

**Comparison of Agricultural Technologies and Risk Analysis of
Smallholder Farmers in Mozambique**

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Abstract

This thesis examines on understanding how maize yields and net returns associated with three farming systems; conventional method, basin planting and jab planting differ, and the extent to which conservation agricultural practices are preferred by risk averse farmers linked to agro-ecological factors, farmer resource endowments, and risk preferences of smallholder farmers in Mozambique. Conservation agriculture practices (CAP) is promoted in sub-Saharan Africa to improve water and soil conservation, improve household income and enhance family and national food security. CAP are based on three 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 The basins and jab planter practices are components of more general soil management CAP.

Univariate and multivariate analysis of variance and risk analysis were used for ranking the farming technologies using on-farm trial data collected from 4 years (2008 – 2011) of 632 farmers of the Central region of Mozambique by CIMMYT. A sensitivity analysis using a power utility function which allowed for certainty equivalent (CE) to vary depending on wealth endowments of producers was employed.

Results suggest that residue cover and seeding maize using CAP basins or jab planter technology generate higher [per hectare] net returns and yields than conventional tillage practices across different elevations. The CAP technologies were risk preferred over the conventional farming method in different altitudes by the mean-variance criteria, and CE criteria across a range of risk aversion levels and at different levels of wealth. The results also suggest as risk premium associated with a technology increases, the tradeoff between wealth and risk increases.

This thesis considers risk for analysis on partial budget. Further research on understanding the decisions in farming systems selections is necessary to consider those factors which are not captured by risk analysis such as household demographic differences, income sources, agricultural inputs and output markets, and availability of labor. All these factors can cause one farming system to be selected over another.

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List of Acronyms

ANOVA Analysis of Variance

CA Conservation Agriculture

CAP Conservation Agricultural Practices

CARA Constant Absolute Risk Aversion

CDF Cumulative Distribution Function

CE Certainty Equivalent

CIMMYT International Maize and Wheat Improvement Center

CRRA Constant Relative Risk Aversion

FAO Food and Agricultural Organization of the United Nations

FSD First Degree Stochastic Dominance

HH House Hold

KS Kolmogorov Smirnov

MT Mozambican Meticals

NPK Nitrogen, Phosphorous, Potassium

RP Risk Premium

SSA Sub-Saharan Africa

SSD Second Degree Stochastic Dominance

US\$ United States Dollar

USAID United States Agency for International Development

CHAPTER I – INTRODUCTION

Mozambique is situated in south eastern Africa with a land area of over 799,380 km². The country is governed as ten provinces and 128 districts. Mozambique has about 36 million hectares of arable land (Gêmo 2011). Approximately 3.9 million hectares (10%) of the arable land are cultivated, with 97% by smallholder farmers (FAO 2005).

Populations of developing countries generally rely on agriculture for their living (Hurley 2010). More than 45% of sub-Saharan Africa's population lives below the poverty line (Jayne et al. 2003). In 2008/09, Pauw et al. (2011) estimated that 55% of Mozambique's population lived in poverty. Agriculture employs 81% of the country's population (Demeke et al. 2009). The livelihood of most Mozambicans centers on farming small plots. Most (94%) rural households depend on the land (Heltberg and Tarp 2002). Production of food staples is dominated by smallholders and is subsistence-oriented (Uaiene et al. 2009). Maize and cassava are the major staple crops (Demeke et al. 2009) (Figure 1). Families sell, on average, 29% of their crop output, generating an average annual value of sales 447,000 Meticaïs (MT) per household (US\$40) (Heltberg and Tarp 2002). Mozambique's agricultural productivity growth rate of 1.02% per year (Nkamleu 2004) is low compared to the population growth rate of 2.65% per year (Da Silva et al. 1996), a concern for achieving food security for the nation and its households.

Agriculture is frequently characterized by high variability of production outcomes which is known as production risk (Hess et al. 2005), i.e., negative outcomes stemming from unpredictable natural causes such as diseases and pests, and unpredictable economic conditions including price volatility of inputs and outputs (Austin and Baharuddin 2012). Maize production in Mozambique is highly dependent on rain, with 86% of cultivated land lacking irrigation (Almeida, et al., 2009). Consequently, 72.6% of the risk associated with maize crop failure in the country has been attributed to drought (Government of Mozambique 2006).



Figure 1 Percentage of household (HH) growing maize

Source: (Haggblade and Nielson 2007)

Land degradation compounds exposure to the production risks faced by smallholders in Mozambique. Land degradation is a major concern because of its adverse impact on agricultural productivity, the environment, and its effects on food security and quality of life (Eswaran et al. 2001; Shively 2001). Land degradation reduces soil productivity caused by erosion and off site sedimentation (Eswaran et al. 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 agricultural practices (Barbier 2000). The productivity of some arable land has declined by 50% due to soil erosion (Eswaran et al. 2001). Yield reductions in Africa caused by soil loss range from 2 to 40%, with a mean loss of 8.2% for the continent (Eswaran et al. 2001).

Technology plays an important role in sustaining agricultural productivity growth. Adoption of sustainable and improved production technologies is important for achieving food security in Sub-Saharan Africa. Yet the region's agriculture is mainly characterized by limited use of improved technologies, under application of fertilizer, and low productivity (Simtowe 2006). These deficits correlate with insecure tenure, labor shortages, and imperfect credit markets (Anderson and Thampapillai 1990; Lutz et al. 1994; Shively 2001).

New agricultural technologies may provide an opportunity to increase or stabilize food production and household income (Feder et al. 1985). Adoption of technology innovations in agriculture has attracted considerable attention among development agencies, researchers, and policy makers because:

1. the majority of the populations of developing countries, including Mozambique, derive their livelihood from agricultural production, and
2. new technologies may provide an opportunity to substantially increase production and income. Understanding farmer risk profiles is important information for designing effective interventions and incentives to encourage adoption.

One technology more commonly promoted in sub-Saharan Africa is conservation agriculture practices (CAP). CAP are based on three 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 (FAO 2001; Ngwira et al. 2013; Thierfelder and Wall 2009).

This thesis examines the economic profitability (net returns) of three farming system alternatives linked to agro-ecological factors, farmer resource endowments, and risk preferences. The question related to production was the extent to which risk attitudes affect how much maize is produced and what methods are used to produce the crop. In this thesis, I focus on understanding how maize production and net returns between CAP (basins or jab planter) and conventional farming practices differ, and the extents to which CAP (basins or jab planter) are preferred by risk-averse farmers.

The objectives of this research are to:

1. Evaluate the economic net returns and maize yields of three maize tillage practices (basins, jab planter and conventional) in Mozambique, and
2. Examine which of the three tillage practices (conventional, jab planter or basins) are preferred by risk-averse producers.

The null hypothesis is that the distributions of net returns and maize yields generated from CAP technologies are not different from the net returns of conventional agronomic practices. In other words, there is no expected difference between profits and maize yields generated by the three practices.

For the risk analysis part of the thesis, the null hypotheses is there is no difference between the CAP basins and jab planter technologies and conventional farming system for risk neutral to risk averse farmers at different initial levels of wealth.

Maize yield and net returns are analyzed with a mixed model analysis of variance (ANOVA). The risk analysis compares the net returns of the practices using a mean-variance criterion, stochastic dominance, and a risk premium comparison. Importantly, the analysis finds that location and elevation play a role in technology ranking.

Data on maize production using alternative tillage practices were collected from agronomic trials in three provinces of Mozambique from 2008 – 2011. Data were generously provided by the International Maize and Wheat Improvement Center (CIMMYT). In total there were 632 plots corresponding with three technologies – conventional tillage, and the reduced tillage CAP basins and the no till treatments CAP jab planter technology available for analysis.

CHAPTER II – LITERATURE REVIEW

The empirical literature suggests that CAP 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).

Most CAP are hypothesized to improve soil and water management. Thierfelder and Wall (2009) examined the effect of CAP techniques on soil moisture in Zambia and Zimbabwe. They found significantly higher water infiltration rates on CAP fields compared to conventionally ploughed fields. In Malawi, Ngwira et al. (2012) found that infiltration was highest with CAP legume intercrops than conventional tillage practices. CAP may also improve infiltration rates compared to the conventional tillage system (Verhulst et al. 2010).

CAP have the potential to increase water use efficiency and reduce the risk of crop failure. Thierfelder and Wall (2009) found maize moisture stress at tasselling affected CAP treatments less than conventionally tilled treatments in Zambia. Thierfelder and Wall (2009) also recorded more efficient rainfall use and higher soil water content under CAP-managed systems than conventional practices. Verhulst et al. (2010) concluded that soil water content during periods of drought resulted in higher average yields for the CAP managed plots over a conventional system. 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 two or three years.

In Malawi, Ngwira et al. (2012) found that during drier seasons, maize production in systems managed with CAP were higher than maize yield produced under conventional systems. Farmers also spent less labor days per unit area producing maize under CAP systems compared to conventional tillage practices. Research conducted by Rockström et al. (2009) on farmer and

research managed experiments in Ethiopia, Kenya, Tanzania and Zambia found that CAP had higher grain yield of maize and tef¹ and improved water productivity compared with conventional farming practices with or without fertilizer. In 2007 – 2009, Thierfelder and Wall (2010) found higher yields were obtained from both direct-seeded maize and a two-year maize-cotton rotation compared to maize produced on conventionally ploughed plots.

Feder et al. (1985) suggested that considering the uncertainty and the fixed transaction and information cost associated with innovations, there may be a critical lower limit on farm size that prevents smaller farmers from adopting new technologies. Yesuf and Köhlin (2009) found that farmers only partially adopted or did not adopt soil conservation and fertilizer technologies, even when the new technology generated higher returns to land and labor than traditional technologies.

Bekele (2005) found that adopting soil and water conservation practices results in higher grain yields and net returns than conventional methods in Ethiopia. Using stochastic dominance, Bekele found that the soil and water conservation strategy dominated conventional practices by second degree stochastic dominance at lower levels of yield and income that often corresponded to unfavorable rainfall conditions. In other words, the soil and water conservation strategy was a preferred strategy to cope with drought conditions for risk-averse farmers.

Ngwira et al. (2013) examined the riskiness of economic returns of minimum or reduced tillage technologies based on maize grain yield in Malawi using stochastic dominance, mean-variance criteria, and relative risk aversion criteria. They found that maize grain yields and net returns from minimum and reduced tillage treatments exceeded the conventional control

¹ Tef is a love grass species native to the northern Ethiopian and Eritrean highlands and has small seeds (<1 mm diameter) and nutritious, high in dietary fiber, iron, protein and calcium.

treatment. Using stochastic dominance criteria, they found that minimum and reduced tillage technologies were preferred by risk-averse farmers compared to conventional maize production systems.

