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# Conservation Agriculture and Maize Production Risk: The Case of Mozambique Smallholders

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## ABSTRACT

Farming systems in southern Africa are characterized by substantial exposure to external risks to crop production. Compounding these external risks are the effects of climate change, soil degradation, and soil fertility decline that mandates developing sustainable intensification practices to address these issues. In 17 target communities of central Mozambique from 2008–2011, we evaluated the performance of conservation agriculture practices (CAPs) to assess the risk perceptions of smallholder farmers regarding these technologies. The study used the results from 638 farms representing three agro-ecological regions. Net returns were generated for each practice and compared using non-parametric procedures. Risk-preferred technologies were identified using mean-variance, stochastic dominance, and stochastic efficiency with respect to risk function criterion. The results suggest that maize yields were higher for the CAPs systems at low and high elevation sites as compared with conventional tillage practices. Yield variability was also lower in higher elevation areas. At higher elevations, direct seeding was risk-preferred, ranking higher by risk-averse farmers than conventional tillage practices. Risk preferences were ambiguous at lower elevations. However, defining producer utility with a power utility function allowed for comparisons of the technologies over a range of risk-aversion levels. At intermediate and higher altitudes, the direct seeding technology dominated the basin and conventional tillage practices. In low altitudes, and assuming producers were extremely risk-averse, the conventional practice might be preferred over CAP technologies. These findings have implications with respect to selecting areas where CAPs are known to out-perform conventional tillage systems before outscaling technology transfer programs to smallholders.


## Core Ideas

- Four-year on-farm experiments were conducted on 638 smallholder farms in Mozambique.
- The field treatments compared yields from conservation agriculture and conventional tillage systems.
- Net returns from each system were compared to conventional farmer tillage practices.
- The analysis identified risk-preferred technologies.
- The conservation agriculture system was preferred by risk-averse producers farming at higher elevations.

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Agricultural production in Mozambique is dominated by smallholder farmers, with 53% of all farming occurring on plots smaller than 1-ha and another 44% on fields between 1 and 5 ha (Falcão, 2009). Maize (*Zea maize* L.) and cassava (*Manihot esculenta* Crantz.) are the major staple food crops (Demeke et al., 2009). Smallholder farm families sell, on average, 29% of their crop output, generating an average annual sales value of $40 per household (Heltberg and Tarp 2002). Limited access to chemicals, fertilizer, herbicides, machinery and improved seed varieties constrain the growth of Mozambique's agricultural sector (Howard et al., 1998; Tarp et al., 2002; Ehui and Pender, 2005; Falcão, 2009). Only 11% of smallholder farmers use animal traction and 3, 5, and 4% of farmers use manure, pesticides, and fertilizer, respectively (Falcão, 2009).

Agriculture is normally characterized by high variability of production outcomes, also known as production risk (Anderson et al., 1977). Production risk is associated with negative outcomes caused by unpredictable events that affect crop production, such as disease, pests, and extreme weather events. Maize production in Mozambique is highly dependent on rainfall, with 86% of cultivated land lacking irrigation (Almeida et al., 2009). Consequently, 73% of the risk associated with maize crop failure in the country has been attributed to drought (Government of Mozambique 2005). Long term climate forecasts for the region indicate that increased heat stress and erratic rainfall will occur due to an increase in average temperature (Burke et al., 2009; Cairns et al., 2012; Cairns et al., 2013); factors that will potentially affect crop production (Lobell et al., 2008).

Land degradation compounds exposure to production risks facing smallholders in Mozambique. Land degradation is a major concern because of its impact on agricultural productivity and its effects on food security and quality of life (Shively 2001). Land use in Sub-Saharan Africa has been characterized by a significant amount of land degradation and conversion to other uses, with farmers abandoning degraded pasture and cropland caused by overgrazing and unsustainable cultivation practices (Barbier 2000).

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**Abbreviations:** CAP, conservation agriculture practice; CE, certainty equivalent; CIMMYT, The International Maize and Wheat Improvement Center; KS, Kolmogorov-Smirnoff test; M-V, mean-variance; SDSD, second degree statistical deviation; SERF, stochastic efficiency with respect to a function.

Conservation agriculture practices (CAPs) are a set of crop and soil management practices that are based on three principles: minimizing soil disturbance by direct sowing of seeds into the soil, protecting soil with crop residues or cover crops, and intercropping and/or crop rotation (FAO, 2001; Thierfelder and Wall, 2009). The yield and soil fertility benefits of CAPs are widely recognized in the agronomic and field crops literature, although the yield benefits are not immediate and require two to five cropping seasons until they become evident (Thierfelder et al., 2015). Other studies also summarized divergent results in a meta-analysis (e.g., Palm et al., 2014) that found fewer benefits. Kassam et al. (2009) and Thierfelder et al. (2012) concluded that CAPs increase soil organic matter contents although variable results have also been found by Cheesman et al. (2016) and Powlson et al. (2016). Other studies confirmed than CA increased or stabilized yields (Thierfelder et al., 2015) when all principles are applied. Previous research suggests that CAPs typically have higher net returns, increase yield stability (Derpsch and Friedrich, 2009; Knowler et al., 2001; Ngwira et al., 2013; Pretty et al., 2006; Thierfelder et al., 2013), and reduce on-farm costs of production by minimizing tillage effort and generating input cost savings (Hobbs, 2007; Wall, 2007). However, interactions between growing conditions, farmer ability, rotations, management practices, and the specific CAP technology implemented on grain yield may be substantial, suggesting the importance of tailoring CAPs systems to agro-climates and cultural conditions (Nyagumbo et al., 2016).

Conservation agriculture practices also promote soil nitrogen fixation, water retention, and minimize soil temperature variation (Sims et al., 2009). Concomitantly, CAPs also improve the soil-water balance, thereby increasing soil moisture content and reducing irrigation demand (Harman et al., 1985; Thierfelder and Wall, 2010).

Thierfelder and Wall (2009) found significantly higher water infiltration rates on CAP fields compared to conventionally plowed fields in Zambia and Zimbabwe in dry years. A greater adaptive capacity to climate change has direct implications on reduced risk of crop failure. In their regional meta-analysis of CA trials, Steward et al. (2018) found that CA systems exhibited greater resilience to heat and drought stress in southern Africa, especially among dryer conditions and sandy soils. However, the same research cautions that observed yield benefits may not uniquely be attributed to CA principles. On-farm and researcher-managed experiments in Ethiopia, Kenya, Tanzania, and Zambia found that CAPs had higher grain yields of maize and improved water use efficiency compared to conventional tillage practices (Rockström et al., 2009). Verhulst et al. (2010) concluded from Mexico that soil water content during periods of drought resulted in higher average yields for the CAP-managed plots over conventional tillage systems. Thierfelder and Wall (2010) observed an improvement in soil quality, ultimately resulting in higher rainfall use efficiency and greater maize yield on CAP plots, especially on fields where crops were rotated every 2 or 3 yr. Ngwira et al. (2012) found that during drier seasons in Malawi, maize yields in systems managed with CAPs surpassed yields produced under conventional tillage systems. Farmers used less labor per-unit area producing maize under CAP systems compared to conventional tillage practices. These results suggest that CAPs can be important risk management tools for farmers across Africa, results that likely are not impacted by farm size.

