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MINERAL VERSUS ORGANIC FERTILIZATION

CONFLICT OR SYNERGISM?

PROCEEDINGS

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TOWARD FARM SPECIFIC RECOMMENDATIONS FOR THE USE OF MINERAL FERTILIZERS IN SAHELIAN CROP-LIVESTOCK SYSTEMS

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Abstract

Low soil fertility is recognized as the major constraint to rainfed cereal production in the Sahel. Given that most farmers can not afford enough fertilizer to cover all their fields, it is important to fine-tune the recommendations to maximize the fertilizer economic return at farm level while minimizing economic risks linked to climate fluctuations. This study was designed to help draw site/year/farm specific recommendations regarding hill placed application of mineral fertilizer either combined or not with organic amendments. A three year, multi-factorial experiment was conducted on-farm on three sites from 2003 to 2005 to test the effect of hill-placed application of small doses of DAP fertilizers on three pearl millet (*Pennisetum glaucum* (L.) R. Br.) genotypes for a range of organic amendments. Results showed a consistent grain yield increase due to fertilizer application for the no-manure plots on 2 sites, the fertility level of the third site being good enough to mask to effect of mineral fertilizer with the exception of 2004, marked by an early drought. In normal conditions, no synergism was detected between organic and mineral fertilizer. However it became apparent in the case of re-sowing or late sowing with a larger effect of mineral fertilizer on manure plots.

Introduction

Increasing agricultural productivity has been recognized by many as a necessary step to improve rural population livelihood and reduce poverty and hunger in sub-Saharan Africa. The Sahel with a population growth rate of 3% per annum and a large fraction of the population living from agriculture must sustain a continuous agriculture production increase to avoid food crises. Because of its relatively low population density the region has, in the past, met its increased food demand by the cultivation of new land. Many agricultural systems in the region have now reached a transition point where additional land resources are exhausted and local organic fertilizer is not available in sufficient quantity. Hence any additional production increase can only be met by intensification and use of external inputs such as fertilizers (Breman, 1990; de Ridder et al., 2004).
The most limiting factor for plant production in semi-arid West Africa is low soil fertility (Bationo and Mokwunye 1991; Buerkert and Hiernaux, 1998) but the use of mineral fertilizer

on staple rainfed crops has not increased. The reasons for this are multiple: lack of profitability (value/cost ratio being to low), incomplete markets for cereal products, lack of cash at the time of planting, unavailability of fertilizer, possible intensification with 'traditional' technologies, and lack of technical information at farmer level (Abdoulaye and Lowenberg-DeBoer, 2000; Pender et al., 2005; Yanggen et al., 1998).

This study was carried out in a zone where the population density is still relatively low and the intensification strategy largely relies on the use of animal manure applied mostly through overnight livestock corralling and on transported farmyard manure (Powell and Ipke, 1992). In those systems manure plays a very strategic role but it is merely a recycling and spatial redistribution of nutrients with a negative nutrient balance at the village and landscape scale (Schlecht and Hiernaux, 2004).The specific objectives of the study were to: (1) evaluate in real conditions the agronomic and economic performance of hill placed application of different formulations of mineral fertilizer under different manuring practices; (2) explain yield response differences by monitoring bio-physical parameters and management practices; (3) draw recommendations for integrated soil fertility management adapted to soils, risk of drought, and manure availability.

Materials and methods

The Fakara region is located 80 km east of Niamey, the capital of Niger, in the Dantiandou administrative district, Department of Tillabery, between the valleys of the Niger River to the west and the Dallol Bosso to the east. The soils are sandy, with low inherent soil fertility and low organic matter. The predominant crop in the Fakara is pearl millet which in most farmers' fields is intercropped with cowpea (*Vigna unguiculata* L. Walp). The average annual rainfall for the zone is 470 mm.

Experimental design. A 3 year, multifactorial experiment was conducted on-farm on three sites from 2003 to 2005 to test the effect of hill-placed application of small doses of di-amonium phosphate (DAP) fertilizers on three pearl millet genotypes for a range of organic amendments (Table 1).

Table 1. Nested structure of the experimental design conducted during 3 rainy seasons (2003-2005)

Sites	Within Sites	Within OM Management Strata
Bagoua, Banizoumbou and Kodey	Organic matter management strata with the following levels: 1st level : no manure / Transported manure / Manure applied through corralling 2nd level (for manured plots only) : manure applied 1) during the preceding dry season 2) one dry season ago (only for years 2004 and 2005) 3) two dry seasons ago (only for year 2005) (5, 6, and 7 strata per-site for 2003, 2004, 2005 respectively)	Multifactorial design with three levels of fertilizer applications, three millet genotypes and three repetitions (27 plots of 10x10 meters)

Before the 2003 rainy season, 3 farmer fields were identified in the villages of Bagoua, Banizoumbou and Kodey based on the presence of the required organic management practices on relatively large contiguous zones. Fertilizer treatments had three levels and consisted of 1) a control without application of mineral fertilizer; 2) hill-placed application of 2g DAP hill^{-1} at millet sowing; 3) same treatment as in 2 plus localized application of 1 g urea hill^{-1} at tillering. The three millet varieties sown were 1) a short duration landrace (Haini Kiré); 2) ICMV89305; and 3) Zatib.