Mazvimavi and Twomlow (2009) used an enterprise budget analysis to compare agricultural practices in Zimbabwe. They found that institutional support and agro-ecological location influenced the adoption intensity of different CAP components. There were significant yield gains realized with CAP, and CAP were preferred to conventional tillage practices.

Alternative views on the effectiveness of conservation agriculture and smallholder farming in sub Saharan Africa (SSA) were also provided by Giller et al. (2009). They concluded that under present circumstances CA practices are inappropriate for the vast majority of resource-constrained smallholder farmers and farming systems in SSA. They also concluded that conservation agriculture is one approach that can offer substantial benefits for certain types of farmers in certain locations at certain times, realizing the plurality of farmers in terms of risk preferences, resource endowments and plant growing conditions. The different opinions require targeted research to identify where and how particular CA practices may best fit, and which farmers in any given community are likely to benefit the most (Giller et al. 2011).

2.1 Expected Utility Theory

The expected utility framework is useful for understanding individual decision making under uncertainty. The mathematical expression of expected utility hypothesis was introduced by Bernoulli in the 18th century (Anderson et al. 1977). According to Bernoulli, people make decisions based on preferences over alternatives that maximize their expected utility rather than expected monetary values (Levy 2006; Schumann 2006). Resource rich and poor people may exhibit different preferences for risk.

Von Neumann and Morgenstern (1947) developed a theory of expected utility based on rational decision making under stochastic outcomes in the form of preference axioms. According to the expected utility hypothesis, a decision maker prefers the alternative with the highest expected utility (Schumann 2006). According to Clemen and Reilly (2001) the axioms related to the consistency with which an individual expresses preferences from an array of risky prospects are as follows:

1. Ordering and transitivity: A decision maker can order (establish preference or indifference) any two alternatives and the ordering is transitive. For example if $A_1 \succ A_2, A_2 \succ A_3 \Rightarrow A_1 \succ A_3$.
2. Continuity: A decision maker is indifferent between consequence A and some uncertain event involving two other consequences A_1 and A_2 , where $A_1 \succ A \succ A_2$. This implies one can construct a reference gamble with some probability $p, 0 < p < 1$, for which the decision maker will be indifferent between the reference gamble and A .
3. Substitutability: A decision maker is indifferent between any original uncertain event that includes outcome A and one formed by substituting for A an uncertain event that is judged to be its equivalent.
4. Monotonicity: Given two reference gambles with the same possible outcomes, a decision maker prefers the one with higher probability of winning the preferred outcome.
5. Invariance: A decision maker's preference among uncertain events are the payoffs (or consequences) and the associated probabilities.

The expected utility hypothesis explains the relationship of an individual's preferences over the probability distribution of the real outcomes through a functional form representing utility.

The empirical model of this decision making under risk study is built on the foundations of

expected utility theory: A farmer who is faced with an alternative having a probability distribution known *a priori* ($p_1 \dots p_n$) over a number of outcomes ($a_1 \dots a_n$), is assumed to maximize the probability weighted sum of the utility of the outcomes, given by $\sum p_i u(a_i)$. A decision maker's attitude towards risk determines the shape of the utility function, with concavity representing aversion to risk. The function correlates a single utility value, $u(a_i)$ with any risky alternative, a_i and has the following properties (Anderson and Dillon 1992; Hardaker et al. 2004):

1. If a_1 is preferred to a_2 , then $U(a_1) > U(a_2)$, (Hardaker et al. 2004).
2. The utility of a risky prospect is its expected utility value $U(a_j) = E(U(a_j))$ (Hardaker et al. 2004).

2.2 Choice of Expected Utility Representation

Two measures of risk aversion that have become standard are the Arrow-Pratt coefficient of absolute risk aversion $r_a(w)$ and the Arrow-Pratt coefficient of relative risk aversion $r_r(w)$ (Arrow 1965; Pratt 1964). Because concavity of $U(w)$ denotes risk aversion, the degree of concavity of $U(w)$, as captured for example by $U''(w)$, represents degrees of risk aversion (Moschini and Hennessy 2001).

The central behavioral concept in expected utility theory is that of risk aversion (Quiggin 1992). Risk aversion is a fundamental feature of the problem of choice under uncertainty (Moschini and Hennessy 2001). The shape of a decision maker's utility function describes their risk preferences (Hardaker et al. 2004). The decision maker's utility function has a positive slope

over the entire range of payoffs, which implies that a greater payoff is always preferred to a lower one. This can be illustrated in mathematical terms as $U'(w) > 0$ (Hardaker et al. 2004).

Risk aversion is the change in the marginal utility as the level of wealth increases, $U''(w)$. This gives rise to the classification of a decision maker's attitude toward risk as risk loving, risk neutral or risk averse in terms of the second derivative (Hardaker et al. 2004; Schumann 2006): $U''(w) < 0$ implies risk aversion, $U''(w) = 0$ implies risk neutrality and $U''(w) > 0$ implies risk loving.

2.3 Constant Absolute Risk Aversion (CARA) and Relative Risk Aversion (CRRA) Utility Functions

The Arrow-Pratt measure of absolute risk aversion is:

$$r_a(w) = - \left[\frac{U''(w)}{U'(w)} \right]$$

where $r_a(w)$ is the coefficient of absolute risk aversion, w is wealth, and $U''(w)$ and $U'(w)$ are the second and first derivatives of the utility function, respectively. Hardaker et al. (2004) stated that the coefficient of absolute risk aversion function can be classified in relation to how it changes with respect to increasing wealth. Schumann (2006) argued that the absolute amount of change can be calculated by using the derivative with respect to wealth of the absolute risk aversion coefficient $r_a(w)$.

If the decision maker exhibits constant absolute risk aversion, $r_a(w) = 0$, the coefficient does not change with the decision maker's wealth. This implies that if a constant amount of money is added to or deducted from all payoffs in the risky prospect, the decision maker's choices based on risk preferences remain the same. A decision maker who exhibits decreasing

(increasing) absolute risk aversion, $r_a(w) < 0 (> 0)$, indicates that an increase in the decision maker's wealth, the constant amount of money that one is willing to pay in the risky prospects increases (decreases) (Levy 2006; Schumann 2006).

Hardaker et al. (2004) and Quiggin (1992) showed that, even if CARA and CRRA have different behavioral implications, CRRA can be derived from CARA given information about the wealth changes involved. The relative risk aversion coefficient is:

$$r_r(w) = wr_a(w) = -\left[\frac{wU''(w)}{U'(w)} \right]$$

where $r_r(w)$ is the change in the proportional amounts of money that the decision maker is willing to pay with risky prospects. When a decision maker exhibits CRRA, $r_r(w) = 0$, implying that as a decision maker's wealth increases, the proportional amount of money they are willing to pay with risky prospects remains the same. The decision maker exhibits decreasing (increasing) relative risk aversion, $r_r(w) < 0 (> 0)$, implying that the more the decision maker's wealth increases, the proportional amount of money that he/she is willing to pay into a risky prospect increases (decreases) (Levy 2006; Schumann 2006).

Figure 2 shows the decision maker's initial wealth and utility, the expected outcome and the expected utility of two equally likely outcomes. Let z_1 be the outcome for $w_0 - z$ with probability $p = 0.5$ and z_2 be the outcome for $w_0 + z$ with probability $1 - p = 0.5$. The expected (risk neutral) outcome will be $p \times z_1 + (1 - p) \times z_2$ and the expected utility will be $p \times U(z_1) + (1 - p) \times U(z_2)$.

The utility associated with the known level of expected wealth $U(Ez + w_0)$ and $EU(w_0 + \tilde{z})$ is the expected utility of wealth;

$$EU(w_0 + \tilde{z}) = 0.5uz_1 + 0.5uz_2 = U(CE)$$

Comparing the two possible outcomes, one yields for sure $E(w_0 + \tilde{z})$, and the other generates

$z_2 = w_0 + z$ and $z_1 = w_0 - z$ combined, as figure 2 indicates, $0.5uz_1 + 0.5uz_2 < u(E(w_0 + \tilde{z}))$.

The figure also shows that there is a $CE < E(w_0 + \tilde{z})$ such that $0.5uz_1 + 0.5uz_2 = u(CE)$.

The certainty equivalent of z is when the decision maker with a concave utility function is indifferent between the random prospect z and the sure prospect CE . Suppose the decision maker starts with the expected utility of wealth, $E(w_0 + \tilde{z})$ but is then confronted with the prospect of gaining or losing z . The highest risk premium he/she is willing to pay to avoid the risk for the decision maker is $E(w_0 + \tilde{z}) - CE$.

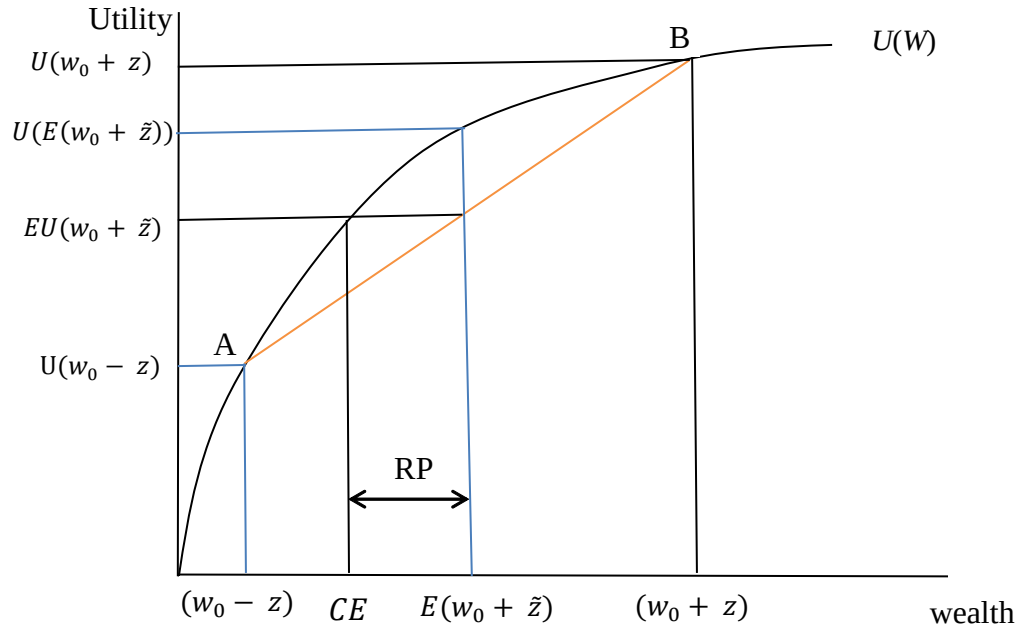


Figure 2 Graphical representation of utility function for risk-averse decision maker

Most farmers are risk averse, i.e. they would accept a lower monetary value for certain than the expected monetary value of the risky decision alternative (Koundouri et al. 2006; Lambert

and Lowenberg-DeBoer 2003). The CRRA assumptions means that preferences among risky technology prospects are unchanged if all payoffs are multiplied by a positive constant, such as initial wealth (w_0) (Hardaker et al. 2004). Therefore, as Arrow (1965) suggested, it is reasonable to assume that the coefficient of relative risk aversion remains more or less constant when wealth changes.

