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Economic profitability and risk analyses of improved sorghum varieties in Tanzania

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This study uses survey data collected in 2012/2013 farming season to determine the net-returns and utility-efficient farm management practices for improved sorghum varieties adopted by small-scale farmers in Tanzania. The reference farm management practice was using JEMBE (handhole) for land cultivation and growing local varieties (landraces). Other farm management practices included using ox-plough for land cultivation with or without applying manure for soil amendment, and using JEMBE for land cultivation with or without applying manure. Improved sorghum Varieties included Tegemeo, Pato, Macia, Wahi, Hakika, Mtama-1, and Sila. We used simulation and bootstrapping to estimate yield distributions and net returns and stochastic efficiency with respect to a function to complement first and second degree stochastic dominance analyses to determine varieties and farm management practice that reduce production and price risk. Under profit maximization and risk reduction assumptions, main results show that Macia and Mtama-1 varieties have high mean yield and low yield variability. Even under low inputs and extreme risk averse farmers, Macia and Mtama-1 were superior choices. Value addition activities increased price offered to farmers, which also reduced price risk.

Key words: Economic profitability, risk analysis, sorghum, stochastic dominance, Tanzania.

INTRODUCTION

Sorghum (*Sorghum bicolor* L. Moench or Mtama in Swahili) is one of the five most important cereal crops in the world. It is has adapted to a wide range of soil conditions, ranging from sandy to water logging and to residual moisture, and from salinity to extremely low soil pH. Because of its broad adaptation, the Association for Strengthening Agricultural Research in East, and Central Africa (ASARECA) categorize sorghum as one of the climate change ready crops (Kimenye, 2014). The great advantage of sorghum is that it can become dormant under adverse conditions and can resume growth after relatively severe drought. Early drought stops growth before floral initiation and the plant remains vegetative; it will resume leaf production and flower when conditions again become favorable for growth. Late drought stops leaf development but not floral initiation. Rohrbach et al.

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(2002) show that sorghum is the second most important staple food after maize, which benefits more that 80% of Tanzanians. The crop is predominant in the central plateau of Dodoma and Singida regions. Other regions with significant sorghum production include Tabora in Western Zone; Shinyanga, Mwanza and Mara in the Lake Victoria region. Regions in the Northern Tanzania (Arusha, Kilimanjaro, and Manyara) are increasingly integrating sorghum in the farming system to mitigate and adapt to the consequences of climate change and to address recurring food shortages resulting from crop failures.

Almost 85% of the sorghum produced in Tanzania is for food consumption at the household level. Non-food industrial use is relatively underdeveloped. Depending on available rainfall, production is occasionally less that demand. Over the last 20 years, average sorghum grain yield in Tanzania have ranged from 442 kg/ha (in 2003) to 1,310 kg/ha (in 2010) (Kombe, 2012). The low average sorghum yield is attributed to low soil fertility, bird damages, Striga weed infestation, use of cultivars with low yield potentials, and socio-economic factors that constrain farmers' access to improved seed. There is a potential of increasing yield from their current low levels through the adoption of improved varieties and improved soil fertility and water management practices (Mgonja et al., 2005). While sorghum utilization is mostly for food purposes, composite flour of sorghum /wheat/cassava produces several value-added products for home consumption and marketing. Sorghum grains are also a source of industrial starch and are important component of processed animal and poultry feeds. Currently, the brewery industries in Tanzania are using sorghum flower to produce lager beer and non-alcoholic drinks and using starch from sorghum for fermentation and bioenergy drink production (Rohrbach and Kiriwaggulu, 2007).

Sorghum research and development activities in Tanzania, trace back to the early 1980s. In that period, the International Crop Research Institute for Semi-Arid Tropics (ICRISAT) started collaborating with the Tanzania Ministry of Agriculture through the Department of Research and Development (DRD) as well as some Non-Governmental Organizations (NGOs). These entities collaborated in developing and evaluating sorghum varieties targeting the dry lowlands. Early efforts led to the release of three sorghum varieties namely Tegemeo, Pato, and Macia in 1978, 1997 and 1998, respectively (Mgonja et al., 2005). Two other varieties released in 2002 are Wahi and Hakika. Another variety released by ICRISAT and DRD in 2008 is NARCO Mtama-1 (or Mtama-1). In addition, a private seed company, Seed Co Tanzania Limited (SEEDCO), released Sila variety in 2008 (Monyo et al., 2004; MAFC, 2008).

The sorghum varieties selected by ICRISAT's and its partner are essentially drought tolerant crops with optimal utilization for human consumption, optimal value adding to produce animal feed and for baking and brewing. The crop is common among agropastoralists in Central and Eastern Tanzania where utilization of crop residues as animal fodders is also important. Furthermore, Tanzania is experiencing a dramatic agricultural policy changes and creating a favorable environment for accessing agricultural inputs. The sorghum seed subsidy scheme was started in 2010 to mitigate the constraint of improved seed adoption due to lack of certified seeds. This scheme is also allowing farmers to have access to improved sorghum seed at lower price. In the past, the modes of sorghum utilization were limited to food consumption at the household level. Due to several marketing initiatives, sorghum is entering the non-food and value adding markets as demanded by the baking, brewery, and animal /poultry feed industries. These value-adding activities require varieties with specific attributes in term of grain quality and other specific characteristics. For example, Macia, Tegemeo, and Mtama-1 varieties meet the specifications for brewing lager beer. Research and extension effort is geared towards linking the small-scale sorghum producers to this new market (Kombe, 2012).

One of the main objectives of this study was determining the economic profitability of improved sorghum varieties among small-scale farmers in the main farming systems in Central, Western, and Northern Tanzania. Economic profitability is particularly important issue for small-scale sorghum producers, as most sorghum production occurs in arid and semi-arid regions that have high rainfall variability. Breeding programs for improved sorghum varieties aim to reduce production risk by selecting drought tolerance and early maturing traits. Profitability analysis and risk assessment are both vital in determining potential for adoption and diffusion of selected varieties. We use stochastic dominance and stochastic efficiency with respect to a function (SERF) to test if improved sorghum varieties increase profitability, reduce production risk, or both. As demonstrated in Bryant et al. (2008) and Shankar et al. (2007), risk assessment using stochastic approach allows for comparison across farmers who plant different varieties and provide valuable insight from a single season of data. Results from this study will allow ICRISAT and DRD to test the validity of its new research strategy, and to identify efficient mechanism and adoption pathways to other mandate crops.

The format of this paper is as follows. The next section of this paper reviews recent literature on economic profitability and stochastic dominance analyses. The subsequent sections outline data collection methods and present data summary, results, and conclusions from the study.

Economic profitability and risk analyses

Most agricultural technologies are technically feasible but this is not a necessary condition for adoption by small-scale farmers. Profitability of available agricultural technology is a propelling factor during the adoption process. Therefore, it is important for research and extension programs to determine the profitability of new or improved agricultural technology under existing small-scale farmer's conditions. One approach is using partial budgeting, which is a simple and very helpful economic and management tool to use when determining the profitability of agricultural technologies at the farm level. Results from partial budgeting are useful in terms of comparing the costs and returns associated with small, specific, and limited changes in farm activities during the adoption process. The process involves tabulation of expected gains and losses from the adoption of new farming methods or practices. Therefore, a partial budget list consists of only those items of revenue and expenses that change after adoption of improved sorghum varieties. These measures include change in returns and costs associated with limited resources. The results provide a limited assessment of risk and suggest a range of prices or costs at which new farming methods or practices are profitable (Doupéa and Lymberyb, 2002).

The partial budgeting process answers the question "what would happen to farm profit if adoption occurs?" Results from the process help researchers, extension agents, and farmers to evaluate the economic effect of incremental changes of certain resources associated with the adoption process (Pitcher et al., 2013). With capital constraint, as is common under small-scale agriculture, higher returns may not be attractive if they require very much higher additional costs. For example, adoption of new agricultural technologies typically requires adopting a package of complimentary inputs such as inorganic fertilizers and small-scale farmers always consider these additional costs in their adoption decision-process. Thus, it is necessary to compare the extra (or marginal) costs with the extra (or marginal) net benefits by estimating marginal rate of return (MRR) that measures the increase in net profit associated with each additional unit of cost. This will determine if the new technology costs more than the farmer's present technology or if the new technology yields more returns than the present one for a comparatively higher cost (Kaliba et al., 2000).

Partial budgeting can therefore be a great tool for looking at a change that only affects one or two areas of production practices. However, this tool also has its limitations. If the results are positive, a partial-budget analysis does not tell you if it occurs because of a change in hard numbers, such as the cost of improved seeds, or soft numbers, such as an increase in the rate of gain. Partial budgeting looks only at one area and does not address the question of whether the change was the best use of limited resources (Swinton and Lowenberg-Deboer, 1998). Moreover, partial budgeting results are not additive and do not look at other areas of the farm activities that may change and affect the budget. Employing sensitivity analysis mitigates some of the limitations as noted by Saltelli et al. (2000) and Boyer et al. (2011); however, results are not good at projecting the future. Sensitivity analysis is only useful when attempting to determine the impact of uncertainties of a variable on adoption outcome. For example, sensitivity analysis could determine the impact of yield, input, and output prices variability on profit and breakeven point.

