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Stochastic dominance analysis of on-farm-trial data: The riskiness of alternative phosphate sources in Burkina Faso

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Abstract

Stochastic dominance was used to determine the risk characteristics of phosphate fertilization of millet, sorghum and maize with commercial NPK fertilizer, rock phosphate and partially acidulated rock phosphate in Burkina Faso. On-farm-trial data from 1989, 1990 and 1991 in three rainfall zones was used.

The analysis shows that among the four treatments tested, commercial NPK fertilizer has the most desirable risk characteristics. It is acceptable to risk averse decision makers for all three crops in all rainfall zones. The no-fertilizer control is dominated by the fertilizer treatments. The rock phosphate treatments have higher yields and in certain cases higher returns than the no-fertilizer control, but those benefits are less sure than for the soluble commercial fertilizer. The distributions of cash returns to rock phosphate treatments are rarely significantly different from those of the control. Rock phosphate treatments never dominate the commercial fertilizer treatment. If farmers have a choice between commercial fertilizer, rock phosphate and partially acidulated rock phosphate, at current prices most of those who use fertilizer would choose the soluble commercial product. If the availability of commercial fertilizer were limited (e.g. by lack of hard currency), some farmers would use rock phosphate—especially the partially acidulated product.

Stochastic dominance permitted a timely and detailed analysis of risk inherent in phosphate fertilizer alternatives. Because on-farm-trials involve a modest number of alternatives, pairwise stochastic dominance comparisons are feasible. The stochastic dominance analysis permits researchers to communicate to extension staff and policymakers not only the degree of risk, but also something about the characteristics of the crop response that contribute to risk. The key to effective use of stochastic dominance is careful study of the distributions and understanding why a technology is dominated or is potentially acceptable to risk averse decisionmakers.

1. Introduction

Farmers, extension specialists and agricultural policy decisionmakers need timely information on risk characteristics of proposed agricultural innovations. Risk affects potential for wide spread adoption of technologies and may determine how an extension effort is implemented. Response of farmers to agricultural policy is heavily influenced by the riskiness of their production practices. The general objective

of this article is to provide an example of stochastic dominance use as a tool in the risk analysis of on-farm-trial data.

The specific objective of this study is to determine risk characteristics of phosphate fertilization strategies tested by the Food Crops Fertilizer Project funded by the World Bank in Burkina Faso from 1989 to 1991. The overall goal of this project was to determine appropriate fertilizer rates and sources for millet, sorghum and maize crops in Burkina Faso.

These cereals are the staple food crops in Burkina Faso. The potential for using local rock phosphate or partially acidulated rock phosphate was a special concern for policy makers. Use of local phosphate instead commercial fertilizer could save foreign exchange and create jobs.

The primary research tool for this risk analysis was stochastic dominance. These comparisons were performed using a Quattro Pro spreadsheet developed at Purdue University (Lowenberg-DeBoer et al., 1990).

Burkina Faso is a small, landlocked country in West Africa. It is bordered by the Cote d'Ivoire, Benin and Ghana on the south, by Niger on the east and by Mali on the west and north. It has a population of about 9.7 million, about 90% of which depend on agriculture for their livelihood.

The organization of this article is to provide in the second section a brief overview of stochastic dominance use for on-farm trial data, in the third section a description of the agronomic data, in the fourth section the results of the stochastic dominance comparisons, and finally to draw conclusions for use of phosphate fertilizer in Burkina Faso and for use of stochastic dominance in analyzing on-farm-trial data. The on-farm-trial methodology has been described by Hien et al. (1990, 1991) and by Hien and Youl (1992). A step-by-step description of the analysis is available from Hien et al. (1993).

2. Research methods

Stochastic dominance is used to rank alternatives according to their risk characteristics. It identifies technologies that are dominated, those that might be acceptable to risk neutral decisionmakers and those that could be used by risk averse individuals. In this context, risk aversion is the preference shown by many humans to avoid alternatives with a substantial probability of low value results. It is not strictly an aversion to variability, because positive variability (that is in the direction of high value results) is desired by many individuals. The theoretical development of stochastic dominance is presented by Anderson (1974). Stochastic dominance is a non-parametric analysis. That is to say it does not focus on parameters (mean, variance, etc.), but on the distribu-

tion itself. As a consequence of this nonparametric approach, stochastic dominance takes into account information that is not easily summarized in statistical parameters.

