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STOCHASTIC DOMINANCE ANALYSIS OF SOIL FERTILITY RESTORATION OPTIONS ON SANDY SAHELIAN SOILS IN SOUTHWEST NIGER

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SUMMARY

The poor fertility of sandy Sahelian soils remains one of the major constraints to pearl millet (*Pennisetum glaucum*) production in West Africa. On-farm trials under farmers' management were conducted in two rainfall zones of Niger in 1996 and 1997 to evaluate the risk characteristics of six soil fertility restoration options. Stochastic dominance analysis was used to compare the fertilizer treatments tested. Results showed that the farmers' traditional method (no fertilizer control), Tahoua phosphate rock (PRT) alone applied at 13 kg P ha^{-1} broadcast, and a combination of PRT broadcast at 13 kg P ha^{-1} and single super phosphate (SSP) hill-placed at 4 kg P ha^{-1} had the most desirable risk characteristics and were acceptable to risk averse decision-makers in both rainfall zones. At current input–output price ratios, most fertilizer-using farmers would choose the combination of PRT broadcast and SSP hill-placed. If the availability of SSP was limited, some farmers would use PRT alone. The demand for risk efficient alternatives could significantly increase if farmers could bear less than half the fertilizer costs at the current output price, although further research is required to say if a fertilizer subsidy could be justified on broader economic or social grounds.

INTRODUCTION

Niger is a vast land-locked country in West Africa with a total area of 1 267 000 km^2 of which only 15 % is suitable for cultivation. The arable area is being reduced slowly due to the southward creep of the 400 mm isohyet (Sivakumar, 1992). Moreover, due to high population growth rate (3.4 % y^{-1}), population density has increased and the per capita cultivated area has been declining. Consequently, the length of the fallow period has decreased, forcing farmers to cultivate marginal lands. Increases in production have resulted more from the expansion of cultivated areas than productivity (Stoorvogel and Smaling, 1990). Since 1986, pearl millet (*Pennisetum glaucum*) yields have been declining at a yearly rate of 2.9 %, although pearl millet remains the main staple accounting for 72 % of total grain cereal area, 80 % of cereal grain production and 77 % of per capita cereal consumption (FAOSTAT, 2002). An estimated 80 to 90 % of the population in Niger relies on the agricultural sector for their livelihoods (UNCTAD, 2002).

Nigerien agriculture is limited by low and variable rainfall as well as the poor physical and chemical characteristics of the predominantly sandy soils. Literature on soils in the semi-arid tropics of West and Central Africa report phosphorus and nitrogen

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deficiencies. However, phosphorus tends to be more limiting to crop productivity than nitrogen (Fussell *et al.*, 1987, Ganry *et al.*, 1974). Traore (1974) reported that crop responses to nitrogen were minimal until phosphorous requirements had been satisfied.

In 1983, nutrient mining in Niger was estimated to be 16 kg N ha^{-1}, 2 kg P ha^{-1}, and 11 kg K ha^{-1}. By comparison, farmers in Niger apply, on average, less than 1 kg ha^{-1} of plant nutrients as compared to 200 kg ha^{-1} in western Europe (Stoorvogel and Smaling, 1990). Therefore, there is an urgent need to restore soil fertility. The use of mineral fertilizers could prevent soil degradation that results from nutrient mining, and play a crucial role in increasing crop yields (Bortlaug and Dowswell, 1994; Dyson, 1995; Quinones *et al.*, 1997; Smaling *et al.*, 1997; Stoorvogel and Smaling, 1990; Bationo *et al.*, 1998). Food security in Niger remains vulnerable and is one of the significant objectives pursued by households. It also constitutes a major driver of uptake of soil fertility amendment options. The long-term development of Nigerien agriculture will largely depend on the development of appropriate technologies as well as farmers' adoption of soil fertility maintenance options.

Constraints to adoption of mineral fertilizers in Niger are hypothesized to be: (i) the low supply of fertilizers which is in turn limited by high import costs and foreign exchange scarcities at the macro-economic level; and (ii) high domestic fertilizer prices, opportunity costs of funds, and poor access to distribution outlets at the micro-level. Total fertilizer imports were estimated at 9812 t in 1996 and 9205 t in 1997, far below the potential needs of 120 000 tons in Niger (Barhouni and Toudou, 1998). Commercial NPK and urea account for more than 70 % of the total supply, and most of this is used to fertilize crops such as cotton and rice. Little or none of this quantity is applied to pearl millet. Fertilizer imports from Nigeria and Europe, and gifts (about 18 % of the total) from the government of Japan are the main sources of supply. Fertilizer supply in Niger is contingent upon fertilizer policies in neighbouring countries such as Nigeria. In 1996, Nigeria liberalized its fertilizer market. Consequently, Nigeria became an expensive source of fertilizer supply and currently there is little imported from that country.

Niger is endowed with two large natural phosphate rock fertilizers deposits at Akker (in the department of Tahoua [15°N, 5°20′E]) and in the Parc-W region in the Tapoa and Mekrou valley south of Niamey (12°43′N, 2°48′E) (Baidu-Forson and Bationo, 1992). These deposits are estimated to be about 200 million t with an average P_2O_5 content of 23 %. This source of phosphorous, which could substitute for phosphorous fertilizer imports, has been under-utilized. The unit cost, including production costs, administrative costs and margins as well as transport costs of Phosphate Rock (PR) in Niger is estimated to be 66 cfaf kg^{-1}, less than the unit cost for Triple Super Phosphate (TSP) at 212 cfaf kg^{-1}, estimated at the ports of Abidjan, Dakar or Cotonou (Dahoui, 1995)[1]. From 1970 to 1984, only about 3600 t were extracted and in 1996, for example, only 49 t were extracted. This limited supply of natural phosphate rocks may be due to limited demand by farmers. Major constraints to the adoption of PR are perceived

[1] 500 CFAF = US $1.00 on average in 1996 and 1997.

by farmers to be the dusty nature of the product, making it difficulty to apply and inappropriate packaging (Dahoui, 1995). Thus, for PR to be a substitute for imported mineral inorganic fertilizers, these constraints have to be removed.