Risk-neutral producers will prefer one technology over another if the expected value of net returns is greater than the net returns generated by a competing technology, irrespective of the variance associated with net returns. However, risk-averse farmers may forgo the adoption of a technology with expected net returns that surpass others if the downside variability of its expected returns exceeds competing technologies. Yesuf and Köhlin (2009) found that farmers only partially adopted or did not adopt CAP and fertilizer technologies even when the new technologies generated higher average returns to land and labor than traditional technologies. Bekele (2005) found that the CAP strategy stochastically dominated conventional tillage practices by the 'second degree' (Hardaker et al., 2004a) at the lower levels of yield and income that often corresponded to unfavorable rainfall conditions, suggesting the CAP strategy was a preferred strategy to cope with drought conditions for risk-averse farmers. Ngwira et al. (2013) used stochastic-dominance, mean-variance analysis, and relative risk-aversion criteria to rank CAPs and conventional tillage practices for farmers in Malawi. Their research found that maize grain yields and net returns from minimum and no-tillage treatments exceeded the conventional control (tillage) treatment, and that risk-averse farmers preferred CAP practices to conventional maize production systems. Mazvimavi and Twomlow (2009) found that institutional support and agro-ecological location influenced the adoption intensity of different CAPs in Zimbabwe, that CAPs produced significant yield gains, and that risk-averse farmers preferred CAPs to conventional tillage practices.

The objectives of this research were to improve understanding about (i) the impacts on maize production and net returns of using CAPs instead of conventional farming practices, and (ii) the extent to which CAPs are preferred by risk-averse farmers. The CAPs evaluated in this analysis include two no-tillage practices; basins and direct seeding (e.g., direct seeding or planting with a planting stick also called dibble stick). Basins are typically dug with hoes or shovels. Direct seeding entails placing seed into a hole made by the dibble stick. Crop residue is retained on the field surface. These low-tech conservation agriculture practices are compared with conventional tillage practices. The International Maize and Wheat Improvement Center (CIMMYT) provided data from on-farm experiments for 638 plots in three provinces of Mozambique. Maize yield and net returns are compared using non-parametric univariate tests. Riskiness among the alternatives is evaluated using mean-variance, stochastic-dominance, and certainty equivalent criteria.

## METHODS AND PROCEDURES

### Experimental Sites

On-farm experiments were conducted in Mozambique's Central region provinces of Sofala, Tete, and Manica. These data provide an opportunity to evaluate the yield performance of CAPs against conventional tillage practices under a variety of farming environments across three provinces. The Sofala province is a tropical and wet coastal environment, located on the eastern coastal plains (less than 350 m above sea level), with mean annual rainfall ranging from 700– 900 mm and mean annual temperature of 25°C. The soil textures vary from sandy to sandy-loam (Nkala et al., 2011). The Tete province is located in the north-central region, and is characterized by temperate plateaus and occasionally semiarid highlands (usually more than 800 m above sea level). The climate is favorable to rain-fed crop production, with mean annual rainfall above 1200 mm and air temperatures ranging from 15°C to 22.5°C. Predominant soils are *Ultisols* and *Oxisols* with higher clay content that can be fertile with appropriate management (Maria and Yost 2006). The Manica province is a strip of land along the border with Zimbabwe in central Mozambique. This province is characterized by a transition altitude (350–800 m above sea level), with mean annual rainfall ranging from 400 to 500 mm and a mean annual temperature of 22.5°C. Soils in the area are highly variable due to topography as well as parent material, which results in soils mapped that range from sandy entisols (fluvisols [FAO]) to soils with low activity clays (*Oxisols*; *Lixisols* [FAO]) that can be fertile with correct management (Maria and Yost 2006; Nkala et al., 2011).

## Treatment Descriptions

There were 638 (2008 - 2011) farmer participants in the 4-yr experiment. Each farmer managed a 3000 $m^2$ plot. Plots were divided into three treatment subplots of 1000 $m^2$, each of dimension 50 × 20 m. Each maize subplot was divided further into 500 $m^2$ sub-subplots with a maize and a legume rotation and sub-subplots (100 $m^2$) where different hybrid and open pollinated maize varieties were tested. The maize varieties used were all early to medium maturing hybrids selected by CIMMYT's Drought-Tolerant Maize for Africa project (seed varieties can be found at www.dtma.cimmyt.org.). The varieties are well adapted to Mozambique's growing conditions. Grain yield was acquired using the harvest sampling procedures developed by Thierfelder et al. (2016), and yields were corrected to 15.5% moisture content. Each plot was installed and operated on the same farm and/or area for at least three seasons.

Treatment 1 (the conventional-tillage, the control) was managed using traditional tillage practices, a practice familiar to maize growers in the study region. Crop residues were cleared by burning or used as animal forage. Treatments 2 (basins) and 3 (direct seeding) were the CAPs. For the basin CAP, farmers planted maize in holes that were manually excavated with hoes. Basins were in 90 cm rows that were 50 cm apart, in dimensions of approximately 15 × 15 cm wide and 15 cm deep. In treatment 3 (direct seeding), maize seed was placed in holes made with a dibble stick or jab-planter 90 cm apart in 50 cm rows. Residual crop biomass was retained on plots for treatments 2 and 3. The average per hectare costs for labor were \$173, \$153, and \$130 (US\$) per ha for conventional, basin, and jab technologies, respectively. On rare occasions, some farmers removed residue for forage or some other use. In other rare cases, neighbors intentionally or inadvertently grazed their animals CAP plots. If residues were removed from the CAP treatment plots, 2.5–3.0 t $ha^{-1}$ of residues (typically maize residues) from other source were applied. All maize plots were planted immediately after the first rains. The target planting density was 44,000 plants $ha^{-1}$ (two seeds per basin) for all treatments.

## Crop Management

Fields were treated with glyphosate (*H*) in the CAP treatments at 2.5 L $ha^{-1}$ before planting (usually 1 to 7 d), or after planting but before plant emergence. In the absence of glyphosate, weeding was done manually or with a hoe, with the view in mind to minimally disturb the soil. Manual weeding was done on all plots when weeds reached 10 cm in height. In the control treatment, the producer weeded by either hand pulling or hoeing. In CAPs treatments, pre-harvest weed control was done after grain maturation. Weeds appearing at the end of the growing period were removed prior to seed production.