Field operations. Millet was sown in hills at a density of 10,000 hills ha^{-1} and 3 plants per hill after the major first rains of the season (> 20mm) except for Banizoumbou in 2004 where sowing was delayed by 40 days due to workload at first rain and a subsequent dry period. Weeding was performed twice a season with traditional hand hoes. Urea was hill-placed (1 g of urea buried per hill) at tillering in plots receiving that treatment.

Observations. Every year the following data were collected for each plot: date of sowing; number of days to emergence; emergence rate 7 DAS; dates of weeding; days to 50% flowering; harvest dates; and weekly soil moisture profile by neutron probe measurements, grain and straw yields. In addition, daily rainfall was recorded at each site.

Analysis. This paper mainly presents the analysis of grain and straw yields. A global analysis was performed in Genstat 9.1 using the Generalized Linear Model (GLM) on those two dependent variables (Payne et al., 2006). Analyses of variance for grain yield were performed individually at the organic management stratum in order to estimate the range of effects of mineral fertilizer application on millet grain yield under various conditions. Profitability (value cost ratio, VCR) was computed as difference of grain yield between the fertilized and the control plot multiplied by the unit market price of grain, divided by the cost of the fertilizer. The VCR is presented for 3 organic management strata for each year in the 3 sites.

Results and discussion

Results of GLM for grain and straw yields are presented in Table 3. All regression coefficients (year, site, manure strata, fertilizer treatment, and variety) are significantly different from zero. In addition, there is clear interaction between site and year illustrating the inter-annual variability in rainfall patterns and sowing dates. Overall, the year 2004 had higher yields than 2003. In 2005, yields were on average 241 kg ha^{-1} lower than in 2003 which can be explained by a lower seasonal rainfall and dry spells during the first part of the season. There is a strong interaction between site and year, especially for Banizoumbou in 2004 (reduction of 372 kg ha^{-1} in grain yield) where sowing was delayed by 40 days after the onset of the rainy season due to labor constraints.

Manure application effects on yields were very marked. For transported manure, an average increase of 295 kg ha^{-1} was obtained with residual effects of 284 and 216 kg ha^{-1} after 1 and 2 years, respectively. For corralling, an average increase of 507 kg ha^{-1} was obtained with residual effects of 328 and 278 kg ha^{-1} after 1 and 2 years, respectively (Table 2).

There were small yet significant differences in grain yields between the pearl millet varieties. ICMV89305 seemed to outperform the other two varieties, followed by the local landrace

(Haini Kiré) and lastly by Zatib. In terms of straw, the landrace outperformed the two improved cultivars with 162 and 225 kg ha^{-1} more straw yield compared to ICMV89305 and Zatib, respectively (Table 2). This probably illustrates past breeders' efforts to increase millet harvest index. However, in mixed crop-livestock systems, straw is an important by-product. Shorter duration with improved varieties can outperform the local landraces in specific situations such as a very short rainy season or late onset of the rains.

Table 2. Regression parameters obtained for grain and straw yields (kg ha^{-1}) using GLM for the model: Y = Constant + Year + Site + Year*Site + Manure + Fertilizer + Variety

	Grain yield		Straw yield	
Parameter	estimate	s.e.	estimate	s.e.
Constant	333.3*	27.1	1345.7*	84.5
Year 2004	109.1*	27.4	-551.7*	85.6
Year 2005	-241.2*	26.8	-1124*	83.8
Banizoumbou	120.1*	28.4	634.4*	88.7
Kodey	-297*	28.4	-1085.5*	88.7
Year 2004 * Banizoumbou	-372.1*	38.5	-1396*	120.0
Year 2004 * Kodey	148.8*	38.5	1131*	120.0
Year 2005 * Banizoumbou	-70.6**	37.2	-619*	116.0
Year 2005 * Kodey	147.2*	37.2	1111*	116.0
Transported Manure	295.0*	21.2	710.5*	66.1
Residual effect of TM after 1 year	284.3*	24.2	688.2*	75.4
Residual effect of TM after 2 years	216.0*	31.3	524*	97.6
Corralling	507.4*	21.2	1262*	66.1
Residual effect of corralling after 1 year	327.6*	21.2	738.2*	66.1
Residual effect of corralling after 2 years	277.5*	21.2	604.5*	66.1
DAP	83.4*	15.0	210.1*	46.8
DAP+Urea	101.2*	15.0	275.8*	46.8
ICMV89305	63.7*	15.0	-162.0*	46.8
Zatib	-14.2	15.0	-224.8*	46.8

Reference levels: year 2003; site of Bagoua; no fertilizer; no manure, Haini Kiré
Percentage of variance accounted for by the model: 49.7 for grain and 48.2 for straw
Probability levels that coefficient is different from zero: * t pr. > 0.999 ; ** t pr. > 0.95