Previous research on soil fertility restoration options has been conducted on-station under researcher management and they have been shown to out-yield farmers' traditional methods significantly (Sivakumar, 1992; Bationo *et al.*, 1990; Bationo *et al.*, 1997; Bationo *et al.*, 1998). However, only a few studies especially in Burkina Faso and Mali have tested these soil amendments on farmers' fields and under farmers' management to assess whether some options were economically profitable or might be preferred by risk-averse decision-makers (Bationo *et al.*, 1990; Hien *et al.*, 1997). The main objective of this study was therefore to determine the risk characteristics of phosphate fertilization strategies tested on farmers' field under farmers' management in two rainfall zones of Niger, within the framework of expected levels of satisfaction (expected utility).

RESEARCH METHODS

Farmers can be assumed to want to maximize satisfaction from expected net cash returns from investments on their farms. They would want to choose among the most risk efficient soil fertility restoration options. In this paper, the sets of risk efficient choices are derived using stochastic dominance analysis. This is a non-parametric method used to rank alternatives according to their risk characteristics. Risk aversion is the preference shown by many individuals to avoid options with a high probability of low outcomes. Stochastic dominance searches for an efficient set of options that are not dominated and hence admissible. Contrary to other methods which focus on parameters of given distributions of outcomes, such as the mean and variance, stochastic dominance uses the entire distribution of the sources of uncertainty and accounts for information that is not easily summarized in statistical parameters (for more details, see Anderson *et al.*, 1977, pp. 282–288).

Stochastic dominance rules

In this study, the first two rules of stochastic dominance are used to rank technology options. The first is based on a reasonable behavioural assumption that decision-makers always prefer more to less if the good is an unscaled measure of preference, such as net cash returns. Stated in terms of cumulative probability functions (CPF), consider a pair of continuous CPFs, F_1 and G_1 defined within the range [a, b] and respectively associated with two acts or risky prospects, *F* and *G*. *F* is said to dominate *G* in the sense of first degree stochastic dominance (FDSD), if $F_1(R) < G_1(R)$ for all possible values of *R* in the range of [a, b] with at least one strong inequality. Therefore, if the cumulative probability of one alternative is greater than the cumulative probability of the other for all levels of outcomes, then the technology with higher probability is dominated by the technology with lower probability. Stated otherwise, in graphical terms, if a cumulative distribution is to the left of another cumulative distribution for all levels of outcomes, the technology with the distribution to the left is dominated by

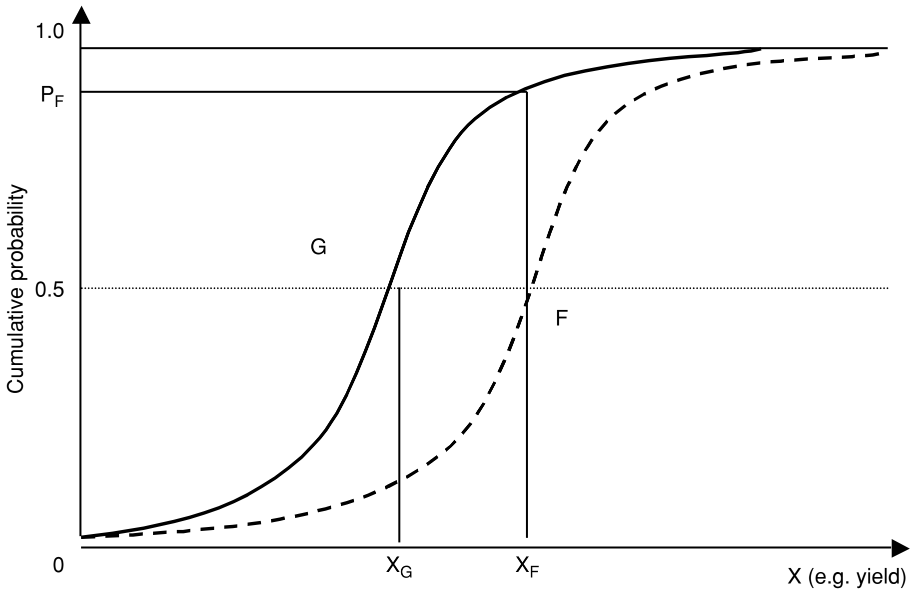

Figure 1. Example of First-Degree Stochastic Dominance (F dominates G in the FSD). See text for explanation of variables.

that with the distribution to the right (Figure 1). Assuming that F and G represent two treatments or technologies associated with yield as the risky prospect, with a 50 % chance one could attain yield (X_G) with the technology represented by G; whereas, with the same chance, one could attain higher yields (X_F) with technology F. Similarly, while one needs a 50 % chance to attain X_F with technology represented by F, one would need a better chance to attain the same level of yield with technology G. Therefore, overall, there is a better chance to attain higher yields using the technology represented by F than G.

In addition to preferring more to less, individuals usually prefer to avoid low values of outcomes, i.e. they are risk averse. In statistical terms, the tendency for an alternative to have low value outcomes is indicated by the area under the cumulative distribution function. F is said to dominate G in the sense of second-degree stochastic dominance (SDSD) if the area under the cumulative distribution of F is less than the area under the cumulative distribution of G for all levels of outcomes. If a distribution is dominated to the first degree, it is also dominated to the second degree. Thus, the second degree rule is useful when two distributions cross each other. From these rules, technology options can be classified into three groups: dominated technologies, technologies that are acceptable to risk neutral individuals (i.e. not dominated by FDSD, but dominated by SDSD), and technologies that could be used by risk averse individuals (not dominated by FDSD and SDSD). In Figure 2, the technology represented by F is not dominated by the technology represented by G or *vice versa* in the first degree. In effect, F and G cross each other at X_1 and X_2. In terms of areas between the curves cumulated from the lower values of yields, the area under F is less than that of G implying that G is dominated by F in the second degree.