Fertilizer applications (*F*) were the same for all treatments at 100 kg $ha^{-1}$ of 12–24–12 of elemental nitrogen, phosphorous, and potassium, respectively (2.25 gm per planting station). It was applied during or shortly after planting to each side of a planting station and covered with soil. Top-dressing was split-applied, once at around 4 wk after planting and the other split at around 7 wk after planting. Urea (46%N) was used for top-dressing at an application rate of 100 kg $ha^{-1}$ on all the maize plots.

## Economic Data

Net returns were calculated for the three treatments using the costs of production and revenue from maize sales. Labor (*L*) was the only variable cost (average ± standard deviation, \$152 ± \$7.47 $ha^{-1}$). Labor costs include the costs of digging basins (in the case of the basin technology), preparing plots, seeding, weeding, chemical, and fertilizer application. Hourly wages also varied by province. Other costs included seed (\$48 $ha^{-1}$), NPK fertilizer (\$357 $ha^{-1}$), glyphosate (\$29 $ha^{-1}$), and insecticides (, cypermethrin, \$8.93 $ha^{-1}$). The seed (*S*), chemical, and fertilizer costs were provided by the partners implementing the project at a fixed rate for the span of the project. Glyphosate and cypermethrin were applied once during the production cycle if weed pressure was high or if pests were damaging the crop. Table 1 reports the total per area cost of each technology by province and districts.

Maize prices (*P*) are the market prices reported at the provincial level, and collected during the experiment for each year. The US\$-Metical exchange rate for the years 2008 to 2011 was accessed from the Information System of the Agriculture Markets in Mozambique (SIMA, 2015). Prices and costs (in Metical) were deflated to US 2010 dollars (Table 1). For each technology, net returns (*NR*) were calculated as the difference between total revenue (yield kg $ha^{-1}$, *Y*, multiplied by the \$ $kg^{-1}$ price) less the total cost $ha^{-1}$. Thus, for farm *i*, technology *j*, location *l*, year *t*, net returns were calculated as

$$NR_{ijlt} = P_{lt} \times Y_{ijlt} - L_{ijlt} - S_t - H_t - I_t - F_t \qquad [1]$$

where *H* and *F* are costs (per ha) associated with herbicide and fertilizer applications, respectively.

## Risk Analysis

A risk analysis of the net returns technologies was conducted to supplement statistical comparisons. Mean-variance and stochastic dominance criteria are discussed below, as well as the methods used to compare certainty equivalents between the alternative tillage practices. The certainty equivalent is the amount of certain money that provides a risk-averse decision maker the same level of utility as the expected utility of a risky alternative (Clemen and Reilly 2001).

### Mean-Variance Criteria

Ranking technologies according to the mean-variance (M-V) approach assumes the dominant alternative must have either a

Table 1. Maize prices and costs used to generate net returns for conventional, basin, and jab-planter technologies, Mozambique, 2008–2011.

| Province | | | Year 2008 | 2009 | 2010 | 2011 |
|---|---|---|---|---|---|---|
| | | | Real maize price (2010 US$ $Mt^{-1}$)† | | | |
| Manica | | | 630 | 220 | 330 | 310 |
| Sofala | | | 640 | 250 | 300 | 280 |
| Tete | | | 630 | 240 | 230 | 280 |
| **Province** | **District** | **Village** | **Conventional** | **Basin** | **Direct seeding** | |
| | | | Cost (2010 US$ $ha^{-1}$) | | | |
| Manica | Barue | Malomue | 530 | 541 | 512 | |
| Manica | Barue | Nhamizh | 536 | 554 | 534 | |
| Manica | Gondola | Pumbuto | 625 | 552 | 550 | |
| Manica | Guro | Guro | 625 | 552 | 550 | |
| Manica | Manica | Ruaca | 625 | 552 | 550 | |
| Manica | Sussund | Nhamati | 625 | 552 | 550 | |
| Sofala | Buzi | Guaragu | 489 | 545 | 545 | |
| Sofala | Buzi | Madjigo | 489 | 545 | 545 | |
| Sofala | Buzi | Nhaufo | 489 | 545 | 545 | |
| Sofala | Buzi | Puanda | 518 | 559 | 559 | |
| Sofala | Gorogo | Nhanguo | 489 | 545 | 545 | |
| Sofala | Nhamata | Lamego | 659 | 627 | 608 | |
| Sofala | Nhamata | Nharuch | 659 | 627 | 608 | |
| Tete | Angonia | Nzewe | 659 | 627 | 608 | |
| Tete | Angonia | Ulongue | 596 | 674 | 601 | |
| Tete | Tsangano | Gimo | 596 | 674 | 601 | |
| Tete | Tsangano | Maguai | 596 | 674 | 601 | |

†, US$ = US dollar.

higher mean net return for a given net-return variance or a lower variance for a given mean (Lambert and Lowenberg-DeBoer 2003). For example, given farming system alternatives A and B with different distributions of net returns, the mean-variance criterion predicts farming system A would be preferred over B if (i) the mean ($\mu$) net return of technology A is greater than the mean of B, and (ii) the variance ($\sigma^2$) around the mean net return of A is less than or equal to the variance of B. In other words, technology A is preferred if $\mu_A > \mu_B$ and $\sigma_A^2 \leq \sigma_B^2$.

### Stochastic Dominance Criteria

If the alternative technologies cannot be ranked with the mean-variance criterion, then stochastic dominance may provide a more decisive conclusion in terms of a risk-preferred ranking. Stochastic dominance compares the cumulative distributions of outcomes (e.g., net returns) based on two observations about people: (i) most individuals prefer more to less, and (ii) most individuals prefer to avoid low value outcomes. Point (ii) implies that people are generally risk-averse. However, assuming that an individual is risk-averse is not the same as saying they prefer to avoid variability in returns. Individuals generally welcome upside variability so long as they benefit from higher yields, higher crop prices, or higher profits. However, the same individuals may be averse to downside variability. An example would be how a farmer selects seed from the various maize varieties; some varieties will yield extremely well in near perfect growing conditions throughout the growing season but yield very poorly if conditions are less than perfect. Therefore, farmers will often choose a variety that has a more stable yield in a greater range of environmental conditions even though it will yield considerably less than the less resilient variety. Persons preferring more to less, but who are unconcerned about the variability of outcomes are risk-neutral.

These assertions are quantifiable according to two decision rules based on the empirical distributions of outcomes: first-degree stochastic dominance (FDSD) and second-degree stochastic dominance (SDSD) rules (Anderson et al., 1977). Stochastic dominance of the first degree assumes that individuals prefer more to less, and states that an alternative is preferred over others if it dominates all other outcomes at every level of probability. Graphically, the preferred empirical distribution is always to the right of other distributions.