Eeckhoudt et al. (1996) suggested that relative risk aversion does not decline as wealth increases. Hamal and Anderson (1982) found that, in extremely resource constrained farming conditions, the coefficient of the relative risk aversion might be as high as four or more. Anderson and Dillon (1992), estimated the degree of relative risk aversion with respect to wealth between 0.5 and 4. Arrow (1965) found the value of relative risk aversion coefficient to be around one. This study evaluates the CRRA utility function over a range of risk aversion levels.

2.4 Conceptual Model

Technology adoption at the individual farmer level is defined as the degree of use of a new technology in long-term equilibrium when the farmer has full information about the new technology and the technology's expected potential (Feder et al. 1985). An innovation is one that alters the farm production function. A production function is the maximum amount of output that can be produced (through the use of a given production technology) with a given amount of input. Uncertainty diminishes over time through the acquisition of experience and information, and the production function itself may change as adopters become more efficient in the application of the technology (Feder and Umali 1993). Furthermore, the production function may be a source of uncertainty for the farmer.

The decisions of farmers are assumed to be derived from the maximization of expected utility of profit (Ayele 2009). Profit is a function of the farmer's choices of input and technology

during a specific time period. In the context of CAP, profit depends on the selection of a technology from available technologies including conventional methods and a set of conservation technologies (Feder et al. 1985).

When outcomes are known for certain and markets are competitive: (i) increasing the price of an output leads to an increase in output, (ii) increasing the price of an input decreases the use of the input, (iii) the marginal cost of production equals the price of output, (iv) the ratio of input prices is equal to the ratio of marginal products, and (v) input and output decisions are independent of fixed costs and wealth (Nicholson 2005). When outcomes are a matter of chance, many of these conventional relationships may no longer hold.

Two major types of risks faced by producers are production risk and price risk (Anderson and Dillon 1992). Production risks are those arising from natural causes including variation in weather, pests, or diseases and their impacts on yields. Price risks affect the prices of the commodities farmers produce and the inputs they purchase (Sadoulet and De Janvry 1995).

A general specification of a production function assumes linearity in the random variable:

$$y = f(X, Z) + h(X, Z)\varepsilon$$

where y is output, X is a vector of input with parameter Z , $f(X, Z)$ is the mean output function, $h(X, Z)$ is the variance function (risk function) and ε is an error term with $E(\varepsilon) = 0$ and $\text{var}(\varepsilon) = \sigma_\varepsilon^2$ (Just and Pope 1978). According to the Just and Pope production function, mean variance is $E[y] = f(X, Z)$ and output variance is $\text{var}(y) = [h(X, Z)]^2 \sigma_\varepsilon^2$. In this context, an input k is risk increasing (decreasing) if the partial derivative $h_k(X, Z) > (<) 0$.

Consider the case where output and input markets are given, prices are known with certainty, and production is uncertain. Assume that farmers maximize the expected utility of

profit $E(U(\pi))$ to choose optimal input quantities, which in turn determines output supply (SC Kumbhakar, 2001). The profit (π) model is

$$\begin{aligned}\pi &= py - wX = p \times f(X, Z, \text{CAP} = j) - w \times X + p \times h(X, Z, \text{CAP} = j)\varepsilon \\ &= \mu_\pi + p \times h(X, Z, \text{CAP} = j)\varepsilon\end{aligned}$$

where $\mu_\pi = pf(X, Z, \text{CAP} = j) - wX$, p is the output price and w the price of variable inputs, and j indicates use of conventional ($j = 0$), basins ($j = 1$) or jab planter ($j = 2$) technologies.

The first-order conditions of expected utility of profit $E(U(\pi))$ maximization is

$$E(U'(\pi)\{f_k(X, Z, \text{CAP} = j) - w_k + h_k(X, Z, \text{CAP} = j)\varepsilon\}) = 0$$

where $U'(\pi)$ is the marginal utility of profit, $f_k(X, Z, \text{CAP} = j)$ and $h_k(X, Z, \text{CAP} = j)$ are partial derivatives of $f(X, Z, \text{CAP} = j)$ and $h(X, Z, \text{CAP} = j)$ functions with respect to input X_k , respectively.

Pope and Just (1978) argued that many risk-averse producers often over apply rather than under apply inputs (e.g., use excessive amounts of pesticides in the face of potential pest problems). This is because some inputs may reduce risk rather than increase it (e.g., irrigation). They demonstrated that a risk-averse producer may use more rather than less inputs than a risk neutral producer.

CHAPTER III – DATA DESCRIPTION

3.1 Agro-Ecological Zones of Mozambique

Mozambique is divided into three macro agro-ecological zones of the North, Centre and South. The country is further sub-divided by climate, soil type and elevation. The Central region is Mozambique's largest in terms of area. The central region spans several distinct agro-ecological zones, and agricultural conditions are generally favorable. The predominantly arid province of Tete is in the north. To the east lies the tropical and wet coastal province of Sofala.

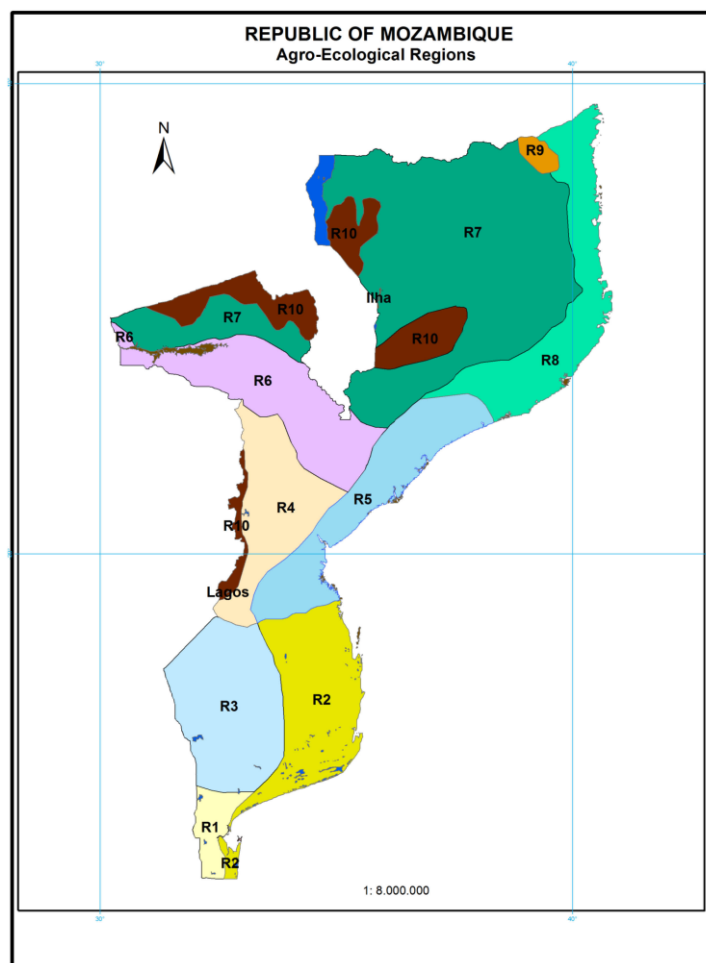


Figure 3 Agro-ecological zones of Mozambique

Source:(Gêmo and Chilonda 2013)

More inland is the Manica province, which has a cooler climate. The ten agro-ecological regions of the country (Figure 3) are denoted by R1 to R10, representing marginal, moderate to high agricultural potential (Gêmo and Chilonda 2013).

The Manica province is dominated by agro-ecological region R4 with a narrow strip of land along the border with Zimbabwe classified as the R10 agro-ecological region. The R4 region is characterized by medium altitudes (600 – 800 meters above sea level), with mean annual rainfall ranging from 400 to 500 mm and a mean annual temperature of 32.5⁰C. The dominant soil type is a mixture of fertile red-clay and shallow sandy soils (Maria and Yost 2006; Nkala et al. 2011). The districts of Gondola, Barwe, Sussundenga, Manica, and Guro and parts of Gorongosa of Sofala province are included in this region.

The Sofala province is in agro-ecological Region R5 is located on the eastern coastal plains (less than 350 meters above sea level), with mean annual rainfall ranging from 700 – 900 mm and mean annual temperature of 25⁰C. The soil types varies from sandy to sandy-loam (Nkala et al. 2011). The provinces of Nhamatnda and Buzi are included in this region.

The Tete province is in agro-ecological region R10 in the north which includes the high lands (usually more than 1000 meters above sea level). This climate is favorable to rain-fed crop production, with mean annual rainfall above 1,200 mm and air temperatures ranging from 15 to 22.5⁰C. Predominant soils are clay, which are fertile (Maria and Yost 2006). Tsangano and Angonia are included in this region.

3.2 Experimental Design of On-Farm Trials

The on-farm experiments were designed and coordinated by the International Maize and Wheat Improvement Center (CIMMYT) in the harvest year of 2008 – 2011 in the Central region districts of Sofala, Tete and Manica. There were n = 632 farmers in the 17 villages. Each farmer

managed a 3000 m² plot. Plots were divided into three treatment subplots of equal dimension of 50 × 20 m². Subplots were 10 m wide. The plots were installed and operated on the same farm and/or area for at least three seasons. Each maize subplot was divided further into sub-subplots comprising hybrid and open pollinated maize varieties.

The first treatment (the control) was managed using traditional ridge and tillage practices. Residues were cleared by burning or used as animal forage. Treatments 2 and 3 were CAP. In treatment 2 (basins), maize was planted in holes hand-excavated with a hoe. Basins were prepared with a spacing of 90 cm × 50 cm and were approximately 15 cm × 15 cm wide and 15 cm deep. In treatment 3, a jab-planter was used to plant maize.

Crop residues from the previous harvest year were maintained on the fields in the basins and jab planter treatments. If residues were removed from the CAP treatment (treatments 2 or 3) plots, 2.5 – 3 tons ha⁻¹ of residues (typically maize residues) from other source were applied. All maize plots were planted immediately after the first rains. The planting density was 44,000 plants ha⁻¹ in control and jab planter treatments.