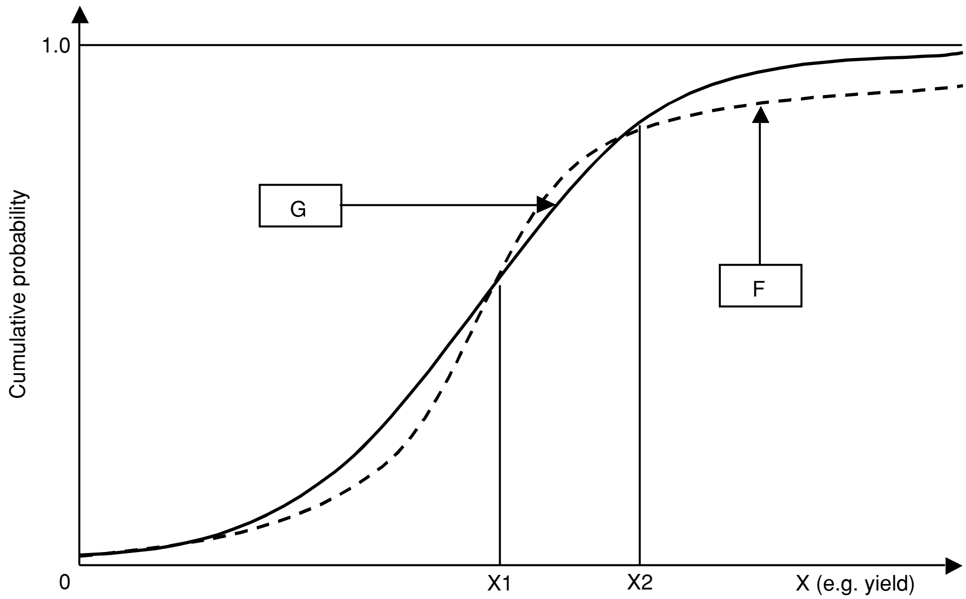

Figure 2. Example of Second-Degree Stochastic Dominance (F dominates G in SSD). See text for explanation of variables.

Estimation of cumulative distributions and Kolmogorov-Smirnov test of differences between pairs of distributions

The empirical approach of stochastic dominance consists of assigning probabilities to outcomes based on the relative frequencies, ranking observations, and using the sum of the probabilities up to and including the probability of a given outcome as an estimate of the cumulative probability. Then, the cumulative distributions are plotted and joined with straight lines to form a cumulative distribution curve. Straight lines are commonly used to link plotted points because information on how the distribution acts between points is lacking. As the number of observations increases, the estimated distribution approaches a smooth curve. In this study, the estimation of cumulative probabilities was based on sparse frequency data of net cash returns that accounted for rainfall and farmer variability. For each treatment, the probability of occurrence of an observation was the ratio W_t/N_t; where N_t is the number of participating farmers in year t and W_t is the weight given to the probability of the occurrence of rainfall at each site in year t. In reality, the year 1996 was an average rainfall year at both sites, while 1997, was below average allowing the incorporation of reliable rainfall risk information, which is useful for making efficient choices. An adapted version of a stochastic dominance spreadsheet in Excel was used to generate risk efficient choices (Lowenberg-DeBoer *et al.*, 1990; Lowenberg-DeBoer and Aghib, 1997).

In order to determine the degree to which distributions are statistically distinguishable, the Kolmogorov-Smirnov (K-S) test was used. The alternative is that the distributions are in fact two estimators of the same underlying distributions that differ because of estimation errors. The K-S is a non-parametric test, and thus is distribution free. It is applied to the maximum vertical distance between the distributions. If the distance between two distributions exceeds the critical level for the chosen significance threshold (e.g. a conventional $\alpha = 0.05$), then it is said that the two distributions are significantly different. In this study, the K-S test was implemented using SPSSPC+ (SPSSPC, 2001).

Simulations: evaluation of fertilizer cost reduction scenarios

Improved technologies may not necessarily fit with farmers' objectives of maximizing net cash returns from their investments on their farms because they may be too risky at current input–output price levels. Therefore, governments may have to develop a set of incentives that could induce adoption of these risky alternatives. This study examined the percentage of fertilizer cost reduction levels by determining the input–output price ratio necessary to induce the adoption of risk efficient alternatives. In other words, at current output price levels, what is the share of fertilizer costs that could induce the adoption of risk efficient alternatives? At current output price levels, farmers are assumed to pay only a share of the total fertilizer costs. This share will vary between 0 % and 100 % with a 10 % increment (0 % depicts the situation where fertilizers are given free to farmers and 100 % is the case where fertilizers are purchased by farmers at their current liberalized market price). At every share level, risky alternatives that dominate the traditional method are simulated.

AGRONOMIC AND ECONOMIC DATA

On-farm trials in Niger were conducted at two sites Banizoumbou (13°31′N, 2°39′E) and Karabedji (13°15′N, 2°32′E) in 1996 and 1997. The two sites differ significantly in the soil chemical characteristics (Table 1) and amount of rainfall (Table 2). One striking feature is their low levels of both available and total nitrogen and phosphorus and organic matter content (less than 0.2 % of organic carbon). However, the levels of effective cation exchange capacity, organic carbon, available phosphorous are higher in Karabedji than in Banizoumbou (Table 1).

In view of the influence of rainfall amount and distribution on the effectiveness of soil amendments and crop yields in the Sahel, time series data on total seasonal

Table 1. Soil chemical characteristics at the two experimental sites.

	Site/rainfall zone	
	Banizoumbou	Karabedji
pH/H_2O	5.84	4.72
Soil pH (KCl)	4.65	4.16
ECEC (Cmol kg^{-1})†	0.85	0.98
Organic carbon (%)	0.16	0.17
Available P (Bray) (mg kg^{-1})	1.93	3.14
Total nitrogen (mg kg^{-1})	168	169
Maximum P sorbed (mg kg^{-1})	46	49

Source: International Crops Research Institute for the Semi-Arid Tropics Soil Laboratory. Sadoré, Niger.

† ECEC: Effective cation exchange capacity.

Table 2. Total seasonal rainfall and probability of occurrence in Banizoumbou and Karabedji, 1996–97.