The second-degree stochastic dominance criterion assumes individuals are risk-averse. Noting that the area under an empirical distribution is a measure of the propensity of an alternative to have low-value outcomes, an alternative dominates others if the area under its empirical density curve is smaller at every outcome probability. First-degree stochastic dominance is simpler to identify than SDSD. In the basic case of a cumulative distribution starting to the right of an alternative distribution and crossing over only once, the distribution to the right at the horizontal axis dominates an alternative if the area between the distributions below the crossover is greater than the area between the distributions above the intersection (Lowenberg-DeBoer 1999). Mathematically, the SDSD criterion is $\int_{-\infty}^{x} F_A(\pi)dx \leq \int_{-\infty}^{x} F_B(\pi)dx$ for all returns ($\pi$) over support $x$ with at least one strict inequality (Anderson and Dillon, 1992).

Stochastic dominance was determined using a customized spreadsheet in MS Excel. The FDSD and SDSD results were supplemented by a univariate statistical comparison using the Kolmogorov-Smirnov (KS) two-sample test, a non-parametric procedure to test the equality of distributions (Smirnov 1939). The null hypothesis of this test is that the distributions cannot be differentiated (i.e., they are from the same data generating process).

### Stochastic Efficiency and Certainty Equivalent Analysis

This procedure identifies and orders utility-efficient alternatives in terms of certainty equivalents (*CE*), conditional on a specified level of risk aversion. The typical assumptions are that farmers prefer more wealth ($w$) to less and are risk-averse; i.e., $U'(w) > 0$ and $U''(w) < 0$ (Clemen and Reilly 2001). The utility gained from wealth is therefore represented as a monotonically increasing concave function. Because the impact of the risk aversion coefficient on technology preferences could vary according to an individual's initial level of wealth, the power utility function is used to depict the behavior of risk-averse individuals:

$$U(NR+w_0)=\begin{cases}\dfrac{(NR+w_0)^{1-\rho}}{1-\rho} & \text{if } \rho>0,\ \rho\neq 1\\ NR+w_0 & \text{if } \rho=0\\ \ln(NR+w_0) & \text{if } \rho=1\end{cases} \qquad [2]$$

where $U(NR + w_0)$ is the farmer's utility function with net returns and initial wealth as arguments, and $\rho$ is the constant relative risk aversion coefficient. When $\rho = 0$, producers are risk neutral and will choose the technology generating the highest expected net returns regardless of variability.

Ranking technologies by their *CE*s is the same as ranking $U(w)$ by expected utility in the order preferred by the decision maker (Hardaker et al., 2004a). The *CE* is determined by setting the expected utility of net returns and initial wealth to the utility denoted in Eq. [3] and solving for the certainty equivalent; i.e., $E[U(NR + w_0)] = U(EC + w_0)$. Solving for *CE*;

$$CE = \begin{cases} (1-\rho)\cdot E\left[U\left(NR+w_0\right)\right]^{\frac{1}{1-\rho}} - w_0 & \text{if } \rho>0, \rho\neq 1 \\ NR+w_0 & \text{if } \rho=0 \\ \exp\left(E\left[U\left(NR+w_0\right)\right]\right)-w_0 & \text{if } \rho=1 \end{cases} \quad [3]$$

where $E[U(\cdot)]$ is the expected utility of net returns and initial wealth. Expected utility was calculated as the average utility of net returns and initial wealth across the sample of farms. Risk-averse farmers prefer the technology generating the largest *CE*.

The value of a technology to a risk-averse decision maker can be approximated by subtracting the *CE* of the less preferred alternative *B* from the *CE* of the preferred alternative *A*; i.e., $VTech = CE_A - CE_B$, where *VTech* is the imputed value of the technology to a risk-averse farmer evaluated at risk preference level ρ. The imputed value a risk-averse producer attributes to a technology changes as their degree of risk aversion changes. Thus, risky alternatives can be ranked, subject to a producer's tolerance for risk. Hardaker et al. (2004b) call this approach, 'stochastic efficiency with respect to a function' (SERF). In this analysis, there are three comparisons; conventional with basins, conventional with direct seeding, and basins with direct seeding. The net returns $ha^{-1}$ for each technology were evaluated over a range of risk aversion levels. The lower bound of ρ was set to zero (risk neutrality) and the upper bound set to a value that drove the ρ associated with a technology to zero (Lambert and Lowenberg-DeBoer, 2003).

Initial wealth was calculated using Mozambique survey data (McNair et al., 2015). The wealth assets of smallholder farmers were classified according to the items they owned enumerated during the survey. These items included animals (chickens, pigs, goats, cattle, and ducks), farming tools (including axes, hoes, sprayers, pumps, sickles, and shovels), and farming equipment (including tractors, plows, oxcarts, wheelbarrows, machetes, motorcycles, bikes, cars, and trucks (McNair et al., 2015). The sum-product of each item and the unit monetary values reported by respondents proxy initial household wealth. The monetary values of these items were converted to 2010 US dollars. The *CE* associated with the estimated net returns $ha^{-1}$ from conventional, basin and direct seeding technologies were calculated at an initial wealth level of \$70, the median wealth of Mozambique producers surveyed by McNair et al. (2015). The median wealth proxy ($w_0$) was used in the SERF sensitivity analysis.

Yield and net returns from each practice were compared by agro-ecological zones according to elevation—high altitude (villages located at an altitude above 800 m), medium altitude (villages located at an altitude between 350 and 800 m), and low altitude (villages located at an altitude less than 350 m). Maize production varies according to these elevations due to differences in soil fertility, temperature, and precipitation (Kidane, 2015). For each technology, expected utility was calculated as the average utility of net returns and initial wealth across treatments and farms in each elevation (based upon Eq. [2]). For the combined comparison (averaging across all elevations), expected utility from net returns and initial wealth was calculated as the average utility also based on Eq. [2].