Fields were treated with glyphosate in the basins and jab planter treatments at 2.5 L ha⁻¹ before planting (usually 1 – 7 days) 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, weeding was done using the most common mode of producer weed control (hand pulling or hoeing). In the basins and jab planter treatments, pre-harvest weed control was also done after the grain maturation. If weeds appeared at the end of the growing period, they were removed prior to seed production.

Fertilizer applications were the same for all treatments at 100 kg ha⁻¹ 12-24-12 (2.25gm per planting station) of nitrogen (N), phosphorous (P) and potassium (K), respectively. Fertilizer was applied during or shortly after planting. In the basins and jab planter treatments, fertilizer was applied to each side of planting stations and covered with soil. Urea was applied in two equal applications of 100 Kg ha⁻¹ on all the maize plots. The first application occurred when maize plants were approximately knee-high. The second application occurred 3 weeks later. The top dressing of urea was applied at 1.1gm per plant at each application.

3.3 Maize Prices and Input Costs

Partial budget analysis was conducted for the three treatments using the variable input costs and revenue from maize sales (Boughton et al. 1990; Upton 1987). Where possible, costs were collected at the village level. The variable costs include labor, seed variety, fertilizers (NP and K), herbicides and insecticides (which include glyphosate and cypermethrin). Where village level cost estimations were unavailable, the average costs for inputs and labor in district were used.

In almost all of the districts, the variable costs associated with the conventional farming system were higher compared to those of the CAP farming technologies (Table 1). This is due to the labor cost associated with the conventional treatment needed to prepare ridges and weeding. In the Tete province, CAP basins had higher variable cost than the conventional system due to the application of herbicides to all CAP farming plots and of insecticides to some CAP farming plots.

Maize prices were collected from the Mozambique Ministry of Agriculture (www.sima.minag.org.mz). Prices were based on the 2008 – 2011 provincial prices and were converted from Mozambique Metical kg⁻¹ to US dollars kg⁻¹. The 2008 price spike corresponds

with the 2007-2008 food price crises caused by concerns over drought in the Ukraine and Russia (Torero 2010). Input costs and maize prices are normalized to real 2010 US dollars (Table 1). Net returns are the difference between the revenue (yield kg ha⁻¹ multiplied by the US\$ kg⁻¹ price) and the total variable cost ha⁻¹.

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

	Real maize price (December 2010 USD kg ⁻¹)			
	2008	2009	2010	2011
Manica district	0.63	0.22	0.33	0.31
Sofala district	0.64	0.25	0.30	0.28
Tete district	0.63	0.24	0.23	0.28
	Average total costs (2010 USD ha ⁻¹)			
	Conventional	Basin	Jab planter	
Manica district	625.44	552.22	549.99	
Sofala district	659.02	626.95	608.44	
Tete district	596.07	644.63	571.06	

CHAPTER IV – METHODS AND PROCEDURES

4.1 Yield and Profit Mixed Model

On-farm trials conducted by farmers have been an established practice in agricultural research to transfer knowledge to farmers and encourage adoption of new technologies (Riley and Alexander 1997). It is important to conduct trials at many sites and in more than one year to develop a broader picture of the performance of multiple systems (Johnson 2006). Analysis of multi-environment trials is conveniently done using mixed models because of computational efficiency (Piepho et al. 2012). Mixed models are particularly useful with unbalanced data, which are quite common in on-farm experiments (Raman et al. 2011; Witcombe and Virk 2009). Mixed models are used to assess the source of variability in maize yields due to treatment effects, seasonality, and managerial differences between farmers. The profit and yields of the CAP are compared with the profit and yields from conventional practices using the on-farm trial model suggested by Schabenberger and Pierce (2001).

The mixed model ANOVA accounts for maize yield variability due to the difference in technologies, and other factors hypothesized to influence yield. Profit (net returns US\$ ha⁻¹) from each treatment are analyzed using the mixed model ANOVA as well.

The model used to analyze treatment effects on maize yield is:

$$Y_{ijkl\ell} = \mu_Y + \beta_k + \rho_{(k)j} + \tau_i + \beta\tau_{ki} + \gamma_t + \nu_\ell + \nu\tau_{\ell i} + e_{ijkl\ell}$$

For profit (π), the model is:

$$\pi_{ijkl\ell} = \mu_Y + \delta_k + \psi_{(k)j} + \theta_i + \delta\theta_{ki} + \phi_t + \eta_\ell + \eta\theta_{\ell i} + \varepsilon_{ijkl\ell}$$

The following notation pertains to both models:

$$\beta_k \approx iid(0, \sigma_\beta^2), \delta_k \approx iid(0, \sigma_\delta^2) \text{ (iid independent and identical distribution)}$$

$$\rho_{(k)j} \approx iid(0, \sigma_\rho^2), \text{ and } \psi_{(k)j} \approx iid(0, \sigma_\psi^2)$$

$$\beta\tau_{ki} \approx iid(0, \sigma_{\beta\tau}^2), \delta\theta_{ki} \approx iid(0, \sigma_{\delta\theta}^2)$$

$$e_{ijkl\ell} \approx iid(0, \sigma_e^2), \varepsilon_{ijkl\ell} \approx iid(0, \sigma_\varepsilon^2)$$

$Y_{ijkl\ell}$ is maize yield (kg ha⁻¹)

$\pi_{ijkl\ell}$ is maize net return (US\$ ha⁻¹)

μ_Y and μ_π are overall mean yield (kg ha⁻¹) and net return (US\$ ha⁻¹), respectively

$e_{ijkl\ell}$ and $\varepsilon_{ijkl\ell}$ are random errors

Fixed effects:

τ_i and θ_i are the effects of i^{th} treatments, $i = 1, 2, 3$

γ_t and ϕ_t are the effects of the t^{th} harvest year, $t = 2008, 2009, 2010, 2011$

ν_ℓ and η_ℓ are the effects of the ℓ^{th} varieties, $\ell = 1, \dots, 9$

$\nu\tau_{\ell i}$ and $\eta\theta_{\ell i}$ are the variety-by-treatment interaction effects

Random effects:

β_k and δ_k are the effects of the k^{th} village $k = 1, \dots, 17$

$\rho_{(k)j}$ and $\psi_{(k)j}$ are farmer within village effects

$\beta\tau_{ki}$ and $\delta\theta_{ki}$ are village-by-treatment interaction effects

The variance terms are σ_β^2 and σ_δ^2 (village error), σ_ρ^2 and σ_ψ^2 (farmer within village error), $\sigma_{\beta\tau}^2$ and $\sigma_{\delta\theta}^2$ (village-by-treatment interaction error) and σ_e^2 and σ_ε^2 (random error of the model). The yield and net return models were estimated separately, testing the null hypothesis that maize yield and net returns of each treatment are not different.

The effects ‘treatment τ_i and θ_i , harvest year γ_t and ϕ_t , and variety ν_ℓ and η_ℓ in each model are fixed effects. The fixed effects of the treatments are included to estimate separate

means for each of the treatments. Treatments and varieties are considered fixed effects, and so too are their interactions $\nu\tau_{\ell i}$ and $\eta\theta_{\ell i}$.

Variations among villages are random effects β_k and δ_k . Farmers live in villages, so the farmer effects are random effects and nested in each village $\rho_{(k)j}$ and $\psi_{(k)j}$. The effect of the interaction between treatment (technology) and farmer is also a random effect $\beta\tau_{ki}$ and $\delta\theta_{ki}$.

Mean Comparison of Profit and Yield

The null hypothesis is that distribution of net returns and yield generated by CAP are not different from the net returns or yields of conventional agronomic practices. In other words, there is no expected difference between the means of profit and yield associated with the three farming practices. The alternative hypothesis is that the CAP technologies net return and yield are different than those generated from the conventional farming system.

4.2 Risk Analysis Methods

An analysis of net returns of the tillage system alternatives across a range of risk preferences is conducted to supplement the statistical comparison. The risk aversion level of farmers is generally unknown. Therefore, the risk preferences for the tillage alternatives are calculated over a range of risk aversion levels.

4.2.1 Mean-Variance Criterion

One method to compare the riskiness of technologies is to examine the mean and variances of returns. This approach assumes that the dominant alternative must have either a higher mean for a given 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 net return distributions, the mean-variance criterion predicts farming system A is preferred to B if the mean

net return of farming system A is greater than the mean of B and the variance around the mean net return of A is less than or equal to the variance of B. If the mean net return and variance of A are both larger than the mean and variance of B, the mean-variance criterion cannot rank the alternative technologies (Hardaker et al. 2004). The coefficient of variation associated with the returns of each technology supplements the mean-variance comparisons.

4.2.2 Stochastic Dominance

In the case where the alternative technologies cannot be ranked with mean-variance criteria additional assumptions about the farmer's risk preferences should be considered. Given two alternatives A and B, each with a probability distribution of outcomes ' π ' defined by CDF's $F_a(\pi)$ and $F_b(\pi)$, alternative A will dominate alternative B in the first-degree sense if:

$$F_a(\pi) \leq F_b(\pi)$$

for all π with at least one strict inequality (Schumann 2006). The three farming systems are compared against each other, represented technology A as CAP and the conventional practice as B. If the CDFs of A are below and to the right the CDFs of B over the whole range or the CDFs of A and B are equal everywhere except for one point where the CDF of A is below and to the right of CDF of B, then A dominates B in the first degree (Hardaker et al. 2004).

A problem arises if the CDF's of each alternative cross. The second degree stochastic dominance (SSD) rule selects distributions that have a smaller area under their cumulative probability distribution than technology alternatives that are not (Lowenberg-DeBoer 1999). A SSD preferred technology means that alternative A is preferred to alternative B if:

$$\int_{-\infty}^x F_a(\pi)dx \leq \int_{-\infty}^x F_b(\pi)dx$$

for all values of π with at least one strong inequality (Schumann 2006).

Stochastic dominance results are estimated using Simetar© software (Richardson et al. 2007). The FSD and SSD results are statistically supplemented using the Kolmogorov-Smirnoff test, a non-parametric procedure to test the equality of distributions (Smirnov 1939). The null hypothesis is the net return distributions of the three technologies are not different.