While partial budgeting is a first step in risk assessment, the procedure cannot make a robust comparison for two distributions. In risk assessment, it is important to check whether profitability distribution of advocated agricultural technology always dominates the existing technology. This is because, for sorghum producers, income and yield stability is an important aspect of the adoption process (Belaya and Bewket, 2013). Profitability and yield distribution of improved varieties must dominate local varieties especially during low rainfall season. This is a fundamental concern for a farmer who is choosing among risky alternatives. To address this issue, Stanger et al. (2008) suggest using stochastic dominance analysis, a graphical tool that checks whether the profitability or yield of improved varieties dominates local varieties under different management practices. That is, improved varieties are always superior under all circumstances. If applied, the technique identifies conditions under which one risky outcome would be preferable to another (Lambert and Lowenberg-DeBoer, 2003).

Essentially, stochastic dominance analysis involves comparing cumulative distribution functions (CDF) of economic profitability measures or yields of improved varieties and local varieties under different management scenarios. The basic assumption is that one or the other technology must be adopted and not a convex combination of both (Hardaker et al., 2004). Here x is a random variable representing each level of net returns, or yield for crop management alternatives such that $f(x)$ is the probability density function (PDF) associated with adoption of improved seeds and $g(x)$ is the probability density function associated with non-adoption (growing local/traditional varieties). Under the first-degree stochastic dominance (FSD) conditions and using the assumption that more is preferred to less; implies that for $f(x)$ to dominate $g(x)$, the cumulative probability of distribution (CDF) of $f(x)$ must always lie on or to the right of the cumulative probability distribution (CDF) of $g(x)$. In other words, improved crop varieties always outperform local varieties (in terms of net returns or yield) and the two distributions never cross, which may not be true (Barrett et al., 2004).

The second-degree stochastic dominance (SSD) invokes the assumptions that a farmer has both positive and diminishing marginal utility. These assumptions mean that for $f(x)$ to dominate $g(x)$, the area under the CDF of $f(x)$ must be smaller than the area under the CDF of $g(x)$. This assumption allows the two-cumulative distribution to cross if the difference in the area before they cross at low distribution is relatively smaller compared to the difference in the area after they cross at upper distribution of the CDF (Barham et al., 2011). This implies that adoption does not necessarily reduce the probability of very low-net returns or yield outcomes but improved varieties dominate traditional varieties and therefore reduce production risk especially for small-scale farmers who are risk averse.

Comparatively, the FSD simply assumes that producers prefer higher net returns (higher yield) to lower net returns (lower yield), and that decision-makers have absolute risk aversion ($r_a(x)$) with respect to net return or yield. The absolute risk aversion coefficient (ARAC) is estimated as $r_a(x) = -U''(x)/U'(x)$, which represents the ratio of the second and first derivative of the farmer's utility function (Pratt, 1964) and the relative risk aversion coefficient ($r_r(x)$) is ($r_r(x) = xr_a(x)$). The SSD, is therefore a more restrictive approach and assumes that decision-makers are risk averse by restricting the bounds of absolute risk aversion with respect to x to be between $0 \leq r_a(x) \leq +\infty$ (Hardaker et al., 2004). The drawback is that given the wide range of absolute risk aversion, the alternative(s) that represent the preferred choice within a given bound can still be too large to be easily manageable (King and Robison, 1984). Other inherent limitations of stochastic dominance are as summarized in Bryant et al. (2008).

Anderson (1974) and Meyer (1977) proposed stochastic dominance with respect to a function (SDRF) as an alternative to FSD and SSD. They propose limiting the absolute risk aversion coefficients between arbitrary lower and upper bounds such that $r_l(x) \leq r_a(x) \leq r_u(x)$, where r_l and r_u are chosen by an individual conducting the research. The ranking of risky scenarios is defined for all decision makers whose lower absolute risk aversion function lies anywhere between lower and upper bounds $r_l(x)$ and $r_u(x)$, respectively. These lower and upper bound functions can be any function of x, although in practice these bounds are often constants with no other assumption on risk aversion (Meyer et al., 2009). The method has stronger discriminatory power than FSD and SSD, because of the introduced tighter risk aversion bounds. The SDRF approach eliminates inefficient alternatives by determining the risk aversion measure $r_a(x)$ that lies between the lower and upper bounds, which minimizes the difference in expected utility ($E(U(x)_F)$-$E(U(x)_G)$), from alternatives $f(x)$ and $g(x)$. When the expected utility difference is non-negative, then, $f(x)$ is preferred or indifferent to $g(x)$ by all decision makers, and elimination of $g(x)$ from a set of alternatives is appropriate. When the value for the expected utility difference is negative then, the decision maker with risk aversion measure $r_a(x)$, prefer $g(x)$ to $f(x)$ and alternative $g(x)$ is not eliminated (Meyer et al., 2009).

However, SDRF may often results in ambiguous rankings and the results tend to depend on the selected value of the lower (r_l) and upper (r_u) bounds. Barham et al. (2011), Hignight et al. (2010) and Hardaker et al. (2004) suggest using stochastic efficiency with respect to a function (SERF) to complement stochastic dominance analysis while taking advantages offered by SDRF. Using risk aversion bounds, SERF works by identifying utility efficient alternatives for ranges of risk attitudes and not by finding (a subset of) dominated alternatives. Therefore, SERF partitions alternatives in terms of certainty equivalent (CE) as a selected measure of risk aversion that varies over a defined range. Based on the specified utility function, CE is the amount of net returns necessary to make the decision-maker (the farmer) indifferent to the available alternatives.

While both SDRF and SERF compare risky prospects for a range of degrees of risk aversion between specified lower and upper bounds, SERF imposes an additional restriction by holding the measure of risk constant as the level of outcomes (x) changes; thereby, potentially contracting the efficient set. The procedure provides a more restrictive approach to compare risky alternative by evaluating technology dominance across a wide range of plausible risk preferences. The technique allows ordering alternatives agricultural technologies in terms of CE values within a range of risk-aversion coefficients. The method does not attempt to pinpoint risk aversion levels elicited by experimentation or estimation to categorize alternatives; rather, it takes risk aversion levels as given and presents a class of rankings based on categories of decision makers within ranges of risk aversion for a given utility function (Meyer et al., 2009).

For SERF, certainty equivalents are estimated assuming different risk aversion coefficients as outlined in Hardaker et al. (2004). For a small-scale farmer, a reasonable agreement is using a negative exponential utility function as it has a concave slope, which characterizes risk-averse farmers (Babcock et al., 1993). The relationship among the utility function $U(x)$, the absolute risk aversion coefficient ($r_a(x)$), and the relative risk aversion coefficient ($r_r(x)$) is as explained above. For a sample of size n from a risk alternatives x (different farm management practices) with i outcomes (yield of different varieties or net-returns from different varieties), certainty equivalent (CE) is estimated as follows:

$$CE(x, r_a(x)) = -\frac{1}{r_a(x)} \ln\left\{\left(\frac{1}{n}\sum_i^n \exp(-r_a(x)x_i\right)\right\} \qquad (1)$$

Anderson and Dillon (1992) suggests using relative risk aversion that range from 0 for risk neutral to 4 for highly risk averse farmer. The $r_a(x)$ are obtained by dividing the range of $r_x(x)$ with the estimated expected returns from the reference technology. The graphical relationship between the CE and the absolute risk aversion coefficients depicts the dominance of one technology relative to another technology, using the reference technology as a benchmark. The decision rule for SERF is to rank the risky alternatives (within the decision-makers' specified risk aversion coefficient) from the most preferred (the highest CEs at specified levels of risk aversion) to the least preferred (the lowest CEs at specified levels of risk aversion). The risk premium is the difference between the CE of dominated/inferior technology and CE of the dominant technology.

METHODOLOGY

Source of data

The data for this analysis is from a sampling survey conducted by Selian Agricultural Research Institute (SARI), Arusha, Tanzania in collaboration with ICRISAT, Nairobi, Kenya. The main author developed the structured questionnaire used in the study. The questionnaire was reviewed during a two-days enumerator-training workshop organized by the main author in May 2013. Twenty-five extension agents working in major sorghum farming systems and three scientists from ICRISAT participated in the workshop. After the workshop, the questionnaire was pretested in Singida Rural (Central Tanzania) and Rombo Districts (Northern Tanzania). Results and problems arising from questionnaire pretesting created the guidelines in refining the final survey instruments used in the study, that is, the village level instrument and the household level instrument.

The selection of participating districts from five regions (Dodoma, Kilimanjaro, Manyara, Singida, and Shinyanga) accounted the intensity of sorghum production and importance of sorghum in the farming system. The districts included Iramba, Singida Rural, and Manyoni districts (Singida Region), Kondoa District (Dodoma Region), Babati District (Manyara Region), Rombo District (Kilimanjaro Region), and Kishapu District (Shinyanga Region). From each district, two Wards (and one village from each ward) were randomly selected from these seven districts[1]. The sample includes fourteen Wards and fourteen villages. To create a representative sample of adopters, it was predetermined that 60% of responding households would be that planted at least one improved sorghum variety during the 2012/13 farming season. For statistical analysis, the sample size per village was predetermined to be at least 50 households. About 822 households participated in the survey, of which 505 were adopters (61.44%) and 317 nonadopters (38.56%). Previously trained enumerators collected the data and respondent was a knowledgeable farmer at the household level.

The village-level survey instrument solicited information on availability of extension and marketing services and supportive agricultural infrastructures at the village level. The respondents were a group of informants including village leaders, extension agents and government and NGOs representatives. The same group estimated labor input and cost for the sorghum enterprise based on their experience. This method was preferred to reduce the size of the questionnaire and recall bias on input use. The household-level instrument has several sections to collect data that linked the households to the village identifiers. Other sections recorded data on price, yield, and other variable costs associated with each stage of sorghum production from land cultivation to transportation and storage activities.