	Rainfall zone			
	Banizoumbou		Karabedji	
Year	Rainfall (X)	Prob. (< X)	Rainfall (Y)	Prob. (< Y)
1996	489 mm	0.77	578 mm	0.50
1997	360 mm	0.32	390 mm	0.08

Source: Direction de la Météorologie, Niamey, Niger (1998).

rainfall were collected at each site. The long-term rainfall averages were estimated to be 454 mm and 578 mm at Banizoumbou and Karabedji respectively. In 1997, because of drought in the month of August, the rainfall fell below the long-term averages at both sites, with 360 mm at Banizoumbou and 390 mm in Karabedji. In 1997, wind erosion resulted in severe sandblast of the seedlings at the beginning of the rainy season in Banizoumbou. Probabilities for the occurrence of rainfall at each site and during the years 1996 and 1997 were computed using INSTAT (1996) (Table 2).

In 1996, participatory rural appraisal surveys were conducted in order to identify potential soil fertility treatments to be tested by farmers. After discussions with farmers, a list of 25 options was identified. Researchers imposed the first four soil restoration options and farmers were asked to choose among the remaining 21 options. From these, two were chosen by more than 75 % of participating farmers, whilst others were not statistically representative. Many of the options rejected involved the use of crop residues and manure. Reasons for rejection were found in the limited availability of manure, and the competing uses of crop residues for house construction and animal feeding against soil amendment. Therefore, the following six treatments were tested and were entirely managed by farmers:

T1: Farmers' control, no fertilizer applied.
T2: Single super phosphate broadcast and incorporated at 13 kg P ha^{-1} (SSP).
T3: Tahoua phosphate rock broadcast and incorporated at 13 kg P ha^{-1} (PRT).
T4: As T3 plus 4 kg P ha^{-1} hill-placed as SSP at planting time (SSP and PRT).
T5: Commercial NPK broadcast and incorporated (15-15-15) applied at 13 kg P ha^{-1}.
T6: As T2 plus 30 kg N ha^{-1} as calcium ammonium nitrate (CAN) broadcast and incorporated. N was split with the first dose applied three weeks after planting and the second dose at six weeks after planting (SSP and CAN).

The distribution of participating farmers per treatment, site and year is presented in Table 3. In each farmer's field, a total of six plots each 900 m^2 was laid out. Then, each plot was split into two parts. In the first half, farmers planted at their usual density and in the other, they were asked to double the planting density. Only data from farmers' usual density were analysed since these reflected farmers' local practices. In fact, farmers in Karabedji rejected the double density in 1997 because they were already planting at a relatively high density. Research field assistants were posted on a full-time basis to monitor the crop management practices used by individual farmers.

Table 3. Description of treatments used by farmers (1996–1997).

Treat No	Treatment abbreviation†	Year, site and number of participating farmers			
		1996		1997	
		Banizoumbou	Karabedji	Banizoumbou	Karabedji
1	Control	25	22	17	23
2	SSP broadcast	48	39	38	43
3	PRT broadcast	31	29	23	40
4	PRT broadcast and SSP hill-placed	27	26	18	24
5	NPK (15-15-15) broadcast	16	14	13	23
6	SSP and CAN broadcast	14	6	4	8

Source: IFDC-ICRISAT on-farm trials.
† See text for explanation of abbreviations.

Table 4. Parameters used for labour cost estimation (1996–1997).

Parameter	Treatment					
	Control (T1)	SSP (T2)	PRT (T3)	PRT and SSP (T4)	15-15-15 (T5)	SSP and CAN (T6)
			(man hour ha^{-1})			
Fertilizer application	0.0	2.7	2.7	8.1	2.7	5.4
Planting	7.0	7.0	7.0	7.0	7.0	7.0
First weeding	48.2	62.7	62.7	63.7	62.7	64.7
Second weeding	42.4	46.3	46.3	48.7	46.3	48.7
Harvest of panicles	15.2	18.3	18.3	19.3	19.3	19.3
Harvest of stalks	6.4	8.1	8.1	9.1	9.1	9.1
Total	119.2	145.1	145.1	155.9	147.1	156.2

Adapted from Baidu-Forson, *et al.* (1994), p.19.

Table 5. Fertilizer prices in Niger 1995–1998.

Type of fertilizers§	Fertilizer price (cfaf kg^{-1})†			
	1995	1996	1997	1998
15-15-15 (NPK)	65	210[135]	268[135]	268
SSP	65	210‡	268[170]	–
CAN	–	210‡	268‡	–
Urea	60	210[140]	268[140]	268
Tahoua phosphate rock (PRT)	25	40[30]	50[40]	50

Source: Centrale d'Approvisionnement en Intrants et Produits Phyto-sanitaires – Niamey.
† Subsidized prices are in brackets.
‡ The price of urea has been used as a base value for the estimation of these prices.
§ See text for explanation of abbreviations.

Farmers were provided with fertilizers and they planted their local pearl millet variety. Data on grain yields were gathered from each plot at harvest.

The economic parameters used to compute cash returns are summarized in Tables 4 and 5. The estimation of cash returns follows standard budgeting principles. The gross revenue is the yield multiplied by the average price of the product that year. The average

Table 6. Summary statistics of grain yields (kg ha^{-1}) and cash returns (cfaf ha^{-1}) by fertility restoration options at Banizoumbou and Karabedji†.

	Treatment					
Statistic	Control	SSP	PRT	PRT and SSP	15-15-15 NPK	SSP and CAN
	Banizoumbou – Pearl millet grain yield (kg ha^{-1})					
Mean	331	568	423	527	681	801
s.d.	196	317	289	357	342	364
Minimum	56	97	35	86	220	187
Maximum	827	1373	1293	1460	1633	1507
	Banizoumbou – Cash returns (cfaf ha^{-1})					
Mean	32 092	28 024	35 919	43 010	32 994	32 067
s.d.	25 167	42 259	38 458	45 974	45 557	48 363
Minimum	– 5324	– 41750	– 18 902	– 17 696	– 31 128	– 50 388
Maximum	95 091	132 972	148 432	167 462	156 802	125 172
	Karabedji – Pearl millet grain yield (kg ha^{-1})					
Mean	432	656	499	689	738	783
s.d.	255	281	268	262	285	305
Minimum	103	95	167	112	328	236
Maximum	1436	1749	1945	1639	1359	1392
	Karabedji – Cash returns (cfaf ha^{-1})					
Mean	48 370	45 282	49 438	72 873	47 340	37 451
s.d.	32419	40 198	34 334	39 064	42 569	45 741
Minimum	2713	– 37 002	3670	– 14 821	– 16 764	– 43 871
Maximum	176 088	182 980	235 148	188 269	130 818	112 154

† Data are averaged across years.

pearl millet grain prices in the market at both sites were 133 cfaf kg^{-1} (US\$ 0.24 kg^{-1}) and 171 cfaf kg^{-1} (US\$ 0.31 kg^{-1}) respectively in 1996 and 1997 (OPVN, 1998). Since farmers in Niger use very few purchased inputs in pearl millet production, it was assumed that the only cash outlay was for fertilizer, including costs of spreading and incorporation. The fertilizer costs were unsubsidised prices as presented in Table 5.