4.2.3 Certainty Equivalent and Risk Premium Analysis

This procedure identifies and orders utility efficient alternatives in terms of certainty equivalents (CE) for a specified risk preference. It is typically assumed that farmers prefer more wealth to less and are risk-averse, i.e., $U'(w) > 0$ and $U''(w) < 0$ (Clemen and Reilly 2001; Lambert and Lowenberg-DeBoer 2003). Therefore, utility is represented as a monotonically increasing concave function. Because the value of the risk aversion coefficient could vary according to the initial wealth, the power utility function is used to reflect constant relative risk averse individuals:

$$U(w) = \begin{cases} \frac{(\pi_i + w_0)^{1-r_r(w)}}{1-r_r(w)}, & \text{if } r_r > 0, r_r \neq 1 \\ \pi_i + w_0, & \text{if } r_r = 0 \\ \log(\pi_i + w_0), & \text{if } r_r = 1 \end{cases}$$

where $U(w)$ the farmer's utility function, π_i is the expected net return ha^{-1} from a technology, $r_r(w)$ is constant relative risk aversion coefficient with respect to wealth, and w_0 is the initial wealth of the farmer.

The certainty equivalent (CE) is the amount of money for certain that provides a risk averse decision maker the same level of utility as the expected utility of a risky alternative (Clemen and Reilly 2001). Ranking alternative technologies by the CE is equivalent to ranking

the utility function by expected utility in the order preferred by the decision maker (Hardaker et al. 2004). The CE is the inverse of the expected utility function U :

$$CE((\pi_i + w_0), r_r(w)) = U^{-1}((\pi_i + w_0), r_r(w)).$$

This implies from above:

$$CE = \begin{cases} (E(U(\pi_i)) \times (1 - r_r))^{\frac{1}{1-r_r}} - w_0, & \text{if } r_r > 0, r_r \neq 1 \\ e^{(E(U(\pi_i)))} - w_0, & \text{if } r_r = 1 \end{cases}$$

where $r_r(w)$ is the risk aversion coefficient with respect to wealth. Strategies with higher CE are preferred to those with lower CE. Under this assumption, farmers view a risky strategy for a specific level of risk aversion the same without regard for their level of wealth.

The difference between the CE and the expected value of the risky alternative technology is the risk premium (RP). The RP measures of the cost of the combined effects of risk and risk aversion (Hardaker et al. 2004).

$$RP = E(\pi) - CE$$

where $E(\pi)$ is expected net return.

The value of the technology to a risk averse decision maker ($VTech$) is calculated by subtracting the CE of the less preferred strategy B from the CE of an alternative preferred strategy A where:

$$VTech(A, B, r_r) = CE(A, r_r) - CE(B, r_r)$$

where ($VTech$) is the value of the technology to a risk averse farmer with risk preferences represented by $r_r(w)$. The value a risk averse producer attributes to a technology changes as their degree of risk aversion increases or decreases.

Null Hypotheses Related to Technology Risk

The null hypothesis is that the empirical distributions of net returns for CAP technologies are the same as the empirical distribution of net return for conventional farming practices. The alternative hypothesis is that the empirical distributions of net returns for CAP technologies are different from the empirical distribution of net returns for conventional farming systems. In the case of the alternative hypothesis, CAP technologies will stochastically dominate conventional tillage methods at all levels of risk aversion.

4.3 Risk Analysis Procedure

4.3.1 Relative Risk Aversion Assumptions

Using the power utility function, the net returns ha^{-1} of each technology are evaluated over a range of risk aversion levels. The range of r_r is between the $r_r^{low} < r_r < r_r^{up}$, with the upper risk aversion coefficient limit (r_r^{up}) determined using the method outlined in Lambert and Lowenberg-DeBoer (2003). The lower bound (r_r^{low}) was set to zero (risk neutrality) and the upper bound was set to the risk coefficient value that drove the certainty equivalent associated with a technology to zero.

4.3.2 Simulation Methods for Certainty Equivalent Comparison

Sensitivity analysis were used to rank the impacts of farmer wealth endowments and the growing conditions characteristics to different agro-ecological zones, given different assumptions about decision maker risk aversion. This analysis is carried out by the following steps.

First, the initial wealth was calculated using survey data of McNair et al. (2015). The wealth assets of 339 smallholder farmers were classified according to the possessions they

owned. These possessions include, 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, motos, bikes, cars and trucks (McNair et al. 2015). The sum-product of each possession and the monetary values reported by respondents proxy household wealth. The 25th, 50th and 75th quantiles were used to proxy different initial wealth (w_0) levels in the simulations. The monetary values of these possessions were given in Mozambique's metical and converted to 2010 US dollars.

The certainty equivalent associated with the estimated net returns ha^{-1} from conventional, basins and jab planter methods are calculated at an initial wealth level of US\$ 70, the median wealth of producers determined from an area survey of farmers in Mozambique (Table 2) (McNair et al. 2015).

Table 2 Initial wealth level at the 25th, 50th and 75th quantile in 2010 US\$ for different groups of maize farmers

Group	N	25th quantile	Median	75th quantile
Conventional users	214	10.07	52.56	141.61
CAP users	125	31.97	103.36	321.18
Weighted value		18	70	205

Note: weighted values are calculated as the sum product of wealth level and the number of observation (weight) and divided by the sum of weights.

Source: (McNair et al. 2015)

Two hypotheses were developed in relation to the base scenario:

1. The initial wealth endowment of farmers may change the value of the technology associated with the different farming technologies, and

2. The crop growing conditions of different agro-ecological zones may be correlated with the risk associated with each farming technology.

To test the first hypothesis, two scenarios of initial wealth level were considered; US\$ 18.00 (the 25th wealth quantile) and US\$ 200.00 (the 75th wealth quantile). The hypothesis that the initial wealth endowment of a smallholder farmer may change the value of technology was evaluated using the certainty equivalent analysis at different levels of initial wealth.

Subsets of data are generated by sorting the on-farm trial sites into three agro-ecological zones according to elevation: high altitude (villages located at an altitude above 800m), medium altitude (villages located at an altitude between 350m and 800m), and low altitude (villages located at an altitude less than 350m). The hypothesis that the degree to which an alternative farming system will be risk preferred may vary according to agro-ecological zones.

CHAPTER V – RESULTS

5.1 Economic and Statistical Analysis of Maize Profit and Yield

5.1.1 Univariate Comparison of Maize Yield

The average maize yield across all sites over the four year study period (2008 – 2011) was 2476 kg ha⁻¹. This compares well above the average maize yield of 1,088 kg ha⁻¹ in Mozambique reported during the same period (FAOSTAT, 2014).

Maize yield means (mean $\pm$ standard error, s.e.) obtained from the jab planter [2607 $\pm$ 70 kg ha⁻¹] and basins [2543 $\pm$ 70 kg ha⁻¹] technologies were higher than the conventional technology [2292 $\pm$ 62 kg ha⁻¹] (Table 3). Comparing the three farming technologies across the districts indicate that Angonia and Tsangano recorded the highest maize yields. These districts are located in the highest elevation zone. The Guro district, located in the mid elevation zone,

Table 3 Conventional planting, basin planting and jab planting on - farm trial maize yields (mean $\pm$ standard error), Mozambique, 2008 – 2011.

District Name	n	Conventional		Basins		Jab planter	
Angonia	85	3769	$\pm$ 160 a	4052	$\pm$ 139 a	4085	$\pm$ 144 a
Barwe	153	2515	$\pm$ 130 b	2875	$\pm$ 152 ab	3097	$\pm$ 155 a
Buzi	162	1283	$\pm$ 68 a	1187	$\pm$ 67 a	1360	$\pm$ 75 a
Gondola	16	1580	$\pm$ 217 a	1813	$\pm$ 290 a	1936	$\pm$ 258 a
Gorongosa	20	1359	$\pm$ 217 b	2255	$\pm$ 287 a	1754	$\pm$ 224 ab
Guro	10	400	$\pm$ 27 b	627	$\pm$ 51 a	652	$\pm$ 45 a
Manica	10	1048	$\pm$ 271 a	1039	$\pm$ 120 a	760	$\pm$ 94 a
Nhamatanda	72	2013	$\pm$ 153 a	2549	$\pm$ 178 a	2554	$\pm$ 211 a
Sussundenga	19	1451	$\pm$ 172 a	1658	$\pm$ 183 a	1566	$\pm$ 189 a
Tsangano	85	3484	$\pm$ 122 a	3818	$\pm$ 163 a	3678	$\pm$ 144 a
Weighted mean		2292	$\pm$ 62 b	2543	$\pm$ 70 a	2607	$\pm$ 70 a

Note: Means in rows with the same letter are not different at the 5% level

recorded the lowest maize yields (Table 3). Comparison of mean differences were calculated using t-tests at $\alpha = 0.05$. There are no yield differences among the different technologies in the high yielding districts of Angonia and Tsangano. In the low yielding district of Guro, maize yields produced under the CAP technologies is significantly higher than maize yields produced under the conventional system. Seven of the ten regions exhibited no significant differences in mean maize yield between the different systems. In the Barwe district, there was no significant yield difference between conventional and basin technologies. In the Gorongosa district, there were no significant differences between conventional and jab planter technology yields. Figure 4 summarizes the mean yields with standard errors. When the standard error (SE) bars overlap, the difference between two means is not statistically significant ($P > 0.05$). This result suggests there are no differences in maize yields in the Gondola and Sussundenga districts across the three farming systems ($P > 0.05$). No statistical differences were evident between the basin and conventional technologies in the Angonia, Buzi and Manica districts. The maize yield from the jab planter and conventional farming systems were not different in Gorongosa and Manica districts. It is evident that the performance of these technologies, in terms of yield advantages, depends on elevation.

The CAP technologies appear to have yield advantages over the conventional farming method. The t-tests of Table 4 indicate that the mean maize yields differed significantly between the CAP and the conventional farming systems CAP basins vs conventional $t = 2.68$, $P = 0.0075$; and CAP jab planter vs conventional $t = 3.35$, $P = 0.0008$. There is no difference between the mean yields of the CAP technologies ($t = 0.65$, $P = 0.5132$).

