	1474.39	14.2[***]
Control vs. crop residue + fertilizer	326.1	1.84	2694.94	15.2[***]
Crop residue vs. fertilizer	22.1	0.20	451.47	4.1[***]
Crop residue vs. crop residue + fertilizer	288.1	2.68[*]	1668.02	15.5[***]
Fertilizer vs. crop residue + fertilizer	266.0	1.47	1216.55	6.7[***]

[*] Denote *T*-statistic of intercepts and slopes are significantly different for each pair at the 5% probability level.

[**] Denote *T*-statistic of intercepts and slopes are significantly different for each pair at the 1% probability level.

[***] Denote *T*-statistic of intercepts and slopes are significantly different for each pair at the 0.1% probability level.

caused by weather factors were more pronounced when soil fertility and crop management were improved.

A pairwise comparison of the slopes of stover and grain yields showed no significant differences between treatments (Table 4). The difference in slope between the crop residue + fertilizer and crop residue treatments was significant, for dry matter being greater than the latter. Total vegetative yields of millet generally respond to fertilization and are usually less sensitive than grain yields to weather fluctuations, notably, frequent rainfall deficits and elevated temperature at certain critical periods of growth (Sivakumar and Salaam, 1999). Adverse weather effects on crops yields has been reported in the United States, where maize yields were reduced by high temperatures and moisture stress in August, at the period of maximum grain fill (Stooksbury and Michaels, 1994; Teigen and Thomas, 1995). Intercepts of grain and stover yields were significantly $(p < 0.01)$ different between pairwise treatments, reflecting relative long-term performance of the various soil fertility strategies.

3.4. Trends in soil fertility

Trends in soil organic carbon, available P and pH are presented in Table 5. Organic carbon plays an essential role in soils of the Sahel with respect to nutrient and moisture retention (De Ridder and Van Keulen, 1990; Bationo and Mokwunye, 1991). Slopes of soil organic carbon over time were negative, meaning loss of organic carbon with cultivation over time, akin to the study of Subbarao et al. (2000). Slopes of the treatments with fertilizer were significantly different from zero. Intercepts of all treatments were also significantly different from zero. Overall, soil organic carbon was greatest in the crop residue treatments but was not statistically different from the treatments without crop residues (Tables 5 and 6). As expected, cropping systems with initial high soil organic carbon levels tend to experience greater proportionate losses over time than those with low baseline organic carbon levels (Yadav, 1998).

Pairwise comparison of treatments was not significant for either intercept or slope (Table 6). On a sandy soil in a US coastal plain, significant differences in loss of organic carbon between conventional and conservation tillage began to show after 7 years (Karlen et al., 1989). Therefore, 9 years may not be enough to detect significant carbon losses in different land use practices in the Sahel, as suggested by Langdale et al. (1990). The low rainfall together and the predominantly sandy soil (>94% sand) in the Sahel are not conducive for rapid decomposition of millet residues to promote short term carbon storage (Giller Ken et al., 1997). This is because, millet residues, like maize or rice, have high C:N or lignin:N ratio, which make them resistant to microbial attack (Tian et al., 1995).

Slopes of available P over time were positive and significantly different from zero in the treatments with fertilizer (Table 5). The intercepts of crop residue + fertilizer were greater than the control. Pairwise differences in slopes of soil parameters between treatments were significant, except in the control versus crop residue and fertilizer versus crop residue + fertilizer treatments (Table 6). Increase in soil P availability in plots fertilized with a mixture of crop

Table 5
Trend analysis of soil fertility parameters as influenced by long-term crop residue and fertilizer management in the Sahel

Treatments	Organic carbon			Available phosphorus			pH		
	Mean	Intercept	Slope	Mean	Intercept	Slope	Mean	Intercept	Slope
Control	0.23	0.29^{***}	−0.016NS	3.16	2.46^{**}	0.23NS	3.96	3.68^{***}	0.08^{**}
Crop residue (CR)	0.28	0.34^{***}	−0.017NS	3.38	2.86^{***}	0.17NS	4.11	3.83^{***}	0.07NS
N + P fertilizer	0.27	0.32^{***}	-0.014^{**}	6.74	3.02 NS	1.24^{*}	3.97	3.61^{***}	0.10^{**}
CR + fertilizer	0.32	0.35^{***}	-0.013^{**}	7.46	3.49^{*}	1.32^{**}	4.21	3.81^{***}	0.12^{**}
	$p < 0.0001$			$p < 0.0001$			$p < 0.001$		

[*] Denote intercepts and slopes are significantly different from zero at the 10% probability level.

[**] Denote intercepts and slopes are significantly different from zero at the 5% probability level.

[***] Denote intercepts and slopes are significantly different from zero at the 1% probability level.