The costs of CAN that were not available in the fertilizer market, were assumed to be the same as that for urea. Labour costs for fertilizer application, first and second weeding, panicle and stalk harvests were adapted from a study conducted in relatively similar environments (Baidu-Forson, 1994). The hourly wage for labour used for applying fertilizer, weeding, and harvesting was the minimum wage (SMIG)[2] of 125 cfaf h^{-1} (US\$ 0.23 kg^{-1}). The opportunity cost of land was assumed to be constant as all farmers owned land.

RESULTS AND DISCUSSION

In this section, the stochastic dominance results based on grain yields are presented, followed by those based on cash returns. Simulation results conclude this section. Table 6 presents the descriptive statistics on grain yields and cash returns for both

[2] SMIG stands for Salaire Minimum Interprofessionnel Garanti.

Table 7. Stochastic dominance comparison of empirical distributions of pearl millet grain yield and cash returns in two rainfall zones, Banizoumbou (Bani.) and Karabedji (Kara.) (1996–1997).

	Treatment and rainfall zone									
	Control (T1)		SSP (T2)		PRT (T3)		PRT and SSP (T4)		15-15-15 (NPK) (T5)	
Treatment	Bani.	Kara.	Bani.	Kara.	Bani.	Kara.	Bani.	Kara.	Bani.	Kara.
					Pearl millet grain yield (kg ha^{-1})					
SSP (T2)	> F†§**	–								
PRT (T3)	–	> S**	< S‡¶	–						
PRT and SSP (T4)	> F**	> S§	< S	> S	> F	–				
15-15-15 (T5)	> F**	> S**	> S	–	> F	–	> S	–		
SSP and CAN (T6)	> F**	> S**	> S	–	> S**	–	> S	–	–	–
					Pearl millet cash returns (fcfa ha^{-s1})					
SSP (T2)	< S¶**	< S**								
PRT (T3)	–	–	> S	> S**						
PRT and SSP (T4)	–	–	> S	> S	–	–				
15-15-15 (T5)	–	–	–	–	< S	< S	< S	< S*		
SSP and CAN (T6)	–	–	–	< S**	< S**	< S**	< S**	< S**	< S	< S**

† F: First degree stochastic dominance of column versus row treatment.
‡ S: Second degree stochastic dominance of column versus row treatment.
§ >: Row treatment dominates column treatment.
¶ <: Row treatment is dominated by column treatment.
* Significant difference between pairs of distribution at 0.05 according to the K-S test (2 tailed probability reported).
** Significant difference between pairs of distribution at 0.01 according to the K-S test (2 tailed probability reported).

years combined, and for all treatments. On average, grain yields and cash returns were lower in Banizoumbou than in Karabedji. This is consistent with better rainfall conditions (Table 2), soil and chemical characteristics (Table 1) in Karabedji than in Banizoumbou. Table 7 presents the stochastic dominance comparison of empirical distribution of grain yields and cash returns and Table 8 presents the simulated results based on fertilizer cost reduction scenarios.

Grain yields

Grain yields showed positive responses to fertilizer at all levels. The cumulative yield distributions for most fertilizer treatments are to the right of the no-fertilizer control (T1) in both sites (see Figure 3 for illustration).

At Banizoumbou, the poor rainfall zone, the cumulative distribution of the fertilizer treatments are to the right of the control distribution at all yield levels, except for the rock phosphate treatment (Figure 3). This means that most fertilizer treatments increase the probability of higher yields under low yield conditions as well as in high yield situations. Figure 3 indicates that the control treatment (T1) has a 50 % chance of achieving a grain yield of 370 kg ha^{-1} or more, while the phosphate rock broadcast with additional single super phosphate hill-placed (T4) has the same probability of achieving 480 kg ha^{-1} or more; the commercial fertilizer NPK (T5) has the same probability of achieving 720 kg ha^{-1} or more, as does the single super phosphate with additional calcium ammonium nitrate (T6). Similarly, the control treatment (T1) has a

Table 8. Stochastic dominance comparison of calculated cash-returns from risk efficient treatments dominating farmers' control strategy at different levels of fertilizer costs borne by farmers in Banizoumbou and Karabedji.

Percent fertilizer costs paid by farmers	Treatment				
	SSP (T2)	PRT (T3)	PRT and SSP (T4)	15-15-15 (NPK) (T5)	SSP and CAN (T6)
			Banizoumbou		
0	> F[†]**	–	–	> F[§]**	> F**
10	–	–	–	> F**	–[¶]
20	–	–	–	> F**	–
30	–	–	–	> F**	–
40–100	–	–	–	–	–
			Karabedji		
0	–	> S[‡]**	–	> S**	–
10	–	> S**	–	> S**	–
20	–	> S**	–	> S**	–
30	–	> S**	–	> S**	–
40	–	> S**	–	> S**	–
50	–	> S**	–	–	–
60–100	–	–	–	–	–

[†] F: First degree stochastic dominance of the treatment over farmers' method.
[‡] S: Second degree stochastic dominance of the treatment over farmers' method.
[§] >: The fertilizer treatment dominates farmers' method.
[¶] -: Undetermined.
** Significant difference between pairs of distribution at 0.01 according to the K-S test (two-tailed probability reported).