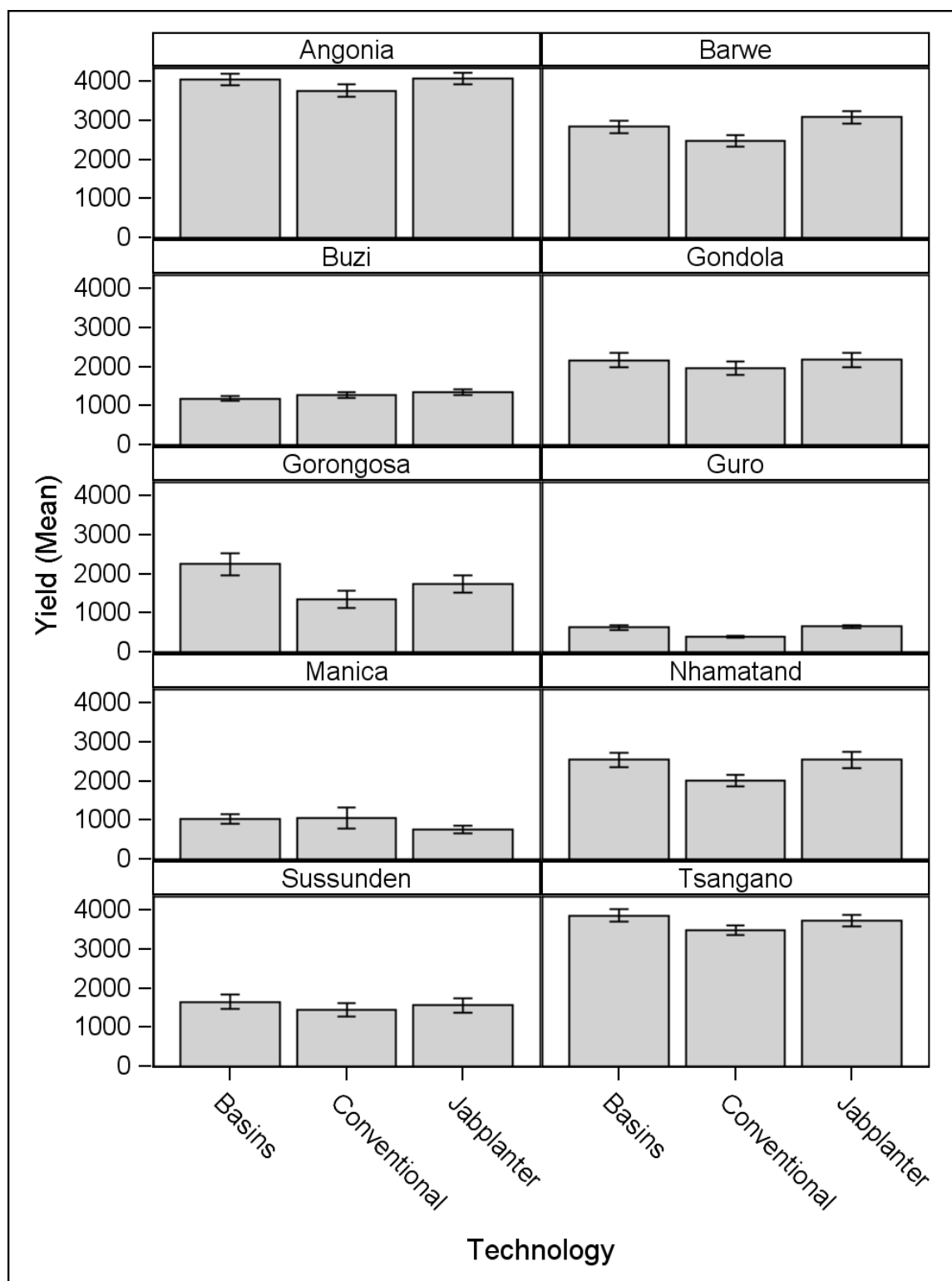


Figure 4 Regional mean maize yields (kg ha⁻¹) and standard errors Mozambique (2008 - 2011).

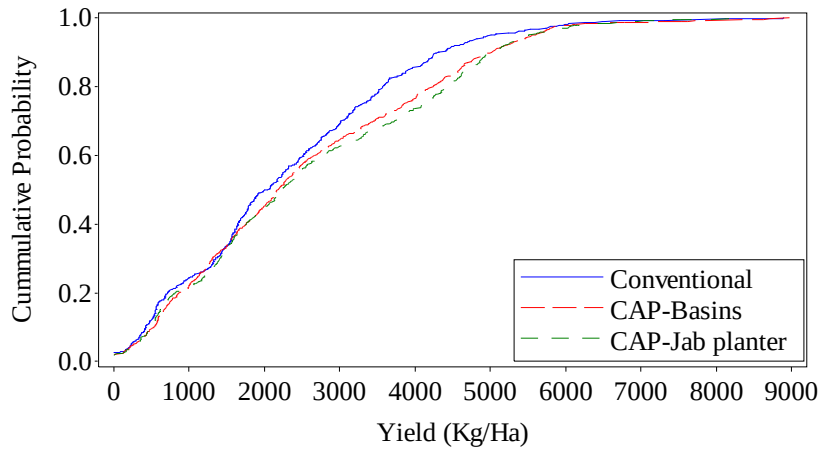
Table 4 Comparison of conventional, basin and jab planter technologies by mean maize yield and elevation, Mozambique, 2008 - 2011.

Technology	Mean Difference kg ha ⁻¹	Std Dev	t Value	Pr > t
Combined				
Basins – Conventional	250	1663	2.68	0.0075
Jab planter – Conventional	315	1671	3.35	0.0008
Jab planter – Basins	65	1761	0.65	0.5132
Altitude >800 m				
Basins – Conventional	331	1363	2.25	0.0248
Jab planter – Conventional	279	1328	1.95	0.0519
Jab planter – Basins	-52	1369	-0.35	0.7247
Altitude between 350 and 800 m				
Basins – Conventional	293	1667	1.78	0.0751
Jab planter – Conventional	446	1718	2.64	0.0087
Jab planter – Basins	153	1824	0.85	0.3940
Altitude <350 m				
Basins – Conventional	161	1174	1.54	0.1231
Jab planter – Conventional	233	1219	2.15	0.0317
Jab planter – Basins	72	1316	0.62	0.5372

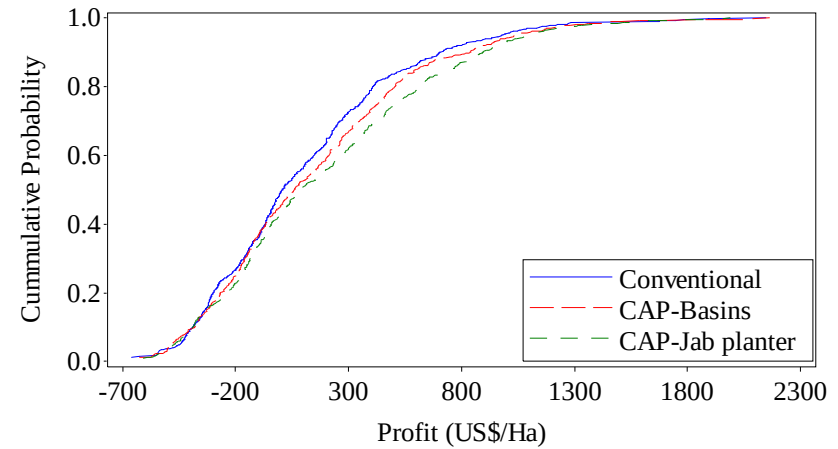
Yield Distributions

The empirical distribution of yields for the CAP technologies lies below and to the right of the conventional farming system with crosses in cumulative probability of around 0.30 and 0.35. This indicates that for most part of the empirical distributions the yields of the CAP technologies are preferred to that of the conventional farming system (Figure 5 A). The K-S test (Appendix A Table A1) of the same distribution shows that there is a significant yield difference between the basins and conventional practices (D-static = 0.0997, P = 0.0037) as well as jab planter and conventional (D-static = 0.1313, P = 00.0001). No significant differences between the CAP technologies (D-static = 0.0459, P = 0.5188) were observed.

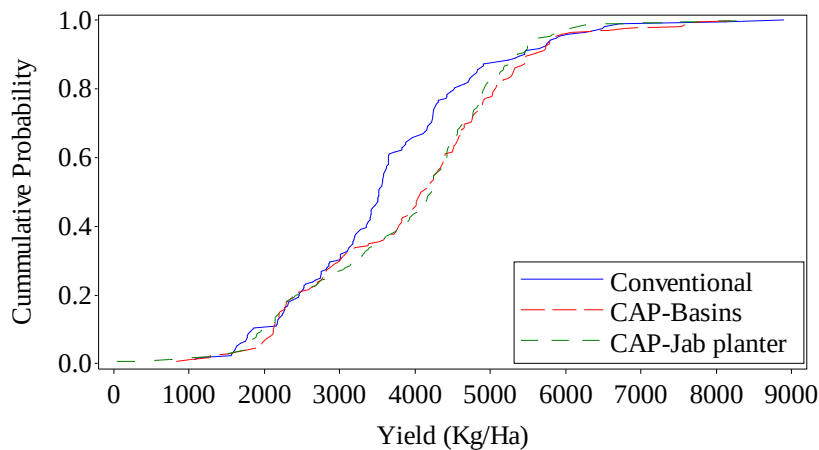
Figure 5 A – H: Empirical cumulative distribution functions for maize yields and net returns in different altitudes, Mozambique 2008 – 2011



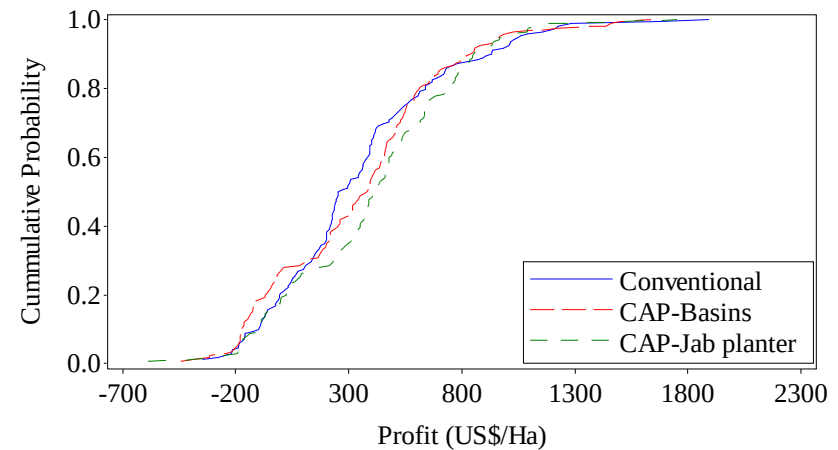
A. Maize Yield: combined Mozambique (2008-2011)