Table 6
Pairwise comparison of slopes and intercepts of long-term trends in soil fertility parameters based on different crop residue practices

Treatments	Organic carbon				Available phosphorus				pH			
	Intercept		Slope		Intercept		Slope		Intercept		Slope	
	$\lvert$Difference$\rvert$	*T*-statistic*	$\lvert$Difference$\rvert$	*T*-statistic	$\lvert$Difference$\rvert$	*T*-statistic	$\lvert$Difference$\rvert$	*T*-statistic	$\lvert$Difference$\rvert$	*T*-statistic*	$\lvert$Difference$\rvert$	*T*-statistic
Control vs. CR	0.05	0.440	0.001	0.009	0.40	1.466	0.06	0.220	0.15	3.394***	0.01	0.226
Control vs. fertilizer	0.03	0.264	0.002	0.018	0.56	1.167	1.01	2.106*	0.07	1.937	0.02	0.553
Control vs. CR + fertilizer	0.06	0.529	0.003	0.026	1.03	2.279*	1.09	2.411*	0.13	3.075***	0.04	0.946
CR vs. fertilizer	0.02	1.050	0.003	0.158	0.16	0.351	1.07	2.348*	0.21	4.190***	0.03	0.599
CR vs. CR + fertilizer	0.01	0.546	0.004	0.219	0.63	1.477	1.15	2.697**	0.02	0.366	0.05	0.914
Fertilizer vs. CR + fertilizer	0.03	1.602	0.001	0.053	0.47	0.809	0.08	1.377	0.20	4.129***	0.02	0.413

* Denote intercepts and slopes (slopes) are significantly different from each pair at the 10% probability level.

** Denote intercepts and slopes (slopes) are significantly different from each pair at the 5% probability level.

*** Denote intercepts and slopes (slopes) are significantly different from each pair at the 1% probability level.

residue and fertilizer is normal and may be explained by chelation of P-fixing sites and anion displacement (Andreas et al., 2000).

Studies have shown that continuous application of N fertilizers such ammonium sulphate and urea on kaolinitic Alfisols ultimately leads to soil acidification (Fox and Hoftinan, 1981; Juo et al., 1995). The study of Juo et al. (1995) further indicated that the extent of acidification could be controlled by choice of cropping systems, soil and residue management. In the present study, moderation of acidification by crop residue is inconsistent, in that all treatments, including the control, showed a positive trend in pH over the 9-year experimental period (Table 5). The intercepts of pH in the crop residue were greater than plots without residues. Intercepts and slopes were significantly different from zero except the slope of pH in the crop residue plots. Pairwise comparison of intercepts of the various treatments is given in Table 6. Results in Table 6 confirmed that pH in crop residues plots are significantly greater than that of fertilizer and control plots. Differences in slopes of pH trends between paired treatments were not significant (Table 6), probably because of enormous seasonal variability in weather factors as earlier experienced by Juo et al. (1995) and Fox et al. (1985).

3.5. Stability of yields and returns

Stability analysis of yields and returns over fertilizer cost is presented graphically in Figs. 1 and 2. Since this is a controlled station experiment, the key environmental variable was rainfall amount and its distribution. Cultivar and management practices' responses to environments in stability analysis are classified as responsive (slope > 1.0) or non-responsive (slope < 1.0), according to Finlay and Wilkinson (1963). Predictability or stability of technologies is also determined by the size of the error mean square or the standard error (S.E.), the larger the S.E., the less, stable the technology is. Accordingly, Hildebrand and Russell (1996) concluded that the most suitable technology should result in a combination of larger yields and small standard error, i.e. stable. Millet in crop residue + fertilizer plots had the greatest yield across environments with relatively large S.E. (slope = 1.79, S.E. = 0.32). Yields in control plots were the least in both good and poor environments. Fertilized millet (slope = 1.26, S.E. = 0.21), also responded to fertilizer application as the environments improve. Yields in the control and crop residue treatments were not responsive to better environments because their slopes were less than 1.0 and S.E. = 0.21. The control and crop residue treatments may be preferred by farmers because of stability (lower S.E.) but will not be suitable technologies in terms of attainment in food sufficiency because of poor grain yields, analogous to the findings of Subbarao et al. (2000).

The returns over fertilizer cost presented a slightly different picture from the grain yield (Fig. 2). Millet fertilized with crop residues + fertilizer generally had