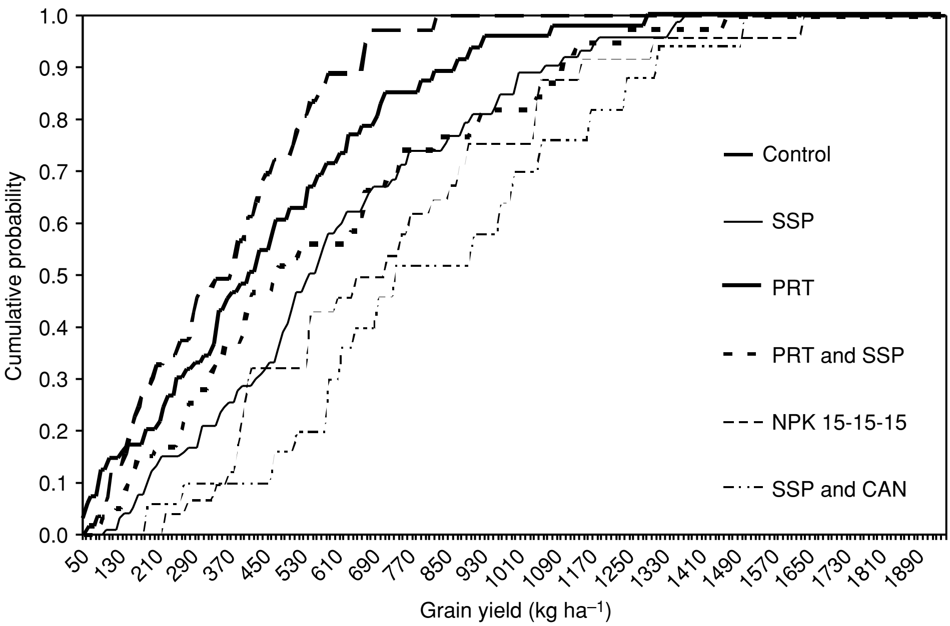

Figure 3. Cumulative distribution of grain yields, Banizoumbou, 1996–97.

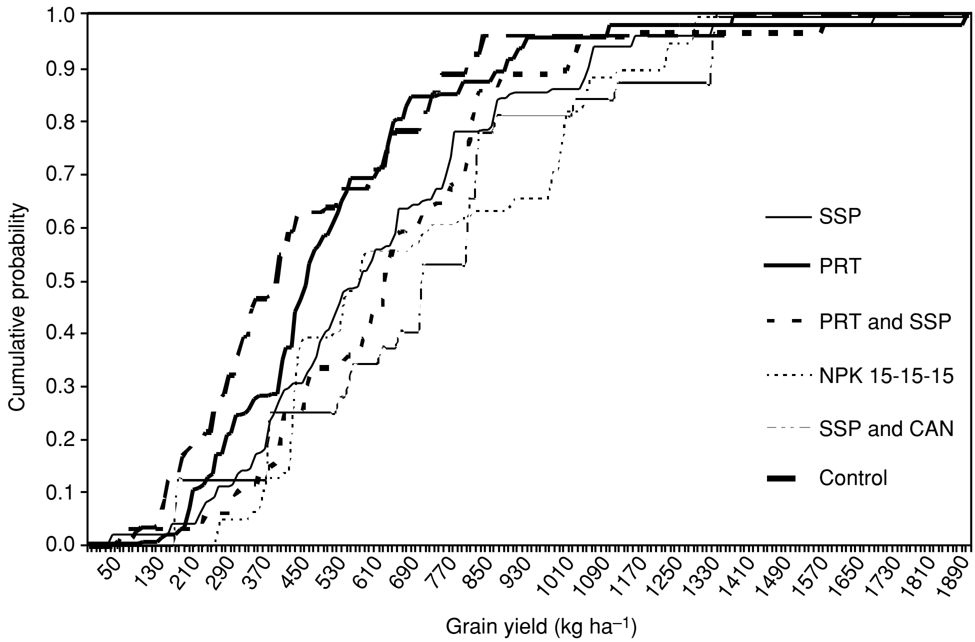

Figure 4. Cumulative distribution of grain yields, Karabedji, 1996–97.

75 % chance of attaining grain yields of 178 kg ha^{-1} or more; but T4 has the same probability of producing 280 kg ha^{-1} or more; and, T5 achieves 400 kg ha^{-1} or more about 75 % of the time. Based on grain yields, farmers' traditional methods and the treatments using rock phosphate (T3 and T4) show more risks than those using the commercial fertilizers, T2, T5 and T6 (Table 7).

In terms of grain yield, the control treatment is dominated by most fertilizer treatments in Banizoumbou according to the K-S test of differences between pairs of treatments. Similarly, the treatments using the water soluble fertilizers (T5 and T6) significantly out perform all the other treatments.

The situation is different in Karabedji. Here, the cumulative distribution curves overlap frequently. However, the area under the control treatment is always greater than that for all the fertilizer treatments except T2, at all yield levels. This indicates that the fertilizer treatments dominate the control at the second degree (Figure 4). However, for most of the fertilizer treatments, the stochastic dominance results are inconclusive.

Compared to Banizoumbou, farmers in Karabedji have a better chance of realizing higher yields. This is explained by relatively high rainfall and better soil physical and chemical characteristics in Karabedji than Banizoumbou. In Karabedji, the control treatment (T1) has a 50 % chance of achieving 450 kg ha^{-1} or more; T4 has a 50 % chance of producing 690 kg ha^{-1} or more, and T5, 630 kg ha^{-1} or more. As in Banizoumbou, commercial fertilizers significantly dominate the control treatment according to the K-S test.

In general, if the government's objective is to attain cereal self-sufficiency[3]; estimated to be about 400 kg ha^{-1} at all costs, there is only about a 40 % chance of attaining this yield level in Banizoumbou and a 55 % chance in Karabedji using farmers' traditional methods. In Banizoumbou, the improved soil fertility restoration options have at least a 60 % chance of reaching this level with the lowest achieved with the phosphate rock fertilizer (T3) and the highest with T6 (91 % chance). Similarly, in Karabedji, the improved soil fertility restoration options have at least a 73 % chance of reaching this level with the lowest again being with the phosphate rock fertilizer (T3) and the highest with the commercial NPK (T5, 94 % chance). Overall, the improved soil fertility restoration options have the highest chance of reaching cereal self-sufficiency compared with the traditional method.