2.1. Stochastic dominance rules

This study uses the first two rules of stochastic dominance to rank technologies. The first rule is based on observation that human beings usually prefer more to less of most goods. This observation is translated into statistical terms by the first degree stochastic dominance rule which states that if the cumulative probability of an alternative is greater than the cumulative probability for another alternative for all levels of outcome, the technology with the higher probabilities is dominated by the technology with the lower probabilities. The observation is put into graphical terms by saying that if one cumulative distribution is to the left of another cumulative distribution for all levels of outcome, the technology with the distribution at the left is dominated by the technology whose distribution is to the right. This type of dominance is called 'first degree stochastic dominance'.

The second stochastic dominance rule is based on observation that, in addition to preferring more to less, human beings usually prefer to avoid low value outcomes, that is to say 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 curve. The alternative with the greatest area under the curve at any given outcome level has the highest probability of low value results. Therefore, an option is dominated if the area under its cumulative probability curve is larger at every outcome level than that of the alternative. This type of dominance is called 'second degree stochastic dominance'. This rule is useful when the cumulative distribution curves of two options cross and the first degree rule cannot rank them.

With the first two stochastic dominance rules alternative technologies can be classed into three groups:

1. dominated technologies;
2. technologies that could be acceptable to risk neutral individuals, and

3. technologies that could be used by risk averse decisionmakers.

The technologies that belong to the second category are not dominated by first degree stochastic dominance, but they are dominated if second degree stochastic dominance is applied. The technologies in the third category are not dominated by any other technology using either first or second degree stochastic dominance.

2.2. *Estimation of cumulative distribution*

In general, researchers do not have exact distributions of outcomes. Distributions must be estimated. In the case of multi-year on-farm-trials, estimation procedures of choice depend on the objective of the analysis, the type of information available and the number of observations (Lowenberg-DeBoer, 1992).

If the goal is to determine impact of general weather and/or price variability, sparse data techniques (Anderson et al., 1977) with inter-annual data are most appropriate. Data used is in the form of annual average outcomes for a technology. In the Sahel the variability in annual averages depends largely on weather and price changes associated with weather driven supply variations. Variability in intra-annual data (farm level observations) reflects pest problems, soil differences, spatial variability of weather, management differences, and other factors.

Sparse data techniques are required when inter-annual data are used because of the small number of data points. On-farm-trials are seldom conducted for more than three or four seasons. Lowenberg-DeBoer et al. (1990) provide an example of sparse data estimation of cumulative distributions from on-farm-trial data.

If the focus is on risk incurred by policymakers and extension agencies in facilitating the adoption of a given technique, an 'empirical' procedure may be used with cross-section time series on-farm-trial data (farm level observations). Policymakers and extension personal are concerned about all sources of risk that might cause an innovation fail. Their perspective is not limited to broad weather and price variability.

The empirical approach assigns probabilities to each observation, ranks the observations, and uses the sum of the probabilities up to and including the probability of a given outcome as an estimate of the

cumulative probability. The cumulative probabilities are plotted and joined with straight line segments to form a cumulative distribution curve. Straight lines are commonly used to link plotted points because information on how the distribution acts between observations is lacking. As the number of observations increases the estimated distribution approaches a smooth curve.

In the simplest case the empirical estimation assumes the observations are equally likely, that is the probabilities are $1/N$. A common problem in using on-farm-trial data is that the number of farmers participating varies from year to year. In that case the equally likely observations assumption generates unequal weighing of crop seasons. For example, if five farmers participated in the first year, 25 farmers in the second year and 12 farmers in the third year, the equally likely observations assumption would assign 11% of the probability to the first year, 60% to the second year, and 29% to the third year. If in fact, the first season had bad crop conditions, the second season had good conditions and the third season had in between conditions, and these three seasons were equally likely, the equally likely observations assumption would over represent good conditions.

A simple way to take into account the number of observations per year is to estimate the probability of an observation as the product of the probability of the season and the probability of the management situation. If the seasons are equally likely and the farmers are representative of the community, the probability of an observation is $(1/t) * (1/n_t)$, where t is the number of seasons and n is the number of farmers participating in year t . The Lowenberg-DeBoer et al. (1990) stochastic dominance spreadsheet was modified to incorporate equal weighing of crop seasons.

2.3. *The advantages and disadvantages*

The primary disadvantage of stochastic dominance is the lack of strong assumptions in the form of the utility function or the underlying distribution of results. Stochastic dominance rules use simple, intuitive observations on human behavior. It will work with any type of distribution, including those that are strongly skewed.