Table 2. Maize yield and profit.

| Elevation | Technology | Mean | SD† | Minimum | Maximum | CV† |
|---|---|---|---|---|---|---|
| | Maize yield (kg ha$^{-1}$) | | | | | |
| <350 m | Conventional | 1496 | 1064 | 0 | 4667 | 71 |
| (n = 254) | Basins | 1657 | 1275 | 0 | 5622 | 77 |
| | Direct seeding | 1729 | 1356 | 0 | 6292 | 78 |
| 350–800 m | Conventional | 2146 | 1537 | 0 | 8883 | 72 |
| (n = 212) | Basins | 2447 | 1760 | 0 | 8979 | 72 |
| | Direct seeding | 2591 | 1858 | 0 | 8301 | 72 |
| >800 m | Conventional | 3628 | 1321 | 1074 | 8897 | 36 |
| (n = 172) | Basins | 3959 | 1403 | 830 | 8256 | 35 |
| | Direct seeding | 3907 | 1335 | 40 | 8399 | 34 |
| Combined | Conventional | 2287 | 1563 | 0 | 8897 | 68 |
| (n = 638) | Basins | 2540 | 1748 | 0 | 8979 | 69 |
| | Direct seeding | 2603 | 1765 | 0 | 8399 | 68 |
| | Profit (US\$ ha$^{-1}$)‡ | | | | | |
| <350 m | Conventional | –88 | 381 | –659 | 1892 | –430 |
| (n = 254) | Basins | –57 | 429 | –627 | 1588 | –755 |
| | Direct seeding | –35 | 446 | –608 | 1899 | –1292 |
| 350– 800 m | Conventional | 139 | 474 | –625 | 2146 | 341 |
| (n = 212) | Basins | 236 | 503 | –554 | 2165 | 214 |
| | Direct seeding | 300 | 535 | –534 | 1989 | 179 |
| >800 m | Conventional | 346 | 392 | –346 | 1893 | 113 |
| (n = 172) | Basins | 346 | 395 | –442 | 1636 | 114 |
| | Direct seeding | 407 | 381 | –589 | 1750 | 93 |
| Combined (n = 638) | Conventional | 104 | 452 | –659 | 2146 | 434 |
| (n = 638) | Basins | 148 | 478 | –627 | 2165 | 323 |
| | Direct seeding | 195 | 499 | –608 | 1989 | 256 |

† SD, standard deviation; CV, coefficient of variation.
‡ US\$ = 2010 US dollar.

## RESULTS

### Mean-Variance Analysis

According to the mean-variance (M-V) criteria, risk-averse producers farming above 800 m (Table 2) would prefer the CAPs direct seeding practice. At 800 m or above, the M-V criteria was unable to assign a rank order between net returns from conventional tillage and the CAPs basin practice. At the low- and intermediate-altitude sites, the M-V was unable to discriminate between any of the technologies with respect to risk efficiency. Combined across all sites, the expected net returns associated with direct seeding CAPs was highest (\$195 ± \$499 ha$^{-1}$) compared with basins (\$148 ± \$478 ha$^{-1}$) and the conventional tillage practice (\$104 ± \$452 ha$^{-1}$). The direct seeding technology generated the lowest coefficient of variation among all comparisons.

### Stochastic Dominance Results

Net return distributions from 638 farms suggest that better growing conditions generally result in higher maize yields. Maize yields associated with the CAP practices are to the right of yields generated by the conventional tillage practices when growing conditions were relatively poor (i.e., the lower 25th percentile of the cumulative distribution, Fig. 1). At the 25th–percentile, the net return distributions from each technology occasionally crossed until the 35th–percentile, after which net returns from the two CAPs practice were to the right of the conventional tillage practice until the 98th-percentile of the cumulative densities. The yield advantages conferred by the

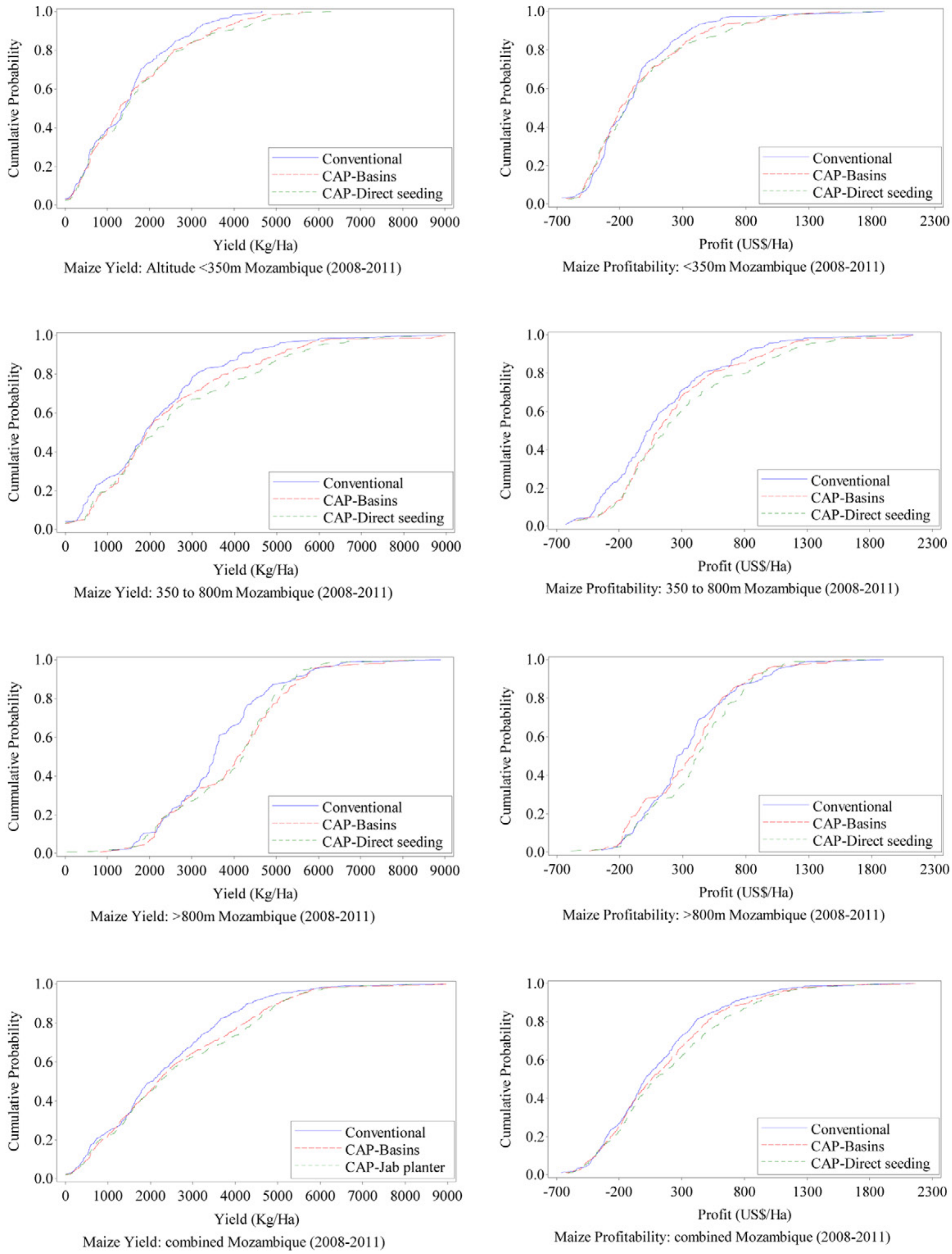


Fig. 1. Cumulative distributions for maize yields and net returns at different altitudes, Mozambique, 2008–2011.