Data analyses

To conduct partial budgeting and stochastic dominance analysis the following facts were considered. Local varieties and using JEMBE (handhole) for land cultivation was the reference farm management practice. In the study area, the main farm management practices that influenced yield included the use of ox-plough for land cultivation and application of farm yard manure on sorghum field. Therefore, farm management technologies include using ox-plough for land cultivation and applying manure for soil amendment, using ox-plough for land cultivation but without manure application, using JEMBE for land cultivation and applying manure, and using JEMBE for land cultivation without manure application. For partial budgeting, incremental costs are from weeding frequency, and bird scaring. Other costs were determined based on land preparation methods and type of varieties planted. Very small farmers (less than 1%) reported using inorganic fertilizer and chemicals such as herbicides, fungicides, and insecticides. These variables were therefore not included in partial budgeting and economic analysis. Improved sorghum varieties were Tegemeo, Pato, Macia, Wahi, Hakika, Mtama-1, and Sila. All other local varieties were grouped as local varieties/landraces.

To increase variability and statistical tractability, variables used in partial budgeting and stochastic dominance analysis were generated through random simulation of observed variables using a bounded normal distribution function (Trautmann et al., 2014). Particularly, stochastic features were incorporated by utilizing the observed minimum and maximum values and estimated sample mean and the standard deviation to generate a random variable with 1,000 observations. The stochastic depended variables included yield and price received by farmers, price of seed, and cost of labor. The generated random variables were used to estimate revenue, cost, and net returns. Bootstrapping (Efron, 1979) with replacement was also conducted to estimate the distribution of yields and net-returns for each variety in each of the farm management practice. In this case, farmers are profit maximizer and face stochastic output and input price. Profit distribution from each crop variety is modelled from the following profit equation:

$$E(NR)=E(P_o)E(Y)-Q_sE(P_s)-Q_lE(w)-FC \qquad (2)$$

In Equation 2, $\boldsymbol{E(.)}$ is expectation operator, $\boldsymbol{NR}$ is net-returns, $\boldsymbol{P_o}$ is output price, $\boldsymbol{Y}$ is yield, $\boldsymbol{Q_s}$ is quantity of seeds, $\boldsymbol{P_s}$ is price of seeds and $\boldsymbol{Q_l}$ is quantity of labor, $\boldsymbol{w}$ is wage, and $\boldsymbol{FC}$ is fixed cost. For comparison purposes, fixed cost is constant across varieties within a given farm management practice and drop-out during the analysis.

Performing SSD and FSD required generating empirical cumulative density functions (ECDFs) representing stochastic variables from each farm management practice. When generating ECDFs for continuous random variables, there is a potential of producing negative values for the distribution function. To avoid negative values the realized value of each stochastic variable formed irregularly spaced grid. This allowed producing a continuous distribution function by linear interpolation over vertices of that grid; that is, over the observed lowest and highest values of the variable. Certainty Equivalent for each improved sorghum variety (and for each management practice) was estimated using Equation (1). The $r_r(x)$ ranged from 0 for risk neutral to 4 for highly risk averse (Anderson and Dillon, 1992). The $r_a(x)$ were obtained by dividing a range of $r_r(x)$ with estimated value of expected (mean) yield or net-returns of the reference technology. Generally, the expected value of a continuous random variable ($\boldsymbol{x}$) that is bounded between $\boldsymbol{a}$ and $\boldsymbol{b}$ and with the probability density function f_x can be estimated through numerical integration as follows:

$$E(x)=\mu_x=\int_a^b xf_x(x)dx \quad for\ a\le x\le b. \qquad (3)$$

[1] Tanzania is administratively divided into Regions, Districts, Wards, and villages. Therefore, the Village is the lowest administrative unit.

Table 1. Land allocation to sorghum varieties for the 2012/13 farming season.

Varieties	*N*	Sorghum varieties		Total acreage		Proportion of land to improved seeds	
		Hectare	St. Dev	Hectare	St. Dev	Mean	St. Dev
Adopters (N=505)							
Tegemeo	96	0.65	0.10	2.67	1.45	0.33	0.25
Pato	46	0.81	0.74	2.78	0.96	0.32	0.27
Macia	278	0.94	0.52	1.91	0.54	0.64	0.53
Wahi	35	0.75	0.56	2.77	1.06	0.34	0.25
Hakika	32	0.83	0.13	1.62	0.54	0.61	0.36
Sila	22	0.72	0.38	2.27	0.91	0.42	0.3
Mtama-1	71	0.65	0.24	2.37	0.69	0.34	0.28
Nonadopters (N=317)							
Langalanga	55	0.85	0.18	2.82	0.84	0.48	0.29
Other cultivars	273	0.75	0.14	2.67	0.85	0.35	0.26

N is the numbers of households, and St. Dev is the standard deviation.

In Equation 3, $E(x)$ is the expectation operator. One way to proceed is to first create two data vectors of x and associated geometric probabilities $f_x(x)$ then multiply and sum the product. We developed several scripts, which were implemented in R environment (R Core Team, 2016) that were efficient in estimating Equations 1 through 3.

To compare different management practices, we used the Welch's t-test (Welch, 1947) to perform equal mean test. The test was performed at 5% level of significance. The test is a two-sample location test used to test the hypothesis that two populations have equal means and accounts for unequal variance. Test of significance for the hypothesis is that the mean difference is equal to zero and the alternative hypothesis is the true difference in means is not equal to zero. We also used the Levene-test (Levene, 1960) at 5% level of significance, which is used to test if two or more samples have equal variances. The Levene-test tests the null hypothesis that the population variances are equal (that is, homogeneity of variance or homoscedasticity). It is an alternative to the Bartlett test (Bartlett, 1937); however, the Levene test is less sensitive than the Bartlett test to data that are not normally distributed. The Bartlett test has a better performance for data that come from a normal or nearly normal distribution. For this study, simulations, bootstrapping, graphics, and data analyses were produced and conducted using user defined functions in R software (R Core team, 2016). The data and R scripts used in the study are available upon request.

RESULTS AND DISCUSSION

Stochastic partial budgeting and marginal analysis

Table 1 shows land allocation to sorghum production by sample households. In Table 1, total acreage is the total land allocated to cereal production in 2012/2013 farming season, with farmer primary growing sorghum varieties, but also maize, different types of legumes, and other crops. The estimated average land allocated to cereal production was 2.43 ha with standard deviation of 0.87 ha. Land allocated to cereal production by adopters and non-adopters were 2.34 and 2.75 ha with the standard deviations of 0.88 and 0.85 ha, respectively. The t-test results indicate that non-adopters had more land allocated to cereal production compared to adopters at 1% significance level. From Table 1, on average, adopters allocated 43% of the land to improved sorghum varieties with a standard deviation of 32%.

Results in Table 1 also shows that majority of farmers cultivated a single variety rather than a combination of different varieties. The widely adopted improved sorghum variety was Macia. About 55% of the adopters planted the variety. Tegemeo variety was second as was planted by 19% of adopter households and Mtama-1 was third, which was planted by 14% of the adopter group. Land allocated to improved sorghum varieties was high for adopters of Macia and Hakika varieties that respectively allocated 64 and 67% of the cultivated land to the two varieties. Hakika and Macia adopters have relative smaller land holdings in terms of land allocated to cereal production in the 2012/2013 farming season. For adopters, farmers with small land holding, depended more on improved sorghum varieties for cereal production compared to other farmers.

The estimated labor costs for important sorghum production activities are presented in Table 2. The highest cost was on manure application followed by land cultivation using ox-plough, bird scaring, and transportation and other activities. Other high cost activities include land preparation using JEMBE (hand-hole), weeding in broadcasted plot, weeding in line-platted crop, and harvesting and threshing. In the study are, differences in farming methods include using JEMBE or ox-plough in land preparation, using line planting or broadcasting of seeds that also influence manure application and weeding cost. Therefore, using JEMBE and ox-plough as land preparation tools are major technical differences between the farmers. The benefits

Table 2. Estimated labor cost for main farm activities in the study area (Tshs/ha).

Activity	Mean	Standard deviation
Land cultivation using JEMBE (hand-hole)	115,541	83,484
Land cultivation using ox-plow	138,722	62,243
Primary and secondary tillage	44,425	27,209
Seed broadcasting	15,187	4,571
Line planting	38,259	21,775
Fertilizer broadcasting	14,858	4,685
Manure application/broadcasted plot	179,421	171,447
Manure application/line planted plot	50,810	64,292
Weeding/line planted plot	107,711	47,689
Weeding/broadcasted plot	112,020	69,960
Herbicide and pesticide application	43,649	28,494
Bird scaring	132,705	100,372
Harvesting and threshing	85,375	37,535
Transportation and others	122,562	90,448

Tshs is Tanzania shillings. The average exchange rate was $1 per 1,200 Tshs in 2013.

Table 3. Sample estimates on average yield, price, and cost variables in the study area.