A primary disadvantage of stochastic dominance is that the comparisons must be made pairwise. For situations in which there are hundreds of possibilities (for example, stock portfolios) stochastic dominance is impractical. For on-farm-trial results this is not a major constraint because the number of treatments is usually limited to three or four.

Stochastic dominance has also been criticized for failing to take into account errors in estimation of the cumulative distributions (see Cochran (1986) for a review of this criticism). Lowenberg-DeBoer et al. (1992) propose use of the Kolmogorov–Smirnov (K–S) test to determine the degree to which the distributions are statistically distinguishable. They suggest doing the stochastic dominance analysis for all comparisons, but to consider the results as only indicative when the K–S test is not significant at a 5% level.

In general, the K–S test is used to determine if two distributions are significantly different (Steele and Torrie, 1980). An alternative hypothesis is that the two distributions are in fact two estimators of the same underlying distribution that differ because of estimation error. The K–S test is ‘non-parametric’. That is to say it is done at the level of the distribution as an entity and not on individual parameters, such as mean, variance, etc. The test statistic is applied to the maximum vertical distance between the distributions. If this distance exceeds the critical level for the chosen significance threshold (for instance $\alpha = 5\%$), then it is said that the distributions are significantly different. The critical level depends on the number of observations. Like stochastic dominance, the K–S test is pairwise. This study uses a spreadsheet template to do the K–S test (Lowenberg-DeBoer, 1992).

2.4. Farmer objectives

A common assumption made by all types of risk analysis is that decisionmakers’ objectives are known. A common criticism is that most farmers have several objectives and the weight placed on each objective is unknown. In Burkina Faso farmers want to produce enough to feed their families and also enough to sell to provide a cash income. In this analysis, it is assumed that a technology with a strong chance of being accepted will be in the third category (accepta-

ble for risk averse decisionmakers) for several objectives. The technologies were tested for the objectives of maximizing food selfsufficiency and monetary income.

For the food selfsufficiency objective the grain yield was used because the trials were monocrops (not intercrops). Thus, any other nutritional index, such as calories or protein content, would be a linear transformation of the yield and would have the same stochastic dominance comparison.

Monetary objectives were measured by the return to family resources. In economic theory, all revenue can be linked to resources used in production. In this case, family resources include land, labor, capital and management. This economic measure was chosen to make use of the available data: grain and stover yields, cereal prices, the price of fertilizers, and labor for fertilizer spreading and incorporation. Labor time for planting, weeding and harvesting were not collected. Average labor times are available, but subtracting a fixed sum from each observation would not change the distribution or the stochastic dominance comparisons.

The estimation of returns used standard budgeting principles. The gross revenue is the yield multiplied by the average price of the product for that year. Cereals prices in local markets were used (see Hien et al., 1993 for details). The stover was valued at 14 FCFA kg^{-1} based on price data collected by the INERA livestock production program at Kamboinsé. In trials, farmers followed their usual practices, except for the fertilizer on certain treatments. Burkinabé farmers use very few purchased inputs in cereals production, thus for the analysis it was assumed that the only cash outlay was for fertilizer, including the cost of spreading and incorporation. The fertilizer cost were: NPK, 105 FCFA kg^{-1} ; urea, 96 FCFA kg^{-1} ; potash, 88 FCFA kg^{-1} ; Burkina rock phosphate, 35 FCFA kg^{-1} ; and partially acidulated rock phosphate, 41 FCFA kg^{-1} (Hien and Youl, 1992). The hourly rate for labor used in spreading and incorporating fertilizer was the minimum wage (SMIG) of 120 FCFA h^{-1} .

3. Agronomic data

The agronomic data included grain and stover yields for millet, sorghum, and maize in three areas

of Burkina Faso. The four treatments were designed to test the efficacy of three potential phosphate sources.

- T1 Control, no fertilizer
- T2 Burkina rock phosphate, plus urea and potash
- T3 Partially acidulated Burkina rock phosphate, plus urea and potash
- T4 NPK (cotton fertilizer) plus urea

Exact amounts of fertilizer varied by zone in accord with extension recommendations (Hien et al., 1990). The amount of urea and potash were chosen to provide the same nitrogen and potassium for treatments T2, T3 and T4. The crop and seed variety were chosen by the farmer. The experimental design was a randomized complete block. Each farmer constituted a block in the design.