CAPs systems translated into comparatively higher net returns throughout most of the empirical distributions (Fig. 1).

Combined across all sites, the direct seeding CAP practice dominated the CAP basin technology by the second-degree criteria (Table 3), but the net returns distributions were not significantly different ($P > 0.10$). Yields for the basin and direct seeding CAP practices (2540 ± 1748 and 2603 ± 1765 kg ha$^{-1}$, respectively, Table 2) were not different ($P > 0.10$). The KS test indicates that the net returns generated by the CAP basin (\$148 ± \$478 ha$^{-1}$) and direct seeding technologies (\$195 ± \$499 ha$^{-1}$) were significantly different from the conventional tillage net returns (\$104 ± \$452 ha$^{-1}$, $P = 0.08$ and $P < 0.001$, respectively). The maize yields generated by the CAPs practices were higher than the conventional practices ($P > 0.05$). Thus, risk-averse producers seeking to avoid low outcome risk would prefer the CAPs direct seeding technology across all the three elevations. However, growing conditions vary across years and elevations. Maize generally grows better in the relatively cooler, higher elevation agroclimates of Mozambique compared to lower elevation sites. In these areas, the rainfall is also more reliable and

Table 3. Komolgorov-Smirnoff two-sample comparison of net returns for conventional, basin and direct seeding technologies, Mozambique, 2008–2011.†

| Technology | D-statistic‡ (net returns) | D-statistic (maize yield) | Stochastic dominance |
|---|---|---|---|
| Combined | | | |
| Conventional vs. basins | 0.07* | 0.10** | No dominance |
| Conventional vs. jab planting | 0.12*** | 0.13*** | No dominance |
| Basins vs. jab planting | 0.06 | 0.05 | Direct seeding, SDSD |
| Altitude £350 m | | | |
| Conventional vs. basins | 0.07 | 0.08 | No dominance |
| Conventional vs. jab planting | 0.09 | 0.08 | No dominance |
| Basins vs. jab planting | 0.05 | 0.07 | No dominance |
| Altitude: 350–800 m | | | |
| Conventional vs. basins | 0.13* | 0.10 | No dominance |
| Conventional vs. jab planting | 0.13* | 0.15** | Direct seeding, FDSD and SDSD§ |
| Basins vs. jab planting | 0.08 | 0.07 | No dominance |
| Altitude >800 m | | | |
| Conventional vs. basins | 0.13 | 0.24*** | No dominance |
| Conventional vs. jab planting | 0.19** | 0.26*** | No dominance |
| Basins vs. jab planting | 0.10 | 0.06 | No dominance |

*,**, *** significant 0.10, 0.05, and 0.001 levels, respectively.

† Based on cumulative distributions of Fig. 1.

‡ Distance statistic, Kolmogorov-Smirnoff (KS) test of the equality between empirical distributions, .

§ FDSD, first degree stochastic dominant; SDSD, second degree stochastic dominant.

more evenly distributed. Lower elevation soils are characterized as sandy Entisols. In the higher elevations, soils are relatively fertile Ultisols and Oxisols. Maize yields and net returns generated at sites located above 800 m drive these results (Table 3).

The maize yields and net returns from the CAP practices generally increased at higher elevations (Fig. 1). However, these yield increases did not always correspond with significantly different net returns or risk-preferred technology choices. At the lowest elevation (0 to 350 m), there were no statistical differences between the net returns or the maize yields of the technologies (Table 3, $P > 0.10$). The maize yield and net return distributions repeatedly cross until the 55th–percentile of their respective distributions (Fig. 1). Determining technology selection based on risk preferences when analyzed by altitude was not possible using stochastic dominance criteria.

At the intermediate elevation sites (350 to 800 m), the net returns from the CAP direct seeding technology (\$300 ± \$535 ha$^{-1}$) were significantly higher than the conventional tillage net returns (\$139 ± \$474 ha$^{-1}$) (Table 3, $P = 0.06$). Maize yields from the CAP direct seeding treatments (2591 ± 1858 kg ha$^{-1}$) were higher than yields produced under the conventional tillage system (2146 ± 1537 kg ha$^{-1}$). The direct seeding technology was also superior to the conventional farmer practice by the first and second-degree stochastic dominance criteria (Table 3). In this intermediate elevation agro-ecology, risk-averse smallholder farmers would prefer the CAP direct seeding technology compared to the conventional tillage practice. Net return comparisons between the conventional tillage and the CAP basin practice, or the basin versus the direct seeding practice, were not statistically different or necessarily preferred by risk-averse farmers ($P > 0.10$).

At experimental sites above 800 m, the net return distribution corresponding with the CAP direct seeding technology (\$407 ± \$381 ha$^{-1}$) was significantly different from the conventional tillage practice net return distribution (\$346 ± \$392 ha$^{-1}$, $P = 0.005$). Stochastic dominance of the first or second degree is undiscernible among the practices (Table 3). Maize yields were clearly higher for the CAPs technologies (basins; 3959 ± 1403 kg ha$^{-1}$, direct seeding; 3907 ± 1335 kg ha$^{-1}$) between the 40th– and 80th–percentiles of their respective distributions, as well as their net returns (Fig. 1). However, it is also evident that the empirical distributions of the respective net returns cross several times as net returns increase, therefore rendering a stochastic dominance ranking between the technologies ambiguous. Thus, at the higher elevation sites, discerning which technology was risk-preferred according to the stochastic dominance criterion is indeterminate. Thus, while CAPs maize yields were higher at the lowest and highest elevations, a clearly dominant, risk-preferred technology is difficult to discern according to the mean-variance and stochastic dominance criterion. The stochastic efficiency with respect to a function (SERF) analysis aids in further ranking these technologies according to their riskiness.

## Stochastic Efficiency and Certainty Equivalent Results

The certainty equivalent curves for all the technologies decrease as risk aversion increases, indicating that the net returns required to make an individual farmer indifferent between alternative farming technologies also decreases (Fig. 2, left panel). The CAP direct seeding technology is the superior choice for risk-neutral and risk-averse farmers because it corresponds with higher certainty equivalent values across the range of aversion parameters evaluated ($\rho = 0$ to 1.2). The CAP basin system is second-preferred. None of the *CE* curves cross and there is little variation in the differences between the *CE* values as the risk aversion parameter was increased. The certainty equivalent of the conventional farming method ($CE = 0$ at $\rho = 0.96$) approaches zero more quickly compared to the basins (at $\rho = 1.1$) and the jab planter technologies (at $\rho = 1.2$) (Fig. 2).