Variables	Tegemeo	Pato	Macia	Mtama1	Wahi	Hakika	Sila	Local
Using ox-plough for land cultivation (N=321)								
Yield with manure	1,889	2,788	2,992	2,820	2,614	2,609	2,386	1,570
Standard deviation	187	203	256	274	197	299	151	76
Yield without manure	1,259	1,394	1,580	1,410	1,307	1,087	1,193	654
Standard deviation	312	338	466	498	359	499	301	138
Using JEMBE technology (N=501)								
Yield with manure	1,962	2,453	2,528	2,482	2,396	2,150	2,290	1,046
Standard deviation	163	210	249	210	221	275	217	66
Yield without manure	1,117	1,115	1,264	1,128	1,198	1,075	1,145	523
Standard deviation	326	350	453	350	442	458	362	110
Other variables								
Sorghum price	562.1	473.0	562.5	651.9	520.6	525.6	531.8	612.5
Standard deviation	29.39	30.84	31.25	42.00	65.8	68.15	67.14	57.11
Seed cost	12,381	10,690	8,221	10,231	9,200	9,150	15,000	9,622
Standard deviation	279	264	289	177	257	393	147	236

Standard deviation are for respective variables. The estimate is from sample households. Yields are in kg/ha, price is in Tshs/kg, and seed costs is in Tshs/ha.

of using ox-plow are that the farmer has time to plant and weed the crops early thus improving yield and productivity. From farmer's experience, in sorghum fields where JEMBE is a tool for land cultivation, usually the yield is less when compared to sorghum fields that where ox-plowed. In addition, farmers who use JEMBE for land cultivation has higher incidence of weeds and have to weed the field twice to control weed infestation. The weeding cost for JEMBE technology is therefore 50% higher compared to the ox-plow technology.

Table 3 shows average yield and price, and other cost as reported by sample households. In the table, for each farm management practice, yield of all improved varieties were relatively high compared to local varieties. The yield of improved sorghum varieties were as low as 1,087 kg/ha for ox-plough technology and 1,075 kg/ha for JEMBE technology alone (Hakika variety) to as high as 2, 992 kg/ha (Macia variety with ox-plough with manure application). This is compared to low yield of 523 kg/ha for local varieties under JEMBE without manure application. The yield of local varieties increased substantially with manure application to about 1,046 and 1,579 kg/ha for JEMBE with manure application and ox-plough with manure application applications, respectively. For improved sorghum varieties, Macia recorded the highest yield in all farm four management practices, followed by Mtama-1 for ox-plough with and without manure application and JEMBE with manure application. Hakika recorded the lowest yield for ox-plough technology and Tegemeo for JEMBE technology. For JEMBE without manure application, the second-high yielding improved variety was Wahi. Average yield of Tegemeo variety was related low compared to other varieties. Despite having lower yield, local varieties have small standard deviation, which implies lower risk in terms of yield variability. For improved varieties, Hakika has the largest standard deviation for both technologies and Tegemeo has the lowest standard deviation.

The farmers also reported quantity of seed sown, area planted, and unit price that were used to estimate seed cost per hectare as shown in Table 3. The seed cost ranged from 8,221 Tshs/ha for Macia variety to 15,000 Tshs/ha for Sila variety. Seed price usually depended on distribution channel, specifically on transportation cost. Sila variety is distributed by Seed Co Limited based in Zimbabwe. Other varieties are produced and distributed by seed companies/institutions based in Tanzania. Differences in distribution cost may account for the high price of Sila variety seeds. The results in Tables 1, 2, and 3 indicate that majority of farmers prefer high yielding varieties (Macia and Mtama-1) followed by varieties with low yield variability (Tegemeo). Results in Table 3 also show that price received by farmers varied across varieties, attributable to market demand and taste and preferences. Farmers growing Mtama-1 received the highest price (652 Tshs/kg) followed by Macia (562.50 Tshs/kg) and farmers growing Pato variety received the lowest price of 473 Tshs/kg. Mtama-1 grains are suited for food and brewing due to high percent extract (above 82%) and low nitrogen contents (less than 2.0%). The grain has no tannin, therefore can be used in poultry feed production. Macia grain utilizations include multiple food uses such as porridge, in composite flour for bread (20% sorghum, 80% wheat) and in biscuits and pasta (50% sorghum, 50% wheat flour). Also, Macia grains are suitable in the production of livestock feed, especially poultry feed. Mtama-1 and Macia grains have alternative market channels that are increase demand and therefore price received by farmers. Also, local varieties received higher price (612 Tshs/kg) when compared to other improved varieties. For improved varieties and for farmers producing at the subsistence level; taste and preference of consumers determine price received. In the study area, local varieties are superior in term of the two attributes.

Estimated net-returns by land cultivation method and manure application are as shown in Table 4. Net-returns is the difference between revenue and total cost and is calculated based on per-hectare basis. Revenue is estimated as a product of yield and price received by farmers after accounting for variability in both yield and price through Monte-Carlo simulation (Equation 2). In Table 4, labor cost was estimated using the data reported in Table 2, basing on farm activities applicable to each farm management practice also considering variability through Monte-Carlo simulation. Revenue (yield x price) and total cost (seed cost plus total labor cost) were obtained through stochastic simulation and budgeting. Marginal return is the percent increase in total revenue relative to percent increase in cost when moving from growing local varieties with JEMBE as a main method for land cultivation (reference technology) to other farm management practices. Notice that large variation in net returns occurs between farm management practices and varieties primarily due to yield, farm get price, and differences in labor use.

Except for net-returns from ox-plough with manure application, the landrace/local varieties recorded negative net-returns (Table 4). Moving from JEMBE alone to other technologies, however, minimized losses. Other varieties that registered negative net-returns were Pato variety under JEMBE without manure application and Hakika variety under ox-plough with manure application. Results in Table 4 also show that Macia and Mtama-1 varieties performed better in generating high net-returns compared to other improved Varieties. Net-Returns ranged from 159,000 Tshs/ha (JEMBE without manure application) to 1,246,000 Tshs/ha (Ox-plough with manure application) for Macia. Similarly, net returns for Mtama-1 ranged from 84,000 Tshs/ha to 990,000 Tshs/ha. These results can be attributed to relative high yield recorded by the two varieties and relatively high price received by farmers. Wahi and Hakika varieties and Wahi and Sila varieties were second group in terms of generating positive net-returns when compared to other improved varieties the ox-plough/manure and JEMBE/manure technologies. Hakika and Pato varieties performed poorly and recorded negative net-returns for ox-plough and JEMBE without manure application. Though relatively low compared to other varieties, net-returns from Sila, Wahi, and Tegemeo were consistently positive and increasing. Local varieties recorded positive returns with ox-plough with manure applications and other management practices minimized loses when compared to the reference farm management practice (JEMBE without manure application).

The estimated average marginal returns for improved varieties under JEMBE without manure application was 7.32 percent and for ox-plough without manure application, JEMBE with manure application, and ox-plough with manure application were 6.96, 4.64, and 5.21%, respectively (Table 4). The highest marginal returns as shown in Table 4 was moving from the

Table 4. Estimated total revenue, total cost, and net-returns (1000 Tshs/ha).

Technology	Seed type	Total revenue	Seed cost	Labor cost	Total cost	Net returns	Marginal returns (%)
Ox-plough/manure	Tegemeo	1,056	12	797	809	246	3.74
	Pato	1,317	11	838	849	468	4.48
	Macia	2,136	8	882	890	1,246	7.30
	Mtama-1	1,840	10	840	850	990	6.81
	Wahi	1,365	9	830	839	525	4.84
	Hakika	1,366	9	830	839	527	4.84
	Sila	1,273	15	820	835	438	4.46
	Local	961	10	695	704	256	4.93
JEMBE/Manure	Tegemeo	1,099	12	774	787	313	4.26
	Pato	1,165	11	816	827	339	4.06
	Macia	1,426	8	861	870	557	4.69
	Mtama-1	1,613	10	815	826	787	6.22
	Wahi	1,261	9	808	817	444	4.66
	Hakika	1,134	9	807	816	318	4.04
	Sila	1,221	15	797	812	409	4.53
	Local	642	10	668	678	-35	2.84
Ox-plough	Tegemeo	714	12	547	560	154	10.32
	Pato	668	11	588	598	70	5.58
	Macia	892	8	632	640	252	6.42
	Mtama-1	941	10	589	599	343	9.85
	Wahi	680	9	581	590	90	6.29
	Hakika	575	9	580	589	-13	4.51
	Sila	632	15	570	585	47	5.77
	Local	400	10	514	523	-123	5.52
JEMBE	Tegemeo	627	12	525	537	90	13.05
	Pato	525	11	564	575	-50	4.31
	Macia	701	8	609	617	84	5.12
	Mtama-1	735	10	566	576	159	8.58
	Wahi	618	9	556	565	53	7.21
	Hakika	572	9	556	565	7	6.10
	Sila	588	15	546	561	27	6.91
	Local	319	10	490	500	-181	

All results are through simulation using Equation 2. The estimates are therefore from respective expected values and not arithmetic means (that is, in Equation 2 $E(x) = \sum xf(x)$).

reference management practice to adoption of Tegemeo variety (13.05%) that increased revenue from 319,000 Tshs/ha to 627,000 Tshs/ha (a 96.6% increase) and increased total cost from 500 Tshs/ha to 537 Tshs/ha (a 7.4% increase). Results in Table 4 also showed that ox-ploughing Tegemeo variety field generated the second highest marginal returns (10.32%). Other varieties that recorded substantial high marginal returns were Mtam1 for ox-plough without manure applications (9.85%), Mtama-1 (8.58%), and Wahi (7.21%) varieties under JEMBE without manure application and Macia (7.3%) under ox-plough with manure application. The lowest gains were Tegemeo (3.74%) under ox-plough and manure applications, and Hakika (4.04%) and Pato varieties (4.06%) under JEMBE manure farm management practices. These results imply that for poor farmers facing both limited resources and incremental cost constraint, adoption of Mtama-1 and Tegemeo is highly recommended. Farmers who are not facing incremental cost constraints, Mtama-1, Macia, and Wahi varieties are the best-bet varieties for adoption when compared to other improved varieties.

Table 5. Mean yield and variance comparison across farm management practices.