The areas were defined by average annual rainfall: Zone A, less than 600 mm; Zone B, between 600 mm and 800 mm, and Zone C, more than 800 mm. Hien et al. (1991) and Hien and Youl (1992) provide a list of sites.

4. Results

In this section the stochastic dominance results are organized by farmer objective, and within objective by area and crop. Sorghum yields and returns in zone B are presented in graphical form as an example. A detailed presentation of the results, including graphical presentation of all estimated distributions, descriptive statistics and K–S test statistics, is given by Hien et al. (1993).

4.1. Grain yields

Grain yields show positive fertilizer effects at all yield levels. The cumulative distributions of fertilizer treatments (T2, T3, T4) are generally to the right of the no-fertilizer control (T1), indicating that they provide higher yields under most conditions than the no fertilizer control treatment. In the example of sorghum in the medium rainfall zone (zone B), the cumulative distributions of the fertilizer treatments are to the right of the control distribution for all yield

levels (Fig. 1). This means that the fertilizer treatments increase the probability of higher yields under low yield conditions as well as in high yield situations.

Fig. 1 indicates that the control has a 50% chance of achieving 675 kg ha⁻¹ or more, while the commercial fertilizer treatment (T4) has the same probability of achieving 1250 kg ha⁻¹ or more. T4 achieves 869 kg ha⁻¹ or more about 75% of the time. T1 has a 75% chance of producing 426 kg ha⁻¹ or more.

In terms of grain yield, the control is dominated by fertilizer treatments in all zones and for all three crops studied (Table 1). In six of the eight cases, the no-fertilizer treatment is dominated in a comparison between distributions that statistically differ according to the K–S test at the 5% level.

The treatments using rock phosphate (T2, T3) show more risk than those using commercial fertilizer (T4). In Fig. 1, the T2 distribution is about half way between the T1 and T4 curves. T2 has a 50% chance of producing about 923 kg ha⁻¹ or more, and a 75% chance of producing about 692 kg ha⁻¹ or more.

For the food self sufficiency objective, the rock phosphate treatment (T2) is dominated for millet in all zones (Table 1). For sorghum, rock phosphate is dominated in zones B and C, but in zone A it cannot be excluded from the risk averse category. In Fig. 1, the T2 curve for sorghum in zone B is always to the left of T4, and thus it is dominated by first degree stochastic dominance. For maize the rock phosphate

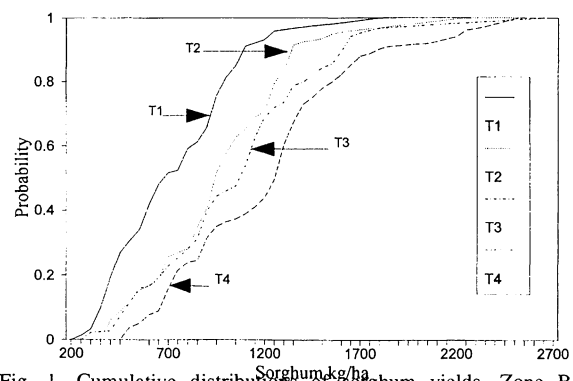


Fig. 1. Cumulative distributions of sorghum yields, Zone B, 1989–91.

Table 1

Risk categories for the food selfsufficiency objective for technologies tested by the Food Crops Fertilizer Project, Burkina Faso, 1989–91, by crop and agro-ecological zone

Zone and Crop	T1	T2	T3	T4
Zone A, Millet	dominated *	dominated	dominated	risk averse **
Zone A, Sorghum	dominated	risk averse	risk averse	risk averse
Zone B, Millet	dominated	dominated	risk averse **	risk averse **
Zone B, Sorghum	dominated *	dominated	risk neutral	risk averse **
Zone B, Maize	dominated *	risk averse	dominated	risk averse **
Zone C, Millet	dominated	dominated	dominated	risk averse
Zone C, Sorghum	dominated *	dominated	risk neutral	risk averse **
Zone C, Maize	dominated *	risk averse **	risk averse **	risk averse **

* Treatment dominated in a comparison between distributions that are statistically different at the 5% level using the Kolmogorov–Smirnov test.

** Treatment undominated in all comparisons and dominates in the first degree in at least in one case in a comparison between distributions that are statistically different at the 5% level using the Kolmogorov–Smirnov test.

treatment is in the risk averse category for zone B and C.

The rock phosphate treatment is undominated in comparison with statistically different distributions only for maize in the high rainfall zone. The distribution of T2 is statistically different from that of the no fertilizer treatment only for sorghum in zones B and C, and for maize in zone C. In general, the rock phosphate results must be considered indicative because the T2 distributions are often not clearly different from that of the control.