B. Maize Profitability: combined Mozambique (2008-2011)

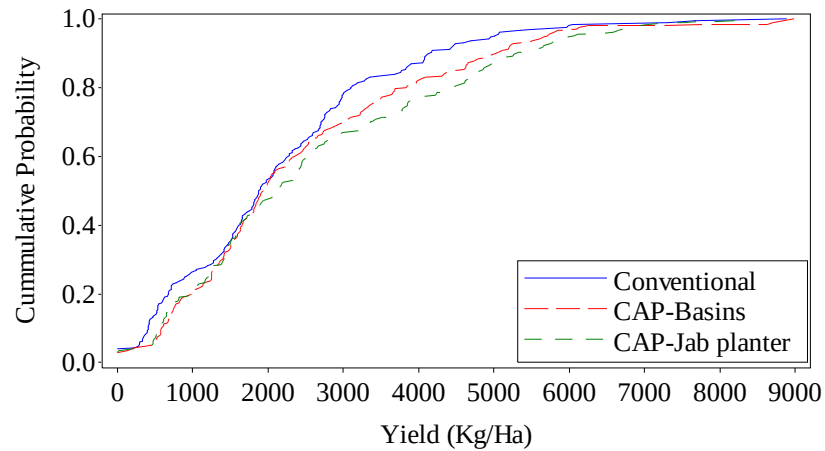


C. Maize Yield: >1000m Mozambique (2008-2011)

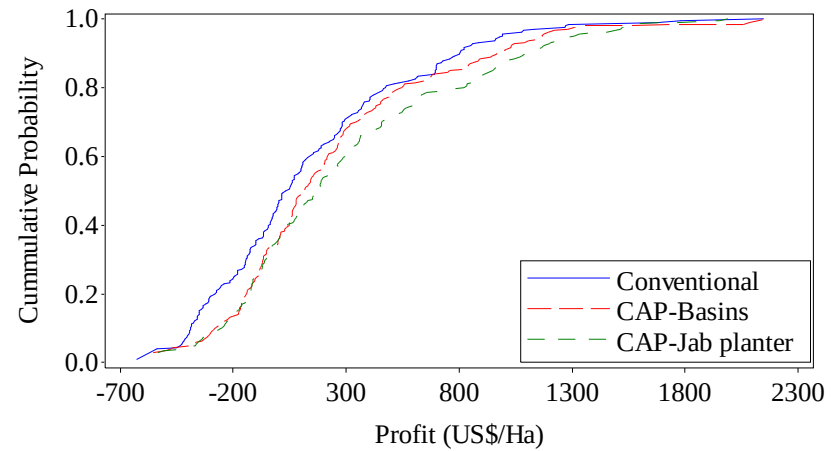


D. Maize Profitability: >1000m Mozambique (2008-2011)

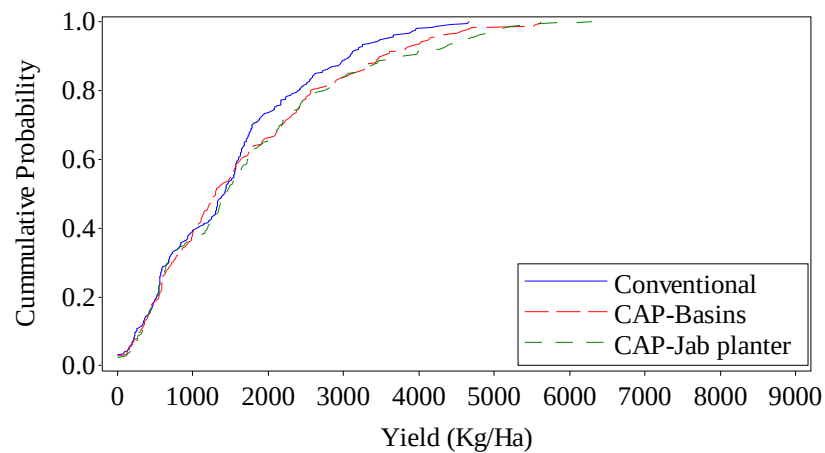
Figure 5 continued



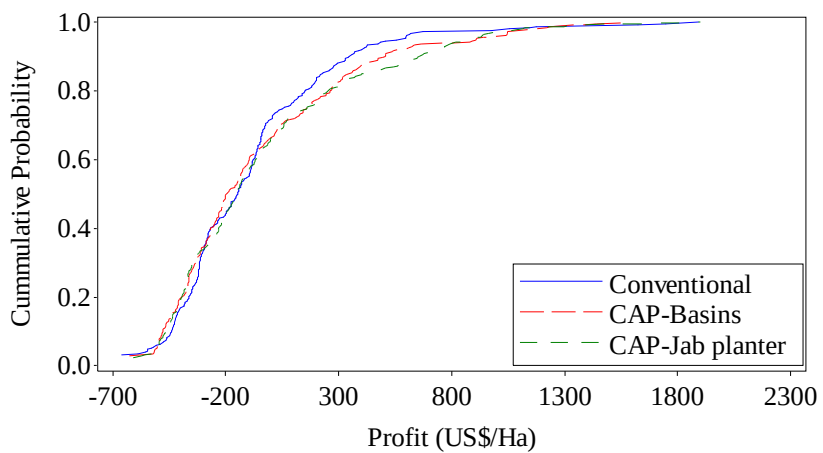
E. Maize Yield: 350 to 800m Mozambique (2008-2011)



F. Maize Profitability: 350 to 800m Mozambique (2008-2011)



G. Maize Yield: Altitude <350m Mozambique (2008-2011)



H. Maize Profitability: <350m Mozambique (2008-2011)

Figure 5 continued

5.1.2 Univariate Comparison of Net Returns

The average net returns (mean $\pm$ s.e) are higher for basins (US\$ 148 $\pm$ 19 ha⁻¹) and jab planter (US\$ 195 $\pm$ 18 ha⁻¹) technologies than those of the conventional farming system (US\$ 104 $\pm$ 20 ha⁻¹) (Appendix A Table A2). The districts of Buzi, Guro and Sussundenga exhibited negative net returns for all technologies. Moreover, the districts of Gorongosa and Nhamatanda

Table 5 Comparison of conventional, basin and jab planter technologies by maize net returns US\$ ha⁻¹, Mozambique, 2008 - 2011.

Technology Comparison	Mean Difference	Std Dev	t value	Pr > t
Combined				
Basins - Conventional	44	465	1.68	0.0923
Jab planter - Conventional	91	476	3.38	0.0007
Jab planter - Basins	47	489	1.69	0.0906
Altitude >800 m				
Basins - Conventional	0	394	0.01	0.9943
Jab planter - Conventional	61	386	1.46	0.1442
Jab planter - Basins	61	388	1.47	0.1437
Altitude between 350 and 800 m				
Basins - Conventional	97	490	2.00	0.0459
Jab planter - Conventional	161	506	3.22	0.0014
Jab planter - Basins	64	519	1.25	0.2111
Altitude < 350 m				
Basins - Conventional	32	406	0.88	0.3807
Jab planter - Conventional	54	415	1.47	0.1434
Jab planter - Basins	22	438	0.57	0.5656

produced negative net returns from the conventional farming system. Manica farms also experienced negative net returns from the jab planter technology. As in the case of maize yield,

Angonia and Tsangano districts generated the highest net returns from maize. The district of Guro experienced the lowest net returns, especially from the conventional farming method. Pair-wise t-test comparisons of net returns suggest a statistically significant difference between the jab planter and conventional farming technologies ($t = 3.38$, $P = 0.0007$) (Table 5). There were no differences in net returns between basins and the conventional farming methods ($t = 1.68$, $P = 0.0923$), or between the CAP farming technologies ($t = 1.69$, $P = 0.0906$).

Figure 5 B suggests that nearly fifty percent of the farmers using the conventional farming system experienced negative net returns during the experiment, compared to 43 percent of the net returns from the basins and jab planter practices. Net returns are higher than the weighted mean net return level of US\$ 149 ha⁻¹, approximately 48 percent with CAP technologies, but only 38 percent with the conventional tillage system.

5.2 Multivariate Mixed Model Results: Yield, Profit

5.2.1 Yield Mixed Model ANOVA

Holding other factors constant, there are no treatment effects that explain variation in maize yield at the 5% level (F-value = 2.69, $P = 0.0748$) (Table 6). Treatment effect may be absorbed by interactions between villages and treatments (Schabenberger and Pierce 2001). Noting that basins and jab planter technologies outperformed the conventional farming methods at different elevations, a more conclusive examination is required to address possible treatment masking by interaction effects. This requires testing the null hypothesis for interaction between villages and treatment variation, $H_0: \sigma_{\beta\tau}^2 = 0$. To test the hypothesis a likelihood ratio test is conducted. This method compares the -2 Res Log Likelihood of the full model accounting for all interactions and a reduced model omitting interactions (Schabenberger and Pierce 2001). From

the full model, the -2 Res Log Likelihood = 32,532. For the reduced model, the -2 Res Log Likelihood = 32,810. Therefore, likelihood ratio test statistic = 32,810 – 32,532 = 278.27. The p – value of the likelihood ratio test of $H_0: \sigma_{\beta\tau}^2 = 0$ is thus $\Pr(\chi^2 \geq 278) < 0.0001$, implying that there is a significant interaction effect between villages and treatments.

Table 6 Summary of Mixed Model ANOVA results for the on-farm trial mean maize yield (Kg ha⁻¹), Mozambique, 2008 – 2011.

Covariance Parameter	Estimate	Standard Error	Z Value	Pr > Z
Village	814562	320507	2.54	0.0055
Farmer (Village)	545100	76150	7.16	<0.0001
Village × Technology	14859	8911.43	1.67	0.0477
Residual	721240	24889	28.98	<0.0001
Effect			F Value	Pr > F
Technology			2.69	0.0748
Harvest Year			95.46	<0.0001
Variety			41.31	<0.0001
Technology × Variety			0.77	0.7514

Note: Covariance parameter estimates are the square roots of the diagonal elements of the observed inverse Fisher information matrix, which equals $2\mathbf{H}^{-1}$

There is a significant effect for harvest year and varieties. However, the interaction between variety and technologies indicates no significant differences across the villages (F-value = 0.77, P = 0.7514). The estimated variance values of the village effect $\sigma_{\beta}^2 = 814,562$, the farmer within village effect $\sigma_{\rho}^2 = 545,100$, village and technology interaction effect $\sigma_{\beta\tau}^2 = 14,859$ and the residual $\sigma_e^2 = 721,240$, are significantly different from 0 (Table 6).

The regression model in Appendix A Table A3 is consistent with the mixed model ANOVA results. Harvest years 2008 and 2010 ($\alpha = 0.05$) and 2009 ($\alpha = 0.01$) had positive and significant coefficients. A significant ($\alpha = 0.05$) and positive coefficients for all varieties were observed, except for *Area nao adubada* which had a negative coefficient. All the variety and treatment interactions were not significant.

5.2.2 Net Return Mixed Model ANOVA

In the maize net return mixed model analysis, there are no significant differences among treatments (F-value = 2.04, P = 0.1419). A likelihood ratio test was conducted to test the null hypothesis there is no significant interaction between village and treatments. From the full model, the -2 Res Log Likelihood = 27,852. For the reduced model, the -2 Res Log Likelihood = 28,081. Therefore, likelihood ratio test statistic = $28,081 - 27,852 = 229$. The p – value of the likelihood ratio test of $H_0: \sigma_{\delta\theta}^2 = 0$ is thus $\Pr(\chi^2 \geq 229) < 0.0001$, implies that there is a significant interaction between villages and treatments. The estimated variance values of the village effect σ_{δ}^2 , farmer within village effect σ_{ψ}^2 , village and technology interaction effect $\sigma_{\delta\theta}^2$ and the residual σ_{ϵ}^2 are significantly different from 0.