Variety	Mean yield	Standard error	Mean yield	Standard error	P-value equal mean	P-value equal variance
	Ox-plough/Manure		JEMBE/Manure		Significance test	
Tegemeo	1882.66	5.74	1958.78	4.99	2.69E-6***	0.0006***
Pato	2786.82	6.27	2458.08	6.70	0.03485**	0.1856
Macia	3796.19	7.96	2531.58	7.69	0.2629	0.2385
Mtama-1	2823.50	8.38	2480.75	6.61	0.0005***	0.0004***
Wahi	2612.55	6.28	2407.36	7.05	0.0006***	0.0003***
Hakika	2604.89	9.10	2161.68	8.68	0.1277	0.0717*
Sila	2388.96	4.57	2297.25	6.71	0.0002***	0.0006***
Landrace	1565.71	2.30	1048.17	2.01	0.0005***	0.0004***
	Ox-plough		JEMBE		Significance test	
Tegemeo	1266.58	9.74	1114.29	10.31	0.0446**	0.1014
Pato	1414.02	10.24	1111.13	10.96	0.1320	0.2087
Macia	1587.38	14.06	1246.08	14.07	0.8783	0.5931
Mtama-1	1440.99	15.58	1129.56	10.67	0.0006***	0.0002***
Wahi	1312.22	11.57	1190.31	13.94	0.0009***	0.0007***
Hakika	1092.43	15.92	1091.32	13.84	0.0006***	0.0005***
Sila	1180.04	9.30	1113.05	11.24	0.0009***	0.0007***
Landrace	654.10	4.20	520.12	3.48	0.0008***	0.0005***

Three, two, and one asterisk (s) implies significant at 1, 5, and 10% level of significance.

Distribution of yield and net-returns

The mean and variance tests on yield distribution by land cultivation methods and management practices are presented in Table 5 and graphically in Appendix 1. The ox-plough and manure application farm management practices were compared to JEMBE with manure application. Also, ox-plough without manure application was compared to JEMBE without manure application. In Table 5, the hypotheses are that mean yield of varieties from ox-plough with manure application is equal mean yield from JEMBE with manure applications or mean yield from ox-plough without manure application and mean yield from JEMBE without manure applications are equal. The probability values were estimated using the Welch's and Levene's t-test for respectively, the means and variances equality test. In Table 5, the means and variances that are statistically significantly different are denoted with asterisks. Statistical significance means that the null hypothesis stating that the compared means or the compared variances are the same is rejected. This means that there is significant statistical evidence to suggest that the means yield and the variances are different across respective farm management practices. For example, the means and variance for Tegemeo variety under ox-plough with manure application and ox-plough without manure application are statistically significant different. Farmers who grow Tegemeo in field cultivated by JEMBE and applying manure are more likely to get high yield and low yield variability compared to farmers who plant the same variety in ox-ploughed filed and apply manure. Standard error is the standard deviation divided by the square root of number of observations; an estimate of the standard deviation of the sample mean based on population mean. Since the standard deviation indicates the risk by showing just how the yield is spread, low value of standard error is preferred to larger value of standard errors.

Comparing ox-plough with manure application and JEMBE with manure application Pato variety had high yield under the former management practices but the spread or the yield distribution was similar across the two practices. The mean and distribution were similar for Macia variety. The varieties that shown statistically significant mean yield and differences in distribution across the two management practices were Mtama-1, Wahi, Sila, and landrace. All varieties indicated high yield under ox-plough with manure application. In both practices the landrace had the lowest standard error. Other varieties with lower standard error were Sila and Wahi varieties and ox-plough and manure application and Mtama-1 and Sila varieties with JEMBE but without manure application. For the two management practices Macia, Mtama1, and Hakika varieties are suitable for risk takers who focus only on yield outcome. Pato, Wahi, Sila, and Tegemeo varieties are for farmers who are relatively risk-averse and consider both yield and yield variability in the adoption process.

Comparative analysis results for mean yield and distribution from ox-plough without manure applications

Table 6. Mean net-returns comparison across different farm management practice.

Variety	Mean net return	Standard error	Mean net return	Standard Error	P-value equal mean	P-value equal variance
	Ox-plough/Manure		JEMBE/Manure		Significance test	
Tegemeo	246,398	3,645	312,716	3,270	0.0028**	0.0125*
Pato	468,467	4,120	338,931	3,977	0.4122	0.5349
Macia	1,245,839	5,685	556,827	4,866	0.0007***	0.0008***
Mtama-1	989,941	6,613	786,917	5,266	0.0005***	0.0004***
Wahi	525,279	6,195	444,020	6,231	0.6868	0.9320
Hakika	526,520	7,457	317,727	6,737	0.0002***	0.0012**
Sila	438,124	5,505	409,058	6,064	0.0012**	0.0030**
Landrace	256,371	3,717	-35,392	3,324	0.0002***	0.0001***
	Ox-plough		JEMBE		Significance test	
Tegemeo	154,008	5,521	89,742	5,943	0.0417*	0.1090
Pato	69,706	5,090	-49,643	5,318	0.1099	0.1136
Macia	251,865	8,109	84,193	8,039	0.8130	0.8658
Mtama-1	342,520	10,329	158,918	7,168	0.0005***	0.0009***
Wahi	90,100	6,558	53,119	7,581	0.0003***	0.0005***
Hakika	-13,246	8,761	6,631	7,629	0.0006***	0.0003***
Sila	46,868	5,646	27,119	6,394	0.0002***	0.0002***
Landrace	-123,221	2,832	-181,272	2,381	0.0008***	0.0007***

Three, two, and one asterisk (s) implies significant at 1, 5, and 10% level of significance respectively, using Welch-test for equal means and Levene-test for equal variances.

and JEMBE without manure application indicates that Mtama-1, Wahi, Hakika, Sila, and Landrace varieties were statistically significant different (have different mean yield and distribution). For this group of varieties, yield was relatively high and Mtama-1 and Wahi have relatively high mean yield under the two practices. The mean and yield distribution of Pato and Macia were relatively similar in both practices. The mean yield for Tegemeo under ox-ploughing was relatively high when compared to mean yield under JEMBE without Manure application. From these results, it can be concluded that manure application as a soil amendment tools highly increased marginal yield. However, the tradeoff between ox-ploughing and using JEMBE for land cultivation is less obvious.

Table 6 shows results on mean net-returns comparison across the four management and the interpretation is analogous to the result presented in Table 5. Varieties with similar net-returns distribution under ox-plough with manure application and JEMBE with manure application were Pato and Wahi varieties. For other varieties, the distributions were different (that is, mean and variance of net-returns were different). Under ox-plough and JEMBE without manure application, Pato and Macia varieties had similar distribution. Tegemeo variety has similar mean but different spread. Other varieties had similar distribution across the two farm management practices. Notice that the net-returns from Landrace under ox-plough with manure application may be superior to farmers with objectives of minimizing yield spread when compared to adopting improved seeds and ox-ploughing without manure application.

Stochastic dominance analyses

The CDFs from stochastic dominance analysis in Figures 1 and 2 were formed from the probability distribution of yield and net-returns of the different varieties under each farm management practice. Results for yield in Figure 1 indicate that under ox-plough and manure application, Macia variety is second-degree stochastic dominant to other varieties since its CDF lies below and to the right of other varieties. It is obvious in Figure 1 that all improved varieties dominate the landraces or local varieties. Tegemeo variety followed by Sila variety are also dominated by other improved varieties. Mtama-1 and Pato varieties dominate Hakika and Wahi varieties.

Results in Figure 1 also show that Pato variety dominated Mtama-1 variety at lower yield level and crosses Mtama-1's CDF at a cumulative probability of about 0.3. This indicates that Pato variety has highest yield about 30% of the time compared to Mtama-1. Since low yield is associated with adverse weather events, Risk-averse farmers would prefer Pato to Mtama-1 and risk neutral farmers would prefer Mtama-1 to Pato variety. In addition, Wahi variety dominated Hakika at lower yield level and crosses Hakika's CDF at a cumulative probability of 0.5. The results imply risk-averse decision-