For risk-neutral farmers, the difference between the s of the jab planter (and basins) and the conventional farming system

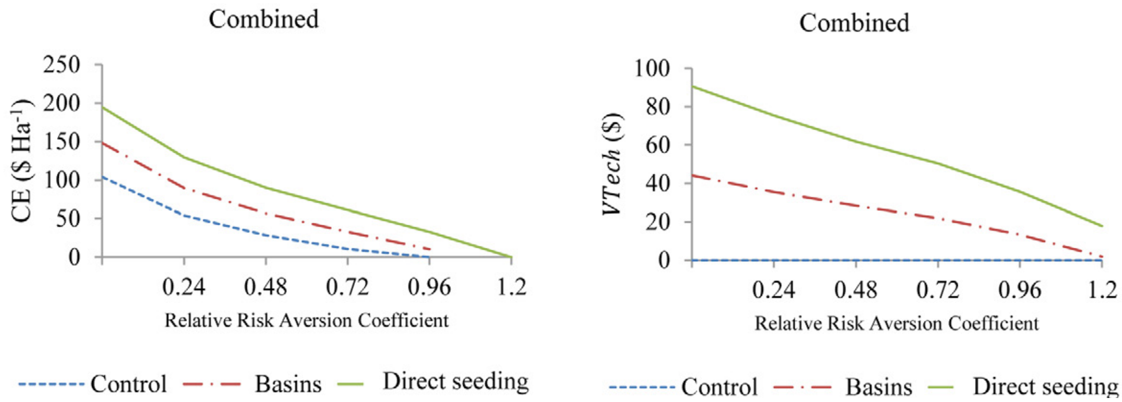


Fig. 2. Stochastic efficiency with respect to a function (SERF) comparison of technology certainty equivalents, combined across all elevations.

was \$91 ha$^{-1}$ and \$44 ha$^{-1}$, respectively (Fig. 2, right panel). This indicates that the imputed value of CAPs technologies for a risk-neutral farmer is \$91D ha$^{-1}$ for the jab planter and \$44 ha$^{-1}$ for the basins technology (respectively), compared with the conventional tillage practice. For risk neutral farmers, the difference between the *CE*s of the basins and the direct seeding technology was \$47 ha$^{-1}$ (Fig. 2). For extremely risk-averse farmers (e.g., at ρ  0.96), the difference between the certainty equivalents of the direct seeding (and basins) and the conventional tillage practice was \$36 ha$^{-1}$ (and \$13 ha$^{-1}$), respectively. An extremely risk-averse individual values the direct seeding system at \$36 ha$^{-1}$ (and \$13 ha$^{-1}$ for basins) relative to the conventional farming system. On the other hand, an extremely risk-averse farmer attributes \$22 ha$^{-1}$ to the direct seeding system over the basin technology.

## Certainty Equivalent and Imputed Value of Technology: Elevation <350 Meters

In low-altitude farming communities, the CAP technologies outperform the conventional farming system up to certain level of risk aversion. The *CE* curves of the basin and jab planter technologies cross the *CE* curve of the conventional tillage system at ρ = 0.72 and 0.96, with values –\$131 ha$^{-1}$ and –\$124 ha$^{-1}$, respectively (Fig. 3). Hence, risk-neutral to moderately risk-averse farmers would prefer the basin and direct seeding CAP technologies to the conventional tillage system. In these low elevation communities, risk-neutral farmers value the direct seeding technology over the conventional tillage practice at \$53, whereas this imputed value for the CAP basin system is \$31. At a moderate level of risk aversion (ρ = 0.48), farmers in low altitude communities would value the jab planter technology at \$22 and the basin technology at \$8, compared to the conventional farming method. The curves associated with the CAP technology values relative to the conventional tillage method are positive up to ρ = 0.72 for basins and ρ = 0.96 for the direct seeding. At the lowest altitude, the CAPs technologies are risk-preferred until a moderately high level of risk (ρ = 0.80), after which the conventional tillage practice dominates.

## Certainty Equivalent and Imputed Value of Technology: Elevation 350–800 Meters

In the mid-range elevation of 350 to 800 m, certainty equivalents are higher for the direct seeding system for risk-neutral (ρ = 0, \$300 ha$^{-1}$) and extremely risk-averse producers (ρ = 1.2, \$30 ha$^{-1}$) (Fig. 3). Ranked second is the CAP basin system. For the risk-neutral producers, the expected value is \$236 ha$^{-1}$ for this practice, but for extremely risk-averse producers (ρ = 1.2), the *CE* is \$36 ha$^{-1}$. Finally, the conventional tillage practice exhibits generates a *CE* for risk-neutral producers of \$139 ha$^{-1}$. For extremely risk-averse farmers ( = 1.2), the *CE* is \$27 ha$^{-1}$.

Risk-averse producers farming maize in intermediate altitude communities value the direct seeding technology at \$60 and the basin system at \$38, relative to the conventional tillage practice. At the highest level of risk aversion evaluated, the *CE*s are similar for each technology.

## Certainty Equivalent and Imputed Value of Technology Analysis: Elevation >800 Meters

In elevations higher than 800 m, the certainty equivalent is higher for the direct seeding technology for both risk-neutral (ρ = 0, \$407 ha$^{-1}$) and risk-averse producers (ρ = 1.2, \$174 ha$^{-1}$) (Fig. 3). This is followed by the conventional farming system for risk neutral (\$346 ha$^{-1}$) and risk averse producers (ρ = 1.2, \$164 ha$^{-1}$). Finally, the basin and conventional tillage technologies generated the same values under risk-neutrality (\$346 ha$^{-1}$), but the for basins is lower than the other technologies assuming an extremely high level of risk-aversion (ρ = 1.2, \$139 ha$^{-1}$).

The imputed value of the direct seeding system compared to the conventional tillage practice for risk-neutral farmer is \$61 ha$^{-1}$. For extremely risk-averse farmers, the difference is \$10 ha$^{-1}$ (Fig. 3). An extremely risk-averse farmer attributes \$25 ha$^{-1}$ to the conventional tillage practice compared to the CAPs basin technology. The value of technology for the direct seeding system is always positive compared to the conventional tillage system, whereas the imputed value of the basin technology is negative compared to the conventional tillage practice. For maize growers farming higher elevations, the risk-preferred technology is the CAPs direct seeding system.