Since farmers have to purchase inputs and the costs of inputs used in the treatments differ, they are interested in comparing relative net returns and their probability of occurrence.

Cash returns

The distribution of cash returns from all six treatments was used for pair-wise comparisons of soil amendment alternatives, within the stochastic dominance framework (Table 7). Unlike grain yield comparisons, the effect of fertilizers on cash returns is less clear than the effect on yields. The cumulative distribution curves for all treatments interact frequently (Figure 5), especially under low yield conditions. The stochastic dominance comparisons show that the phosphate rock, and a combination of phosphate rock and single super phosphate treatments dominate other improved treatments. In addition, in both rainfall zones, the farmer's traditional method was also found to be in the risk efficient set providing justification for the classic Shultz's well-known hypothesis that farmers are poor but (risk) efficient.

The effect of fertilizer on cash returns is less transparent than the effect on yields, especially in Banizoumbou, the low rainfall zone (Figure 5). The commercial fertilizer treatments (T5 and T6) are dominated by all other fertilizer treatments. Unlike grain yield comparisons, the control is not dominated by the other treatments. T1 and T4 have a 50 % chance of realizing cash returns of 35 000 cfaf ha^{-1} (US\$ 64 ha^{-1}) and above. At the same probability, T5 and T6 could achieve 32 000 cfaf ha^{-1} (US\$ 58 ha^{-1}) and 23 000 cfaf ha^{-1} (US\$ 42 ha^{-1}). Overall, stochastic dominance results demo- nstrate that treatments T4 and T3 significantly dominate all other treatments except for the control (Table 7). T3 and T4 are statistically different from T5 and T6 suggesting that these distributions are not estimators of the same underlying factors.

In Karabedji, the cumulative distribution of cash returns overlap frequently (Figure 6). The areas under the cumulative curves for T2, T5 and T6 are always

[3] This figure was computed using an average pearl millet yield of 340 kg ha^{-1} in addition to 15 % of this yield as cereal imports; i.e. 391 kg ha^{-1} during the last ten years. This figure assumes that cereal deficits will only be filled by pearl millet. In effect, in Niger, pearl millet is the main staple accounting for about 77 % of total per capita cereal consumption.

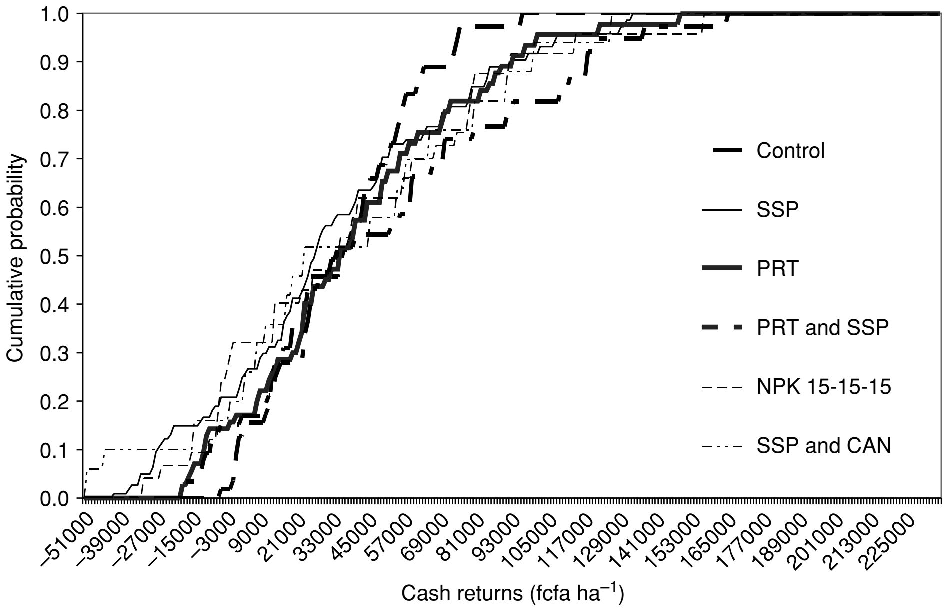

Figure 5. Cumulative distribution of cash returns, Banizoumbou, 1996–97.

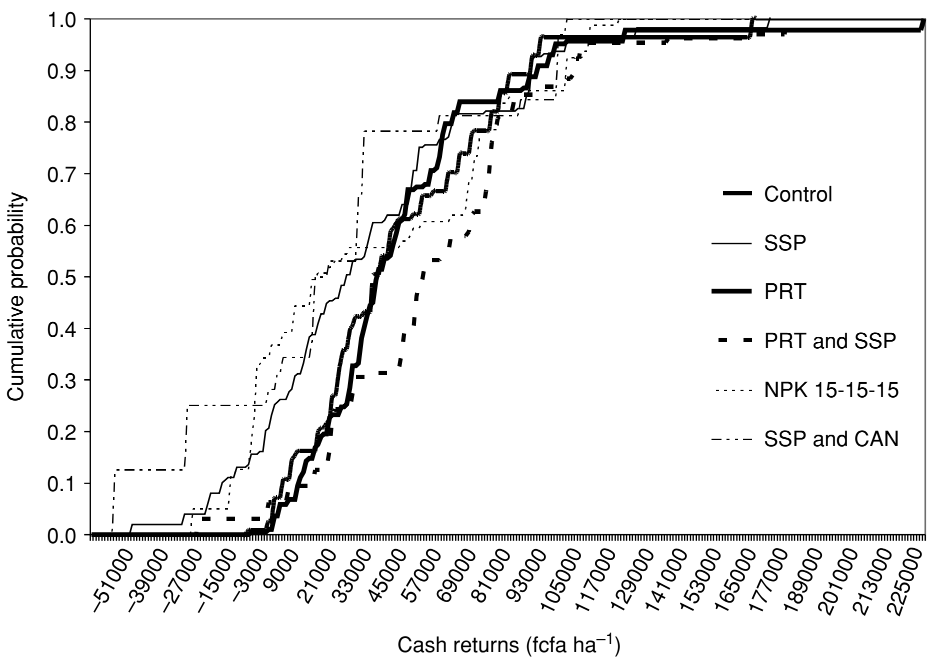

Figure 6. Cumulative distribution of cash returns, Karabedji 1996–97.