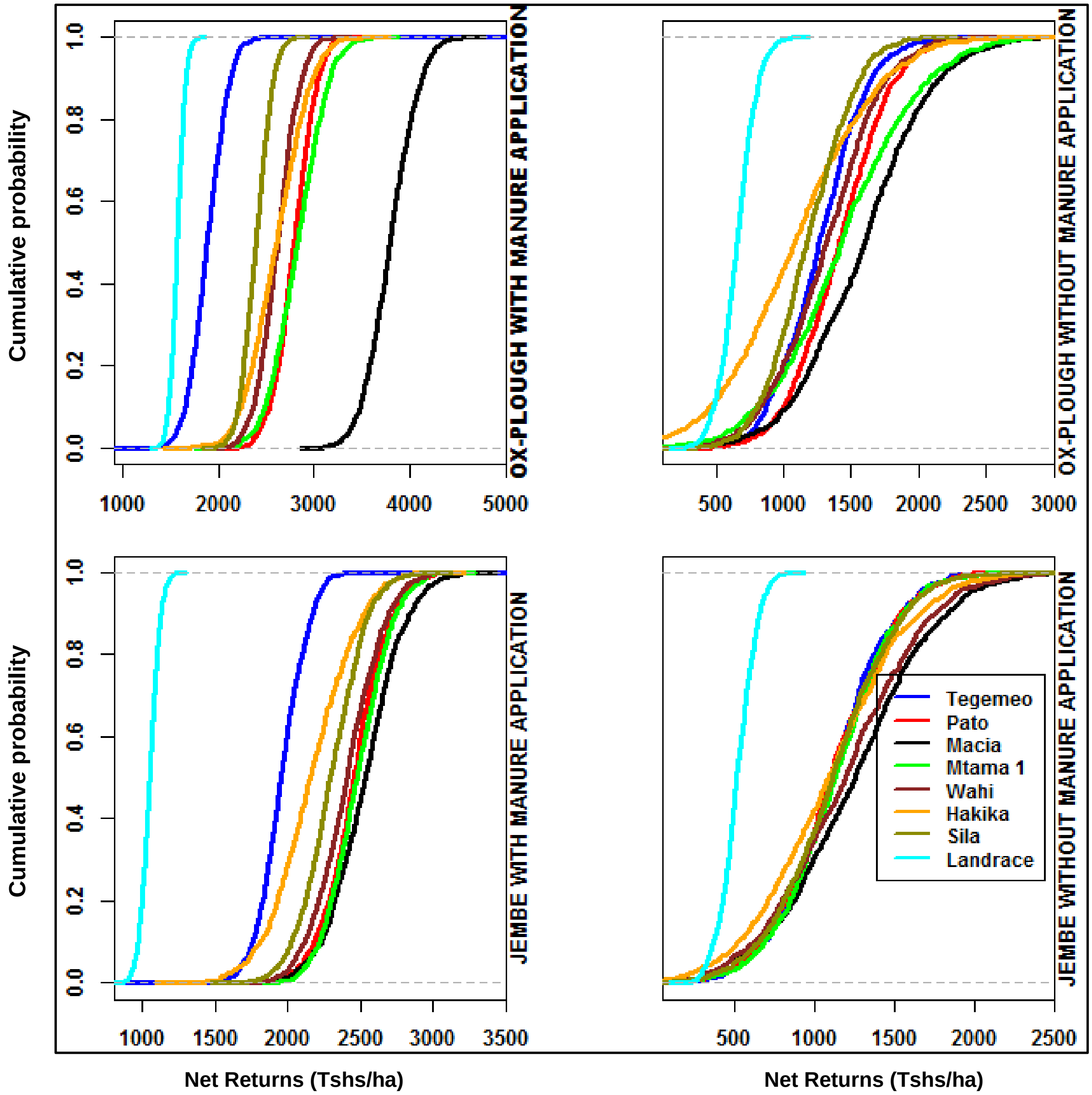

Figure 1. Cumulative distribution of yield in kg/ha.

makers will be incapable of discerning a preferred dominant variety between Wahi and Hakika varieties.

Figure 1 also show that for other farm-management practices, Macia variety is still second-degree stochastic dominant compared to other varieties. All improved varieties also dominate the landrace varieties. Results for JEMBE with manure application are almost similar to the results of ox-plough with manure application discussed above. Also in Figure 1, results for ox-plough without manure application are almost similar to results for JEMBE without manure application. While Pato and Mtama-1 relatively dominates the other four improved varieties, the CDF of Pato variety lie below and to the right of Mtama-1 until a cumulative probability of 0.5 is reached, where it crosses the CDF of Mtama-1. For the other four varieties, Figure 1 revealed that the CDFs crosses at several points. The CDF of Tegemeo crosses (from below) the CDFs of Mtama-1, Pato, and Hakika varieties at a cumulative probability of 0.1, 0.2, and 0.8, respectively. Also, the CDF of Sila variety crosses (from below) the CDFs of Mtama-1 and Hakika varieties at a cumulative probability of 0.1 and 0.7, respectively. Risk averse farmers will prefer Tegemeo and Sila varieties and risk neutral farmers would prefer Pato and Hakika under ox-plough and JEMBE without manure application.

The CDFs of net-returns in Figure 2 reveal that Macia and Mtama varieties alternatively dominated all other varieties under ox-plough and JEMBE with manure

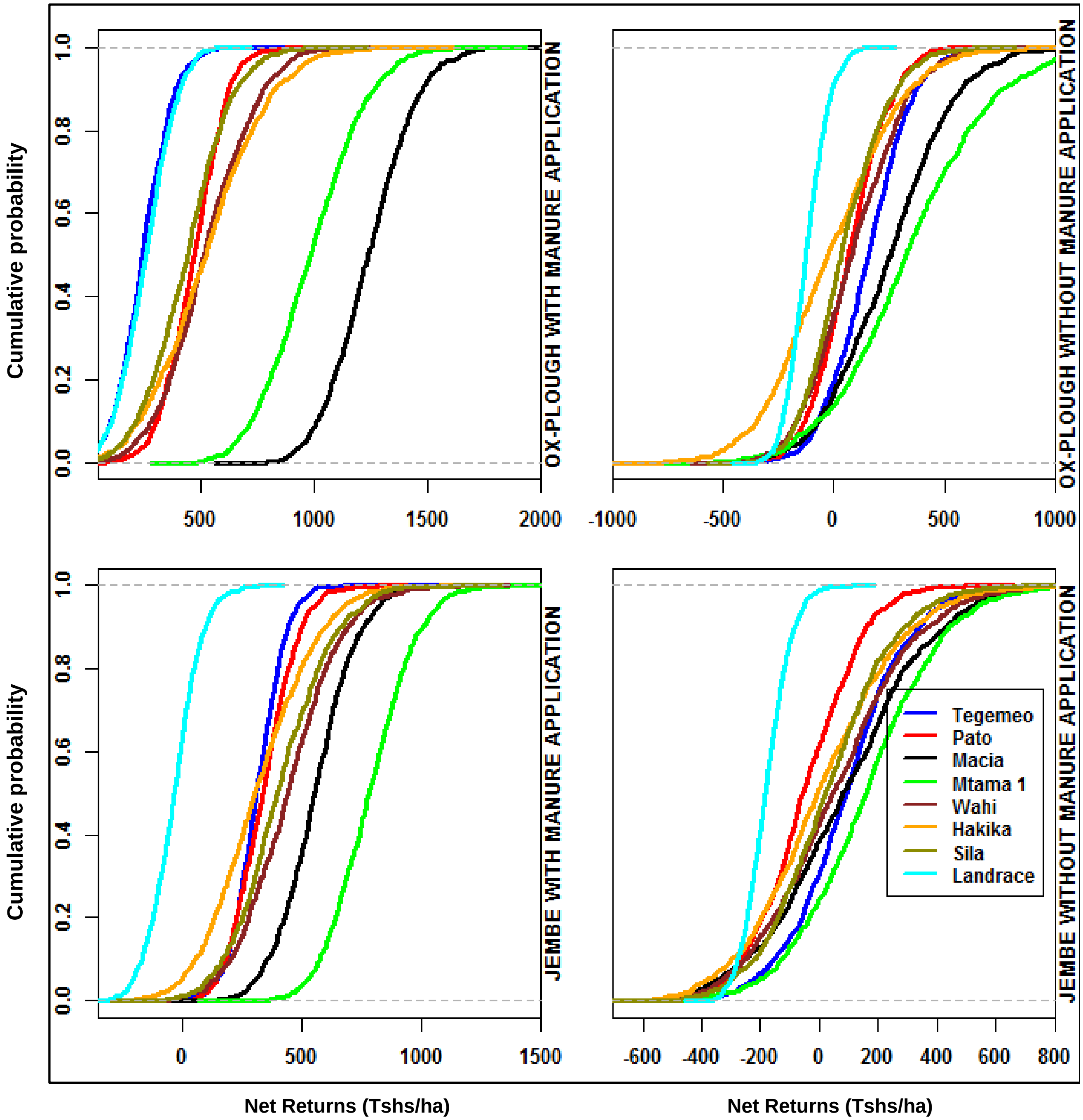

Figure 2. Cumulative distribution of net returns in 1000 Tshs/ha.

application and Wahi variety dominate other varieties under JEMBE with manure application. All varieties dominated Tegemeo and landrace varieties under ox-plough with manure application. All varieties also dominated landraces under JEMBE with manure application. Results in Figure 2 also show multiple lower-tail crosses among different improved sorghum varieties under ox-plough without manure application and JEMBE with and without manure application. For example, the Hakika variety under ox-plough without manure application dominates the landrace varieties when the net loss is about 100 Tshs/ha (at about 30% of the time). The CDF for Sila variety lies below and to the right and crosses the CDF for Hakika variety when net-returns equal zero (at a breakeven point) and when the cumulative probability is about 0.7. Therefore, net-returns for Hakika variety are negative 70% of the times compared to Sila variety. Under similar farm management practice, the CDFs for Pato and Tegemeo lies below and crosses the CDFs for Wahi, Macia and Mtama -1 when the cumulative probability are respectively 0.3, 0.1 and 0.05 and when net-returns is zero.

Under JEMBE with manure applications, the four varieties with multiple crossing are Tegemeo, Pato, Hakika, and Sila. Among the four varieties, Sila is the variety with the highest net returns above a net returns level of 250,000 Tshs/ha (at about the 70% of the time). The CDF for Pato variety lies below and to the right and crosses the CDF for Hakika variety when net-returns equal about 400,000 Tshs/ha when the cumulative probability is about 0.65.maize. Risk averse farmers would relatively prefer Pato to Sila and risk takers would prefer Sila to Pato. Similarly, the CDF for Tegemeo variety lies below and to the right and crosses the CDF for Hakika variety when net-returns is about 200,000 Tshs/ha and when the cumulative probability is about 0.5. Therefore, risk averse farmer would be indifferent between Tegemeo and Hakika variety under JEMBE with manure application. Under JEMBE without manure application, there are several multiple crosses before the breakeven point when the net-returns equal to zero and the cumulative probability is less than 0.2. Under this scenario, Mtama-1 and Tegemeo minimize losses followed by Sila, Macia, and Pato varieties. When net-returns are positive (80% of the time), Mtama-1 dominate all other varieties and landrace and Pato varieties are dominated by all other varieties. The CDF for Tegemeo variety lies below and to the right and crosses the CDFs for Macia and Wahi varieties when net-returns equal about 100,000 Tshs/ha and 200,000 Tshs/ha and with the cumulative probability of about 0.5 and 0.75, respectively. Again, farmers who are risk averse would be indifferent between Tegemeo and Macia varieties and farmers who are risk averse would prefer Tegemeo to Wahi variety.