The treatment using partially acidulated rock phosphate (T3) shows less risk than the non-acidulated rock phosphate (T2). In the example of sorghum in zone B (Fig. 1), T3 has a 50% chance of yields at or above 1087 kg ha⁻¹ and a 75% chance of yields over 744 kg ha⁻¹. The T3 advantage is primarily seen under higher yield conditions. In Fig. 1, the T3 distribution is generally to the right of the T2 distribution above 900 kg ha⁻¹. Under low yield conditions the two curves intertwine and are virtually indistinguishable. The T3 distribution starts to the left at a lower minimum yield than T2.

For millet, T3 is dominated in zones A and C, but it is not excluded from the risk averse category for zone B (Table 1). For sorghum, T3 is in the risk neutral category for zones B and C, and in the risk averse category for zone A. T3 is not completely dominated by T4 for sorghum in zone B because T3 is the right most distribution for very high yield conditions (Fig. 1). For maize, T3 is dominated in

zone B and in the risk aversion category in zone C. T3 is undominated in comparisons involving statistically different distributions only for millet in zone B and maize in zone C. The T3 distribution differs statistically from the control distribution in five of the nine cases. Because of the higher solubility of its phosphate, T3 provides a more reliable crop response and its yield distribution is more clearly distinguished from the no fertilizer treatment than in the rock phosphate (T2) case.

4.2. Cash return

The effect of fertilizer on cash returns is less clear than the effect on yield. The cumulative distribution

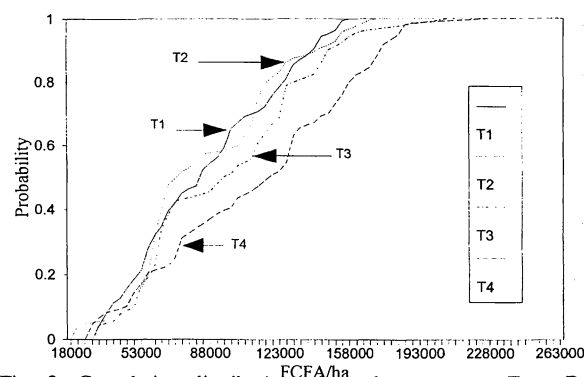


Fig. 2. Cumulative distribution of sorghum returns, Zone B, 1989–91.

curves for all treatments intersect frequently, especially under low yield conditions (see Fig. 2 for an example). The stochastic dominance comparisons show that the commercial fertilizer treatment is in the risk averse category for all three crops in all zones (Table 2), but only three of the eight cases are the result of statistically different distributions.

Unlike grain yield comparisons, the cash return analysis does not place the control in the dominated category in every case. T1 is in the risk averse category for sorghum in zone B because its minimum value is larger than the minimums for the fertilizer treatments. In Fig. 2 this is shown by the fact that T1 intersects the horizontal axis to the right of the other distributions. In a stochastic dominance comparison the distribution with the largest minimum cannot be dominated. T1 in the risk neutral category for millet in zones A and C, and for maize in zone C.

For the cash return distributions, advantages of the no fertilizer treatment shows up in low yield seasons. Fertilizer must be applied before the season's rainfall and other factors are known. As a consequence, cost are incurred, even if lack of rainfall or other constraints limit fertilizer response. If yields are limited by weather, the fertilizer response is small, but the cash returns for the fertilizer treatments are less than that of the control because of the fertilizer cost.

The case of returns to the rock phosphate treat-

ments (T2, T3) is more complex than that of the commercial fertilizer (T4). The rock phosphate treatment (T2) is dominated for millet in all zones and for sorghum in zone C.

Only in the case of sorghum in zone C is this domination the result of a comparison between statistically significant distributions. T2 is in the risk averse category for sorghum in zone A and maize in zone B. T2 is in the risk neutral category for sorghum in zone B and maize in zone C.

T2 is not dominated by the first stochastic dominance rule for sorghum in zone B because the T2, T3 and T4 distributions intertwine at about 53 000 FCFA (Fig. 2).

In the analysis of monetary returns, the partially acidulated rock phosphate (T3) is dominated for millet in zone A and maize in zone B. T3 is in the risk averse category for millet and sorghum in zone B and maize in zone C. T3 is in the risk neutral category for sorghum in zone A and C, as well as for millet in zone C.