Compared to the control, application of DAP gave an average yield increase of 83 kg ha^{-1} and DAP + urea an increase of 101 kg ha^{-1} (Table 2). Those responses are averages for all manure strata and larger responses to fertilizer were obtained for the non-manure plots and for manure plots in specific conditions. Large differences in grain yield and VCR can be observed between sites, years and manure strata. For 2 of the 3 sites (Banizoumbou and Kodey), with low inherent soil fertility and overused soils, the best return to investment for the three years was for application of DAP on plots without manure application. For the Bagoua site, there was no clear response to DAP even on the plots that did not receive any manure, except for the year 2004. At this site, the use of small quantities of mineral fertilizer gave a positive VCR only in 2004, when non-manure and transported manure plots had to be re-sown after the failure of the first sowing. This suggests that such small doses of mineral fertilizer might be of very strategic use in productive fields when a sowing failure at the onset of the rainy season occurs. Similar trends were observed for Banizoumbou in 2004 due to the delayed sowing : for the DAP treatment, VCR ranged from 4.70 to 10 for the no manure, transported manure and corralled strata. N leaching with the advancing wetting front following rapid organic matter mineralization at the start of the rainy season can prevent young seedling from accessing that N in case of delayed sowing. Giving access to P through localized DAP application probably induced faster root growth, enabling the plant to catch-up with N in the soil profile.

Table 3. Grain yield response to mineral fertilizer per site/year/manure stratum. Standard error of difference (sed) was obtained by individual Anova (one analysis per site/year/stratum) for the 3 cultivars combined (9 repetitions at the fertilizer treatment level). Value cost ratio (VCR) is monetary value of additional millet grain yield compare to control divided by the cost of fertilizer (millet grain price : 12,000 CFA / 100 kg bag; DAP : 12,000 CFA/50 kg bag; Urea: 10,000 CFA/50 kg bag)

Site	Year	Manure	Control	DAP	DAP + Urea	sed	VCR DAP	VCR DAP+U
Bagoua	2003	No manure	427	439	406	60	0.30	-0.37
		Transp. manure	708	636	631	106	-1.80	-1.36
		Corralling	952	968	903	92	0.40	-0.86
	2004	No manure	361	569	588	100	**5.20**	**4.01**
		Transp. manure	692	862	712	67	**4.25**	0.35
		Corralling	1187	1153	1133	113	-0.85	-0.95
	2005	No manure	207	230	289	37	0.58	1.45
		Transp. manure	384	379	375	44	-0.13	-0.16
		Corralling	592	493	566	55	-2.48	-0.46
Bani	2003	No manure	236	435	497	56	4.98	4.61
		Transp. manure	668	689	697	90	0.53	0.51
		Corralling	1689	1288	1508	281	-10.03	-3.19
	2004	No manure	8	210	153	53	**5.05**	**2.56**
		Transp. manure	505	913	874	129	**10.20**	**6.51**
		Corralling	787	975	1109	150	**4.70**	**5.68**
	2005	No manure	84	302	404	48	**5.45**	**5.65**
		Transp. manure	466	465	521	84	-0.03	0.97
		Corralling	322	469	557	54	**3.68**	**4.15**
Kodey	2003	No manure	72	232	241	42	**4.00**	**2.98**
		Transp. manure	500	461	471	52	-0.98	-0.51
		Corralling	324	530	576	102	**5.15**	**4.45**
	2004	No manure	240	373	382	42	**3.33**	**2.51**
		Transp. manure	676	740	755	100	1.60	1.39
		Corralling	831	741	871	73	-2.25	0.71
	2005	No manure	85	220	198	19	**3.38**	1.99
		Transp. manure	360	345	367	50	-0.38	0.12
		Corralling	440	315	302	57	-3.13	-2.44

Whilst this paper only presents part of the experimental dataset, several recommendations can already be drawn from the above analyses. It is clear that site, year and rainfall specific management is of paramount importance for the promotion of mineral fertilizers in the Sahel region. Simple decision support systems should be developed and made available to

extension services and development agencies to guide fertilizer users. Further research should concentrate on developing reliable models that integrate the effect of P on root growth, the effect of water stress on yields and the dynamics of N.
Many Sahelian countries suffer from food security problems due in part to erratic rainfall but also to soil fertility decline. Strategies in terms of food security should not only focus on emergency food and seed aid but should also try to implement responsive fertilizer aid in zones where the on-set of the rainy season has been delayed or where crop failure has occurred because of early drought. If well implemented, the benefits for the countries could be very large: 20 kg of DAP can produce 200 kg of grain (a volume ratio of 1 to 10) which subsequently can save public money on food aid and large transport costs linked to it. This of course implies a need to revisit early warning systems to be able to identify vulnerable zones during the first third of the rainy season, and to have readily available strategic stocks of P fertilizer throughout the country.

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