Stochastic efficiency with respect to a function (SERF) provides a more restrictive approach than stochastic dominance. To avoid dividing by zero the range of ARAC needed for the analysis was calculated by dividing the relative risk-aversion coefficients of between 0.00001 and 4.00 by the expected yield or net-returns of the reference technology. The estimated expected yield using Equation (3) were 1,561.96, 1,046.26, 652.45 and 518.25 kg/ha under ox-plough with manure application, ox-plough without manure application, JEMBE with manure application, and JEMBE without manure application. The respective expected net-returns were 255,499.40 Tshs/ha, -34,400.59 Tshs/ha, -122,226.00 Tshs/ha, and -1779, 678.80 Tshs/ha under similar farm management practices. The respective certainty equivalent for each ARAC, which was estimated using Equation 1 are presented in Figure 3.

The results of SERF for yield in Figure 3 show that the CEs relative to ARAC curve for all varieties decrease as the farmers become more risk averse and the net-returns necessary to make the decision-maker indifferent between alternatives decreases. The results also show that Macia variety was a superior choice under ox-plough with manure application since it has higher certainty equivalents across the range of expected producer risk preferences of 0.00 to 0.003. The second-most preferred choices are Mtama-1 for risk neutral farmer and farmers who are moderately risker. For extreme risk-averse farmers, they will be indifferent to growing Mtama-1 or Pato varieties. Moreover, indifference may also occur between Wahi and Pato varieties for relatively risk neural farmers whereas for risk averse farmers Wahi is superior to Pato variety. There are clear boundaries between different varieties under JEMBE with manure application and Macia variety was the superior choice followed by Mtama-1 and Pato. Tegemeo was an inferior choice. Under ox-plough and JEMBE with manure application Hakika variety was an inferior choice and superiority of other varieties depend on risk preferences. For relatively risk neutral and moderately risk averse farmers, superior choices (ranked in term of relative importance under ox-plough without manure application) are Macia, Pato, Mtama-1, Wahi, Tegemeo, and Sila. For extremely averse-farmers, superior varieties under similar management practices are Pato, Macia, Tegemeo, Wahi, Sila, and Mtama-1.

Comparable SERF results for net-returns under different management practices are shown in Figure 4. Macia and Mtama-1 varieties under ox-plough with manure application present a clear superiority choices and Tegemeo is an inferior choice when compared to other varieties. For moderately risk averse farmers, superior choices would be Wahi, Sila, Pato, and Hakika; and for risk averse farmers, the choices would be Pato, Wahi, Sila, and Hakika. Except for highly extreme risk averse farmers a list of superior choices under ox-plough without manure application are Pato, Macia, Tegemeo, Wahi, Sila, and Mtama-1. Expect for Macia and Wahi varieties that crosses for extremely risk-averse farmers, the order of reducing production and price risk under JEMBE with manure application are respectively, Mtama-1, Wahi, Macia, Sila, and Hakika and inferior choices are Tegemeo and Pato. Equivalently, for risk neutral and moderately risk averse farmers, a list of superior choices under JEMBE without manure application include Wahi, Mtama-1, Hakika and Macia and inferior choices are Pato, Sila, and Tegemeo. For extremely risk averse-farmers, the respective similar list is Mtama-1, Macia, Wahi and Tegemeo varieties as superior choices and Pato, Sila, and Hakika varieties as inferior choices.

A utility-weighted risk premium is calculated as the difference between the CE values using a dominant variety in each farm management practice. A risk premium is defined as the additional yield or net returns

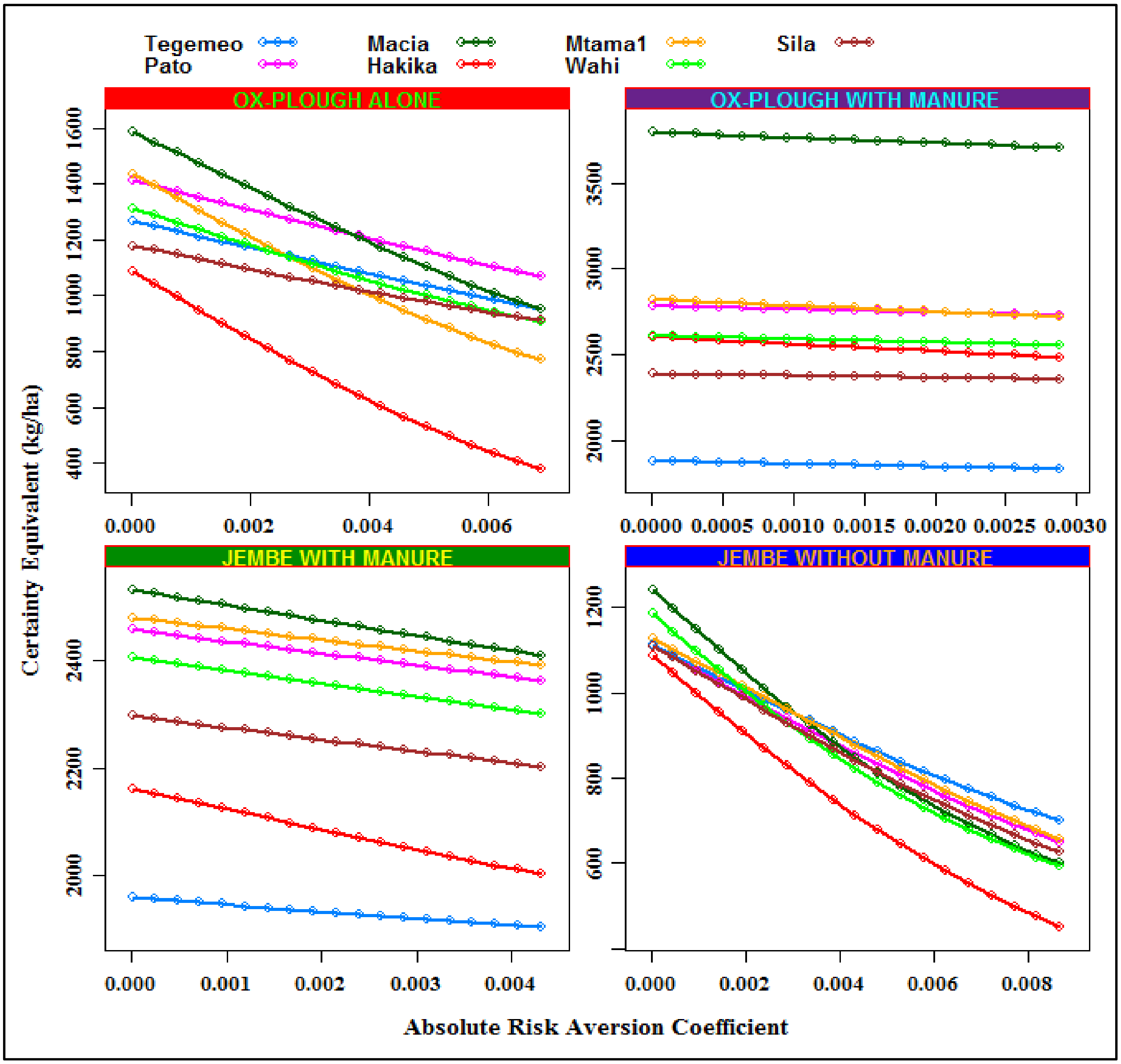

Figure 3. The SERF results for yield.

that farmers would have to be compensated to convince them to switch to an alternative sorghum variety. To estimate average premium for each variety under each management practice, we used the Z-value of $r_a(x)$ (standardized $r_a(x)$) to categorize group risk into four groups: Risk neutral; moderately risk averse; very risk averse; and, extremely risk averse. The category is Risk neutral if the Z-value were less than -1; moderately risk averse if the Z-value are between -1 and 0; very risk averse if the Z-value are between 0 and 1; and extremely risk averse if the Z-value are greater than one.

Results of estimated average risk premium are presented in Table 7. Reading the Table (row wise), the zero values in the table represent a variety with low risk or a variety with the highest certainty equivalent. Macia is a row risk variety for JEMBE with manure application, Tegemeo is a low risk variety for JEMBE without manure application but only for risk neutral and moderately risk averse farmers. Since a risk premium is the actual excess of the expected return on a risky asset over the known return on the risk-free asset, higher values of risk premium in Table 7 imply that farmers must be paid much higher compensation to convince them to switch from variety with lower risk to another variety with relatively higher risk and vice versa. Generally, farmers who are risk neutral are willing to forego (less amount of returns) to switch from low risk variety to a relatively high risky variety.