For the monetary income objective, the benefits of commercial fertilizer are relatively clear. T4 is always potentially acceptable to risk aversion decisionmakers. The rock phosphate results are less clear. The distributions of T2 and T3 intersect frequently with the T1 distribution. For example, for sorghum in zone B, the T1 and T2 curves cross four times and even at relatively high income levels, they are not well separated (Fig. 2). The T1 and T3 curves for

Table 2

Risk categories for the monetary return objective for technologies tested by the Food Crops Fertilizer Project, Burkina Faso, 1989–91, by crop and agro-ecological zone

Zone and Crop	T1	T2	T3	T4
Zone A, Millet	risk neutral	dominated	dominated	risk averse
Zone A, Sorghum	dominated	risk averse	risk neutral	risk averse
Zone B, Millet	dominated *	dominated	risk averse	risk averse **
Zone B, Sorghum	risk averse	risk neutral	risk averse	risk averse
Zone B, Maize	dominated *	risk averse	dominated	risk averse **
Zone C, Millet	risk neutral	dominated	risk neutral	risk averse
Zone C, Sorghum	dominated *	dominated *	risk neutral	risk averse **
Zone C, Maize	risk neutral	risk averse	risk averse	risk averse

* Treatment dominated in a comparison between distributions that are statistically different at the 5% level using the Kolmogorov–Smirnov test.

** Treatment undominated in all comparisons and dominates in the first degree in at least in one case in a comparison between distributions that are statistically different at the 5% level using the Kolmogorov–Smirnov test.

sorghum in zone B cross three times, but beyond 71 000 FCFA ha⁻¹ the T3 distribution is to the right.

5. Conclusions

The stochastic dominance shows that among the four treatments tested, commercial NPK fertilizer has the most desirable risk characteristics. The commercial fertilizer (T4) is in the risk averse category for the food self sufficiency criteria and for the monetary returns objective for all three crops considered and for all climatic zones. The K–S test indicates that the comparison of the commercial fertilizer treatment and the no fertilizer control is relatively robust.

The no-fertilizer control is largely dominated by the fertilizer treatments. For the food self-sufficiency objective the control is dominated in every comparison. For the cash return comparisons, the control has the advantage of limiting costs in cases when yields are constrained by weather. In that case, the yield response is small, but the fertilizer treatments have higher costs and hence lower net returns.

The rock phosphate treatments (T2, T3) have better yields and in certain cases higher returns than the control, but those benefits are less sure than for the soluble commercial fertilizer. From a cash return point of view, the rock phosphate treatments offer few advantages. The distributions of cash returns to the rock phosphate treatments are rarely significantly different from those of the control. The T2 and T3 distributions intersect each other frequently, as well as crossing the T1 curve. The rock phosphate treatments never dominate the commercial fertilizer treatment.

It should be noted that this analysis compares the risk characteristics of three fertilizer application strategies with the no fertilizer option. The risk of fertilizer application on cereals relative to the risk inherent in the farmer's other activities (livestock raising, commerce, etc.) has not been tested. The interaction of risk and other decision factors (labor constraints, capital availability, etc.) has not been examined. In addition, the trials focused on first year effects of one commercial fertilizer mix did not compare risk across various soluble fertilizer compositions or carryover effects.

In general, the analysis shows that risk associated with use of soluble commercial fertilizer is less than that of rock phosphate. The rock phosphate treatments showed yield increases, but the effect was less sure than for the commercial fertilizer. If farmers had a choice between the commercial fertilizer, rock phosphate and partially acidulated rock phosphate, at current prices most of those who use fertilizer would choose the commercial product. If the availability of commercial fertilizer is limited in Burkina Faso (for example, by lack of hard currency), some farmers would use rock phosphate, especially the partially acidulated product.

Stochastic dominance permitted a timely, but detailed analysis of the risk inherent in the phosphate fertilizer alternatives tested. The availability of spreadsheet templates facilitated use. A stochastic dominance analysis permits researchers to communicate to extension staff and policymakers not only the degree of risk, but also something about the characteristics of the crop response that contribute to risk. For example, if a fertilizer treatment is risky primarily because of monetary losses in a few low yield situations, policymakers can judge whether that is important enough to block an extension effort. Alternatively, they might choose to design a program targeted to minimize the effects of this risk. The key to effective use of stochastic dominance in farming systems research is careful study of the distributions and understanding why a technology is dominated or is potentially acceptable to risk averse decisionmakers.

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