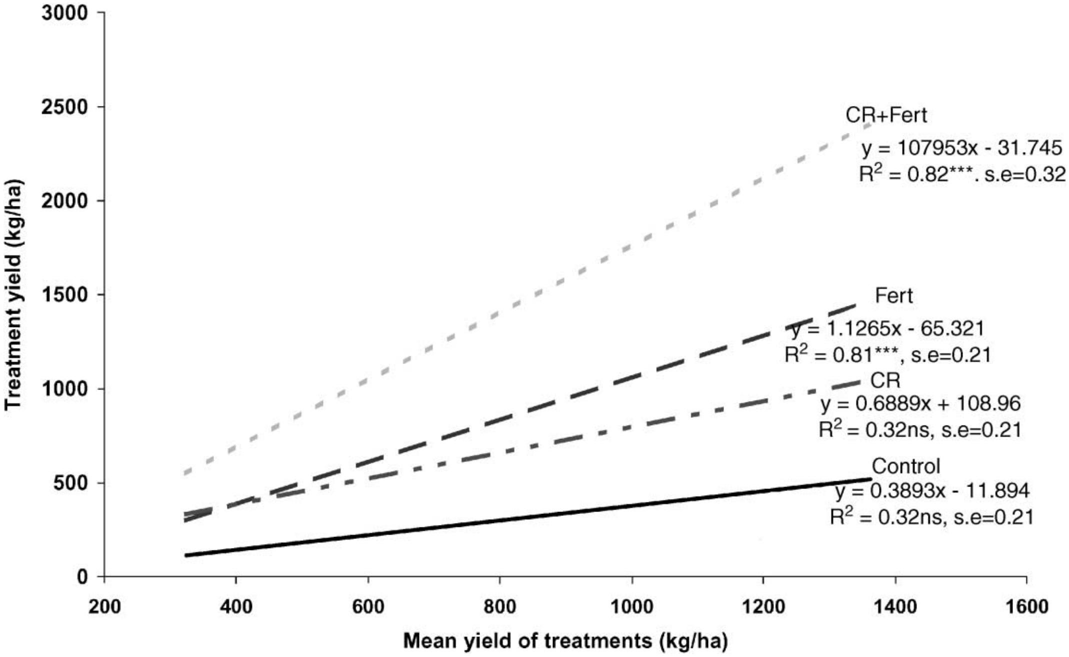

Fig. 1. Regression of millet yield with mean seasonal yields.

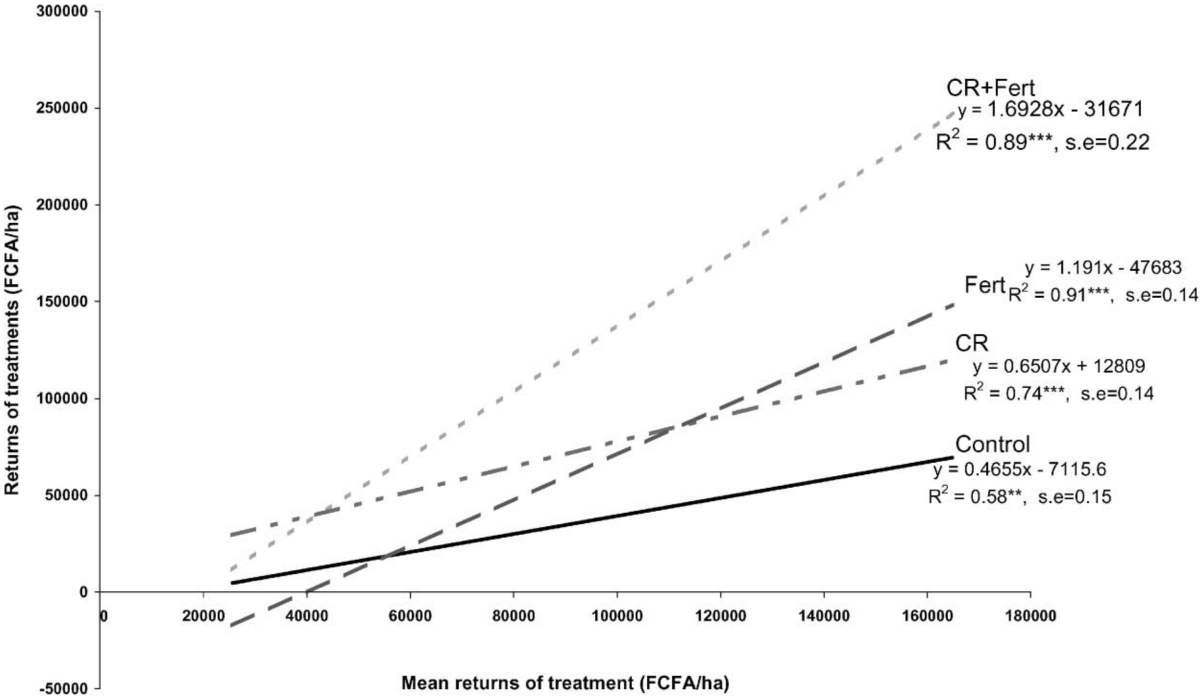

Fig. 2. Regression of millet returns over variable cost of fertilizer with mean returns of treatments.

greater returns (slope $= 1.69$, S.E. $= 0.22$) than those of other treatments (slopes < 1.0). It is interesting to note that use of fertilizer (slope $= 1.19$, S.E. $= 0.14$) was attractive in good environments and that use crop residue (slope $= 0.65$, S.E. $= 0.14$) was more economical than fertilizer in poor environmental conditions. In conclusion, the present study validates the hypothesis that integrated use of organic and inorganic fertilizers are appropriate land use management practices for the Sahel based on both economic and biological attractiveness.

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