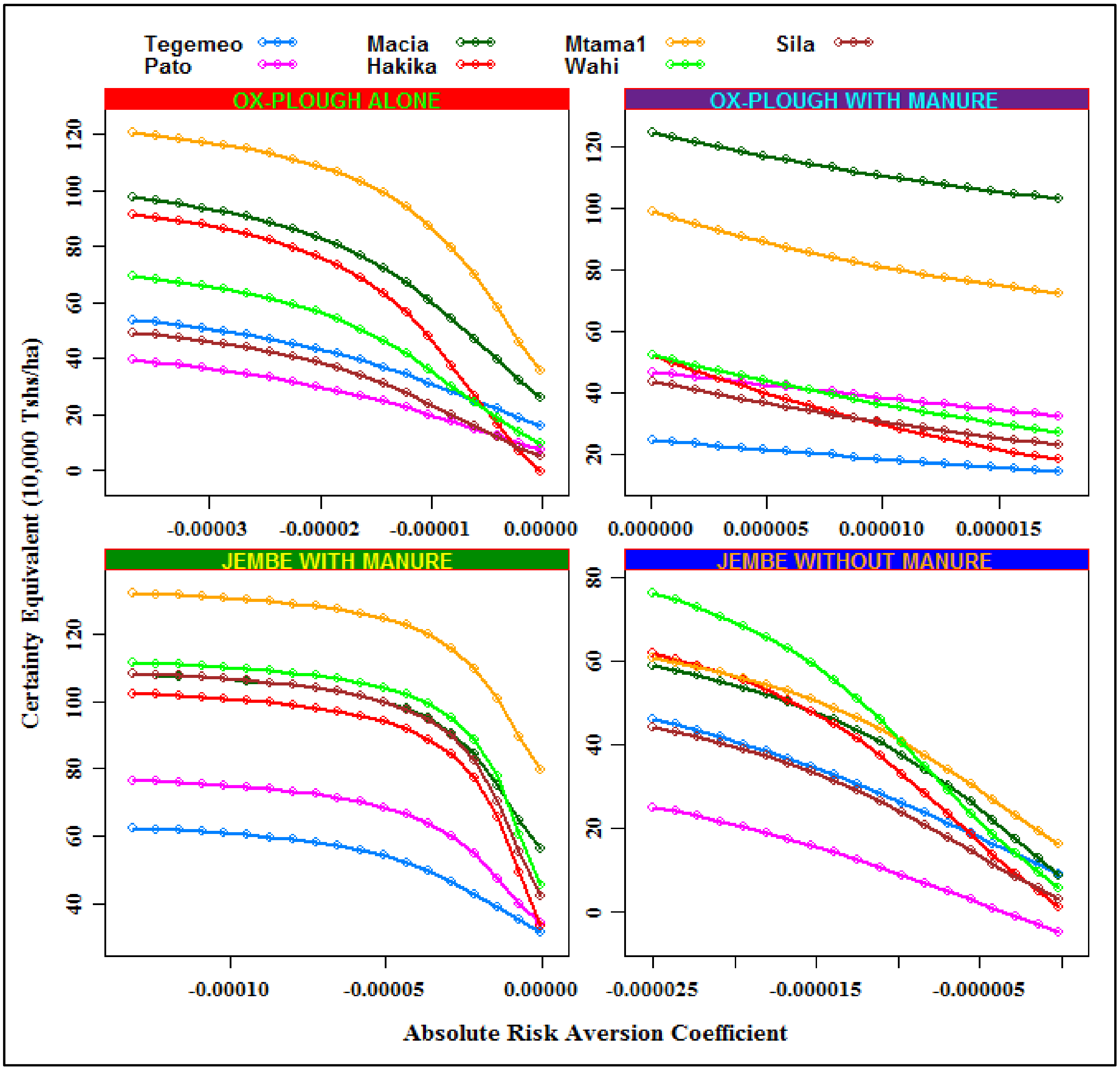

Figure 4. The SERF results for net returns (1000 Tshs/ha).

Results in Table 7 show that extremely risk averse farmers who produce Macia variety under JEMBE with manure application, would have to be compensated with 567 kg/ha or 71 kg/ha to switch to Tegemeo and Pato varieties, respectively. Macia producers that are risk neutral, would require compensation of about 510 and $49 kg/ha to switch to Tegemeo and Pato varieties, respectively. For the yield subsection, high risk premium is recorded in the ox-plough with manure application farm management practice. For example, risk-neutral producers must be paid almost 1,877 kg/ha to switch from Macia to Tegemeo variety, and extremely risk-averse producers must be paid $1,910 kg/ha to switch to Tegemeo variety.

Generally, high compensations were needed under ox-plough with manure application and JEMBE with manure application to respectively switching from Macia varieties to all other varieties and from Macia to Tegemeo varieties. Low compensations were needed under JEMBE with manure application and JEMBE without manure application to switching from Macia varieties to Mtama-1 and Pato varieties and from Macia to Pato varieties, respectively. However, due to relatively higher price, in terms of net-returns; Mtama-1 is the preferred variety for producers under JEMBE with manure, ox-plough alone, JEMBE without manure application for moderately risk averse and very risk averse farmers. Also, in terms of net-returns, Macia is the first choice for

Table 7. Estimated mean risk premium for yield and net-returns.

Group	Risk Categories	Tege-meo	Pato	Macia	Hakika	Mtama1	Wahi	Sila
Mean risk premium for yield (kg/ha)								
JEMBE with manure	Risk Neutral	510	49	0	404	21	109	209
	Moderately risk averse	527	55	0	395	29	113	215
	Very risk averse	548	64	0	384	39	118	224
	Extremely risk averse	567	71	0	373	48	123	232
JEMBE without manure	Risk Neutral	0	46	94	239	37	103	69
	Moderately risk averse	0	25	57	194	10	74	45
	Very risk averse	82	21	0	138	67	34	32
	Extremely risk averse	97	105	0	150	85	52	106
Ox-plough alone	Risk Neutral	119	0	103	675	285	164	166
	Moderately risk averse	126	0	23	589	210	152	190
	Very risk averse	209	75	0	542	178	203	286
	Extremely risk averse	300	155	0	505	154	262	385
Ox-plough with manure	Risk Neutral	1,877	981	0	1,219	985	1,154	1,354
	Moderately risk averse	1,887	989	0	1,212	982	1,162	1,369
	Very risk averse	1,899	998	0	1,202	977	1,172	1,386
	Extremely risk averse	1,910	1,007	0	1,194	974	1,181	1,402
Mean risk premium for net-returns (1 000 Tshs/ha)								
JEMBE with manure	Risk Neutral	577	506	247	385	0	266	323
	Moderately risk averse	700	557	246	307	0	205	249
	Very risk averse	698	556	241	299	0	205	241
	Extremely risk averse	696	554	239	297	0	205	238
JEMBE without manure	Risk Neutral	87	234	61	143	0	95	143
	Moderately risk averse	148	318	42	92	0	21	175
	Very risk averse	259	451	125	120	99	0	271
	Extremely risk averse	296	502	165	139	144	0	312
Ox-plough alone	Risk Neutral	320	412	162	400	0	357	421
	Moderately risk averse	598	718	264	372	0	520	663
	Very risk averse	663	799	247	310	0	519	706
	Extremely risk averse	688	809	234	292	0	512	711
Ox-plough with manure	Risk Neutral	893	710	0	843	305	755	800
	Moderately risk averse	912	717	0	821	300	747	802
	Very risk averse	945	737	0	782	285	736	803
	Extremely risk averse	985	766	0	736	264	724	806

farmers under ox-plough with manure application and Wahi is the first choice for farmer who uses JEMBE for land cultivation and are very or extremely risk averse.

Conclusion

In this study, we use farm survey data to estimate yield and net-returns from landraces or local and improved sorghum varieties in Tanzania. The data were collected from 822 sample households in major sorghum farming systems in Central, Western, and Northern Tanzania. About 505 sample households were adopters (61%) and 317 nonadopters (39%) of improved sorghum varieties. Extension officers working in the region were trained and were instrumental in pretesting the questionnaire and in data collection. During the survey, respondents were knowledgeable farmer at the household level. We used different approach including simulation, bootstrapping, stochastic dominance analysis, and stochastic efficiency with respect to a function to examine yield and risk associated with adopting improved sorghum varieties by small-scale farmers. In the farming system, ox-plough and JEMBE (handhole) were the main implements for land cultivations, manure application was the main soil amendment practice, and the farmers either planted improved or landraces/local varieties or both as a monocrop.

The results show that small-scales planting landraces typically face negative net-returns when all costs of production are considered. Results from stochastic dominance analysis and stochastic efficiency with respect to a function reveals that manure application and ox-ploughing are important farm practices with a potential of shifting the production function by increasing both yield and reducing yield variability. Macia and Mtama-1 were second-degree stochastically dominant to all other varieties under ox-ploughing and JEMBE with manure applications. In terms of yield; results from stochastic efficiency with respect to a function indicate that Macia is the preferred variety for producers over the entire range of risk preferences under JEMBE and ox-plough with manure application. The variety was also preferred for extremely risk averse-farmers under ox-plough and JEMBE without manure application.

Pato variety was preferred by risk neutral and moderately risk averse farmers under ox-plough without manure application. In term of net-returns, Mtama-1 and Macia varieties were predominantly first choice varieties. The two varieties dominated other varieties due to high yield and price. High price is attributed to market opportunities opened by the growing demand from the brewery and animal feed industries. These new opportunities are allowing farmers to receive significantly high price and invest more in production activities such as ploughing and manure application. Although these activities add cost, the marginal gain in yield and net-returns are enough to outweigh marginal costs. There is therefore a need to simultaneously promote the adoption of improved sorghum varieties in the area and develop new market opportunities and value adding activities along the value chain. Since most farmers are using manure as a soil amendment activity, there is a need of conducting studies to establish manure application rate and developing improved varieties that are more responsive to manure application. Also, promoting small-scale mechanization (use of ox-plough) will increase both production and productivity of available limited resources in the region.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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