higher than the corresponding values T1, T3 or T4 at all levels of cash returns. The farmer's traditional method (T1), the application of 13 kg P ha^{-1} from PRT broadcast (T3) and a combination of 13 kg P ha^{-1} from PRT and 4 kg P ha^{-1} from SSP hill-placed (T4) are in the farmers' risk efficient choice set because they are not dominated at the second degree. These are technologies likely to be preferred by risk-averse utility maximizers (Figure 6). The probabilities of achieving higher returns in Karabedji are greater than those for Banizoumbou. This is largely explained by the climatic conditions in Karabedji compared with Banizoumbou that provide opportunities for better fertilizer responses. With 50 % probability, the control treatment (T1) could achieve 47 000 cfaf ha^{-1} (US\$ 85 ha^{-1}) or more, and T4 could reach 63 000 cfaf ha^{-1} (US\$ 115 ha^{-1}) or more. This compare with 36 000 cfaf ha^{-1} (US\$ 65 ha^{-1}) in Banizoumbou for the same treatments. The K-S test indicates that the comparisons between pair-wise distributions are relatively robust. Out of nine such distributions, six pairs are statistically different according to the K-S test. Likewise in Banizoumbou, T3 and T4 are statistically different from T5 or T6 in Karabedji.

Simulation results: fertilizer cost reduction scenarios

The shares of fertilizer costs borne by farmers varied between 0 % and 100 % with increments of 10 %. Results from the simulated sets of risky alternatives that dominate farmers' traditional practice are presented in Table 8. In the first scenario in Banizoumbou, where farmers are given fertilizer for free, the options T2, T5 and T6 dominate farmers' traditional method and are likely to be preferred by risk neutral farmers. However, if farmers bear more than 30 % of the current fertilizer costs, no improved option will dominate the control treatment. Similarly, in Karabedji, farmers will demand more of the risky alternatives if fertilizer costs are reduced by at least 50 %.

If the Nigerien government supplies fertilizer for free to farmers, in Karabedji, therefore, T3 and T6 are soil fertility maintenance options likely to be adopted by risk-averse farmers. The percentage of cost reduction necessary to induce adoption of risky alternatives seems to be relatively high with regard to the government's scarce foreign currency reserves. This calls for a careful assessment of other potential technologies with attributes that may significantly increase yields while being risk efficient and acceptable to risk averse utility maximizing farmers.

Overall, the stochastic dominance comparison of soil amendment options show that: at both sites, if a farmer has no access to single super phosphate (SSP) and natural phosphate rock (PRT) combined, or natural phosphate rock alone, the utility maximizing strategy will be to remain with the traditional practice. However, there was a lower response to PRT in Banizoumbou than Karabedji. This is well explained by its poor dissolution due to low rainfall. Like other phosphate fertilizers, PRT cannot dissolve when the soil is dry and yield responses by crops to PRT are linearly related to the mean annual rainfall between 500 mm and 1300 mm (Mokwunye, 1995). In order to increase the reactivity of PRT, it needs to be totally or partially acidulated. In general, at both sites, if farmers have no access to PRT and/or SSP, the utility maximizing strategy remains the traditional technology of no fertilizer. Although all other options (applying 13 kg P ha^{-1} from SSP broadcast, applying 13 kg P ha^{-1} from NPK or applying a combination of 13 kg P ha^{-1} from SSP and 30 kg N ha^{-1} from CAN broadcast [T6]) lead on average to the highest yields, when accounting for the high input costs and gross revenue, these options appear to be more risky and are likely to be rejected by utility maximizing farmers. In order to induce the adoption of risk efficient alternatives, farmers would have to bear less than half the fertilizer costs. Consequently, the input and product markets would have to perform better to lower the cost of fertilizer or to increase grain price substantially to offset the current costs.

In effect, domestic marketing costs account for more than 50 % of the farm gate price of fertilizers. In order to correct fertilizer market failures, government intervention may be warranted in the form of reducing the port fees, reducing transport costs through port, rail and road improvements, coordinating timing of fertilizers clearance for the port and providing incentives for firms to invest in transport services (Kelly *et al.*, 2003). If none of these is possible in the short-term then the Nigerien government may have to consider subsidizing fertilizer.

CONCLUSIONS

Mineral fertilizer applications could significantly increase farmers' yields or provide cash income. Stochastic dominance analysis of soil fertility restoration options showed that at both sites for all grain yield levels, the commercial fertilizers had higher probabilities of achieving food self-sufficiency than the treatments involving phosphate rock. However, these conclusions differ significantly when it comes to cash returns signalling the presence of input–output price distortion. The stochastic dominance analysis showed that among the five fertilizer treatments tested, at the relative input cost used in the analysis, at both sites, it will be efficient to apply 13 kg P ha^{-1} from natural rock phosphate broadcast with an additional 4 kg P ha^{-1} from single super phosphate hill-placed or the application of 13 kg P ha^{-1} from phosphate rocks broadcast alone. Choice of options by farmers is dependent on the availability of fertilizers, the opportunity costs of funds and farmers' resource endowments. However, if farmers have no access to PRT and/or SSP, they are better off using their traditional practices because the farmers' control treatment was found in the risk efficient set. In order to induce the adoption of risky alternatives, the government may consider subsidizing fertilizers.

This analysis compared the risk characteristics of six fertilizer treatments with the farmers' traditional method as the control. The risk of fertilizer application to pearl millet relative to the risk in farmers' other activities (e.g livestock, commerce) has not been tested. Thus the interaction of risk and other decision factors (e.g. labour constraints, capital availability) has not been examined. Also, the carry over effects of fertilizers has not been accounted for. These caveats need to be explored in future research.

Simulation results show that for farmers to adopt risk efficient options, they would have to bear less than half the fertilizer costs. However, further research is necessary to ascertain if the levels of fertilizer subsidies are socially optimum. In addition, farmers are of different types based on the level of endowments in livelihood assets. Wealthier farmers are likely to benefit more from subsidies. Additional research is needed to refine policy options targeting the different types of farmers.

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