## CONCLUSIONS

The implications of this research echo that of Palm et al. (2014) and Nyagumbo et al. (2016) cautious skepticism on the blanket promotion of CAPs in sub-Saharan Africa. Their research cautioned that while CAPs may offer substantial benefits to farmers, these benefits may be due to other factors aside from the technology considered, including farmer skill, access to technical support and other endowments, and topographic and climatic features affecting growing conditions. This present research evaluated the agronomic and financial benefits across a

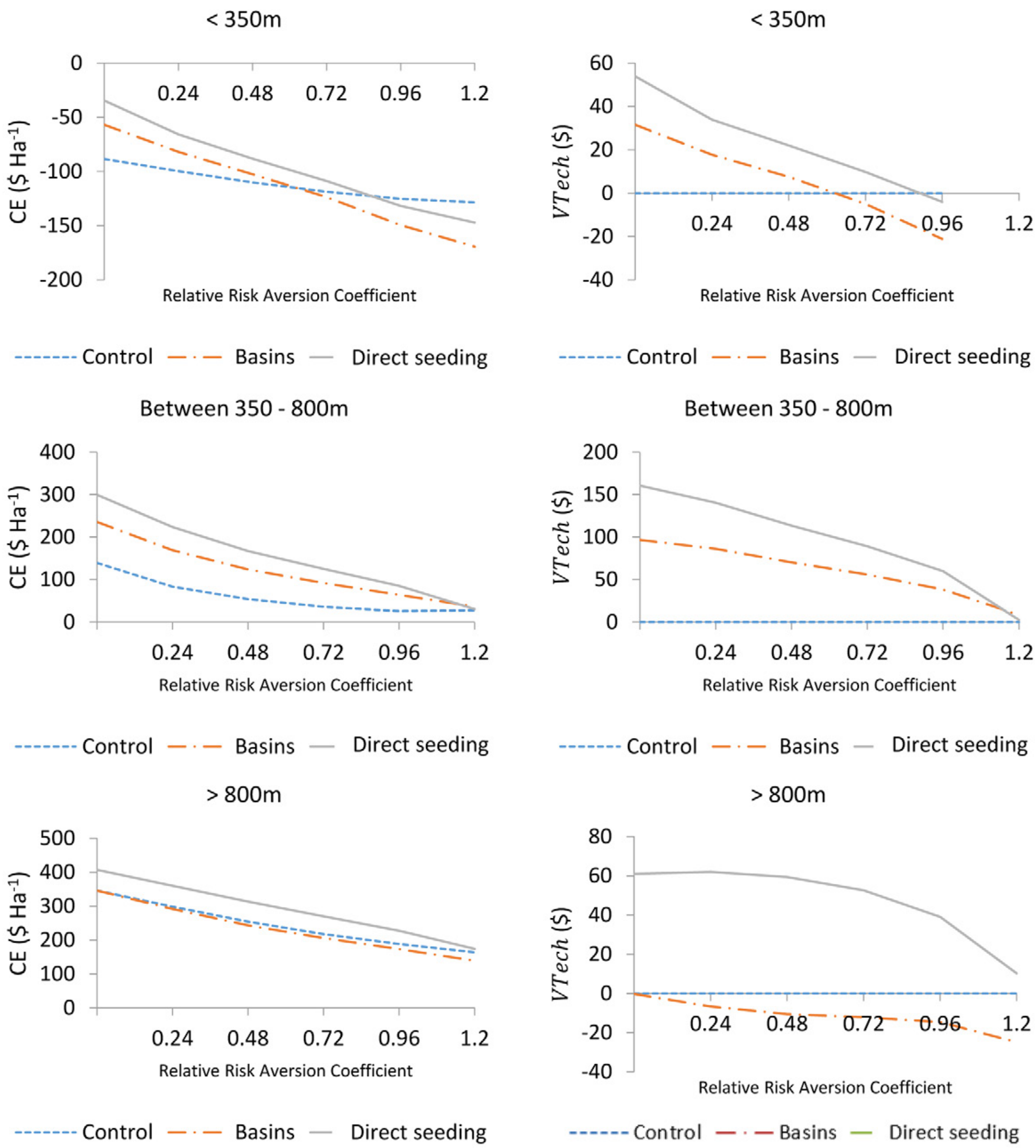


Fig. 3. Stochastic efficiency with respect to a function (SERF) comparison of technology certainty equivalents at <350, 350–800, and >800 m.

range of agro-ecologies and suggests there are likely significant interaction effects between soil, precipitation, and temperature and the CAPs analyzed, notwithstanding variations in prices and costs.

This research compared the maize yields and net returns associated with three farming systems–basin planting, direct seeding and conventional tillage systems–based on a 4-yr experiment involving on-farm trials conducted by smallholder farmers ($n = 638$) in Mozambique. The basin and direct seeding systems are two types of conservation agriculture practices (CAPs). CAPs are based on three core principles: minimizing soil disturbance by direct sowing of seeds into the soil, protecting soil with cover crops or crop residues, and intercropping and/or crop rotation. Yields and net returns were compared using a nonparametric two-sample procedure. Technologies were ranked according to risk preference criterion. The ranking criteria were based on mean-variance analysis, stochastic dominance, and stochastic efficiency with respect to a function.

On average, the CAPs basin and direct seeding systems appear to generate higher yields than the conventional farmer practice of conventional tillage. Naturally, any classification scheme ultimately suffers from loss of detail, and this conclusion is conditional on agroecological conditions pertaining to elevation, soil type, and precipitation. Four-year average maize yields were unambiguously higher for the CAPs systems compared to usual farmer practices for high-elevation plots. The results were mixed for plots located at intermediate elevations and undifferentiable for communities located in the lower elevations of the study area. This finding has implications for programs promoting the adoption of CAPs practices with respect to the allocation of scarce financial and personal resources. Farmers experimenting with CAPs in the lower to intermediate elevations may experience, on average, higher yields from implementing CAPs, but the variability of yields may be discouraging. At higher elevations, the yield variability of the CAPs practices (as measured by the coefficient of variation) is lower than yields observed at the other elevations. The lower variability and higher yields translate into statistical differences between yields from the conventional tillage practice and the CAPs.

Three methods were used to rank the CAPs and the conventional tillage practice in terms of farmer risk preferences. The first method, mean-variance analysis, indicated that direct seeding dominated the conventional farmer practice. However, the mean-variance criterion was unsuccessful at ranking the technologies according to their riskiness at the other elevations. The second ranking criteria–stochastic dominance–also indicated that jab-planting was risk-preferred to the conventional farmer practice at the highest elevation. At the lower elevation, CAPs could not be ranked with respect to the conventional practice, but the direct seeding technology would be preferred over the basin system by risk-averse producers. The assumptions required by the mean-variance and stochastic dominance approaches are minimal (i.e., a functional form of utility is not required). Yet, the advantage of maintaining weak assumptions comes at the cost of not allowing risk preferences to vary across individuals. Assuming producer preferences are completely defined by a power utility function exhibiting constant relative risk aversion, the stochastic efficiency with respect to a function (SERF) analysis provided a method whereby an imputed value could be attributed to the CAPs technologies relative to the conventional farmer practice.

The certainty equivalents suggest an interaction between the assumed level of risk aversion and altitude. Extremely risk-averse farmers in lower altitude communities may in fact prefer the conventional farmer practice. At the highest altitude, the direct seeding technology always dominates the conventional farmer practice. However, the conventional practice is preferred to the basin technology at moderate or extreme levels of risk aversion.

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