Appendix A Table A4 suggests there is evidence of differences in net returns by harvest year and varieties ($p < 0.0001$). The interaction between varieties and technologies was not significant.

5.3 Risk Analysis Results

5.3.1 Mean-Variance and Stochastic Dominance Criteria Results

Table 7 shows that the basins and jab planter tillage systems generated the highest mean net returns but had relatively higher standard deviations around their means (s.d = 478 and 499,

respectively) compared to the conventional farming system standard deviation ($s.d = 452$). Examining the coefficient of variations, the jab planter has the smallest ($CV = 2.56$), followed by basins ($CV = 3.23$) and lastly the conventional farming system ($CV = 4.35$). The return distributions are right skewed. Most values are concentrated to the left of the mean, with long tails in the positive direction. Returns from the jab planter technology were least skewed ($S = 0.74$) compared to basins ($S = 0.97$) and conventional systems ($S = 1.09$) (Table 7). In terms of upside variability, the kurtosis of jab planter ($K = 0.23$) is preferred followed by basins ($K = 1.22$) and then the conventional system ($K = 1.67$) (Table 7). The jab planter is the preferred technology followed by basins and lastly conventional farming methods when ranked by the mean-variance criteria by this definition of risk preference.

The net returns cumulative distribution functions (CDFs) for the conventional, basins and jab planter tillage systems are shown in Figure 5 B. The CDFs of the technologies cross each other at multiple points, including intersections in the negative tails. Therefore, none of the technologies exhibit first-degree stochastic dominance. This implies risk-averse farmers will be unable to unambiguously differentiate a risk preferred technology.

The jab planter is the preferred farming system for risk neutral farmers because it exhibits a higher net return (US\$ 195 ha⁻¹), followed by the CAP basins (US\$ 148 ha⁻¹) and the conventional farming exhibits the lowest net return (US\$ 104 ha⁻¹). Table 7 suggests the conventional farming method generated the lowest maize net return ha⁻¹ (-US\$ 659 ha⁻¹), followed by basin net returns (-US\$ 627 ha⁻¹) and jab planter net returns (-US\$ 608 ha⁻¹). The conventional farming method would be always ranked last compared to the CAP technologies by risk-averse producers. The basin technology would be less preferred to the jab planter technology by risk-averse producers.

Table 7 Summary statistics comparing maize net returns US\$ ha⁻¹ for conventional, basin and jab planter technologies, Mozambique, 2008 - 2011.

	Conventional	Basins	Jab planter
Combined:			
Weighted mean	104	148	195
CV*	4.35	3.23	2.56
Standard deviation	452	478	499
Skewness	1.09	0.97	0.74
Kurtosis	1.67	1.22	0.23
Minimum	-659	-627	-608
Maximum	2146	2165	1989
<i>N</i>	632	632	632
Altitude ≤ 350 m:			
Weighted mean	-88	-57	-35
CV	-4.3	-7.55	-12.92
Standard deviation	381	429	446
Minimum	-659	-626	-608
Maximum	1892	1588	1899
<i>N</i>	254	254	254
Altitude Between 350 and 800 m:			
Weighted mean	139	236	300
CV	3.42	2.13	1.79
Standard deviation	475	503	535
Minimum	-625	-554	-534
Maximum	2146	2165	1989
<i>N</i>	206	206	206
Altitude > 800 m:			
Weighted mean	346	346	406
CV	1.13	1.14	0.93
standard deviation	392	395	381
Minimum	-346	-442	-589
Maximum	1893	1636	1750
<i>N</i>	172	172	172

Note: *Coefficient of variation

The Kolmogorov-Smirnoff test statistically compares the distribution of net returns. The null hypothesis is that the distributions are the same. The empirical distribution of the net returns from the conventional and the jab planter technologies are different (KS D-static = 0.1187, P = 0.0003). Comparing the maize net returns of basins versus the jab planter technology (KS D-static = 0.0649, P = 0.1339) and the conventional method versus basins (KS D-static = 0.0712, P = 0.0812), the null hypothesis of distribution equality cannot be rejected.

a. Mean-Variance and Stochastic Dominance Analysis: Elevation > 800 m

In elevations higher than 800m, the jab planter is the risk preferred technology by the mean-variance criteria because it exhibited a higher net return (US\$ 406 ha⁻¹) with lowest standard deviation around its mean (s.d = 381) and lowest coefficient of variation (0.93) (Table 7). The net returns of the conventional farming methods and basins are tied at US\$ 346 ha⁻¹. The conventional system has slightly lower standard deviation around its mean net return (s.d = 392) and coefficient of variation (1.13) compared to the basin technology standard deviation (s.d = 395) and coefficient of variation (1.14). A pairwise t-test comparison of the three systems suggests there are no significant differences in mean net returns ha⁻¹ (Table 5).

The Kolmogorov-Smirnoff test shows a significant difference between the empirical distribution of jab planter and conventional farming system net returns. There are no significant differences between the net return empirical distributions of the jab planter and basins technologies, or between the basins and conventional farming systems (Table 8).

b. Mean-Variance and Stochastic Dominance Analysis: Elevation 350 – 800 m

In the mid-range elevation of 350m and 800m, the three farming technologies cannot be ranked by the mean–variance criteria because none of the technologies exhibit a higher net return and lower variance when pairwise comparisons are made. However, the jab planter exhibits the

lowest coefficient of variation of net returns ha^{-1} (1.79), followed by basin net return ha^{-1} (CV = 2.13), and lastly the conventional farming system net return ha^{-1} (CV = 3.42) (Table 7). Pairwise

Table 8 Comparison of the maize net returns US\$ ha^{-1} for conventional, basin and jab planter technologies, Mozambique, 2008 - 2011.

Technologies	D-statistic*	Pr(D $\geq$ 0)
Combined:		
Conventional vs. Basins	0.0712	0.0812
Conventional vs. Jab planter	0.1187	0.0003
Basins vs. Jab planter	0.0649	0.1399
Altitude $\leq$ 350 m:		
Conventional vs. Basins	0.0709	0.5464
Conventional vs. Jab planter	0.0906	0.2487
Basins vs. Jab planter	0.0551	0.8351
Altitude between 350 and 800 m:		
Conventional vs. Basins	0.1311	0.0581
Conventional vs. Jab planter	0.1311	0.0581
Basins vs. Jab planter	0.0825	0.4845
Altitude $>$ 800 m:		
Conventional vs. Basins	0.1279	0.1199
Conventional vs. Jab planter	0.1860	0.0052
Basins vs. Jab planter	0.1047	0.3030

Note: *Distance statistic, Kolmogorov-Smirnoff test of the equality between empirical distributions, $H_0 : D = 0$.

t-test comparisons suggest a significant difference between the CAP technologies and the conventional farming system, but no differences between basins and jab planter technologies. By this comparison smallholder farmers would prefer the CAP technologies over the conventional farming method (Table 5).

The empirical distribution of net returns indicates that the CAP technologies dominate the conventional farming methods by first degree stochastic dominance. The Kolmogorov-Smirnoff test (Table 8) suggests no difference between the distribution of net returns ha^{-1} for basins and jab planter technologies as well as basins and conventional farming methods.

c. Mean-Variance and Stochastic Dominance Analysis: Elevation < 350 m

In the low elevation region (less than 350m), the three farming technologies exhibited negative net returns; conventional (USD \$ -88), basins (USD \$ -57) and the jab planter (USD \$ -35). The jab planter exhibits the lowest coefficient of variation of net returns ha^{-1} (-12.91), followed by the basins CV of net returns ha^{-1} (-7.55), and lastly the conventional farming system CV of net returns ha^{-1} (-4.3) (Table 7). By this comparison smallholder farmers would prefer the CAP technologies, even though, the pairwise t-tests suggest there is no significant difference between the three farming systems (Table 5).

The empirical distributions suggest that the basins and jab planter technologies do not stochastically dominate the conventional farming method. The Kolmogorov-Smirnoff test indicates no significant differences between the net returns ha^{-1} distribution of basins, jab planter and the conventional farming systems (Table 8).

5.3.2 Certainty Equivalent Results

The r_r upper limit was set to 1.2 to incorporate the level of risk that drove the certainty equivalent associated with a technology to zero. The lower r_r limit is 0, which assumes risk neutrality. The CE curves were generated by calculating the CE values for each curve over the entire range of the risk aversion parameters. The initial wealth, w_0 level was USD \$70.00, the median wealth of the households surveyed by McNair et al. (2015).

The results of certainty equivalent curves are displayed in Figure 6. The jab planter is the superior choice for risk neutral and risk averse farmers because it has higher certainty equivalent values across the range of risk preferences. The second preferred technology choice is the basin technology. The certainty equivalent curve for all the different farming technologies decrease as risk aversion increases, suggesting the net returns needed to make an individual farmer indifferent between alternative farming technologies also decreases. None of the CE curves cross, and there is little variation in the differences between the CE values as risk aversion increases. The certainty equivalent of the conventional farming method ($CE = 0$ at $r_r = 0.96$) approaches zero more quickly compared to the basins (at $r_r = 1.1$) and the jab planter technologies (at $r_r = 1.2$) (Figure 6 A).

For risk neutral farmers, the difference between the CEs of the jab planter (and basins) and the conventional farming system was US\$ 91 ha⁻¹ and US\$ 44 ha⁻¹, respectively. This indicates that the value of technology for a risk neutral farmer is US\$ 91 ha⁻¹ for the jab planter and US\$ 44 ha⁻¹ for the basins technology compared with the conventional farming methods, respectively. For risk neutral farmer, the difference between the CEs of the basins and the jab planter farming technology was US\$ 47 ha⁻¹. In this case, for a risk neutral farmer the value of the jab planter technology is US\$ 47 ha⁻¹ relative to the basin farming method (Figure 6 B).

The difference in certainty equivalents between the farming technologies decreased as the relative risk aversion coefficient level increased (Figure 6 B). For extremely risk averse farmers, at $r_r = 0.96$, the difference between the certainty equivalent of the jab planter (and basins) and the conventional farming method was US\$ 36 ha⁻¹ (and US\$ 13 ha⁻¹), respectively. An extremely risk averse individual values jab planter at US\$ 36 ha⁻¹ (and US\$ 13 ha⁻¹ for basins) relative to

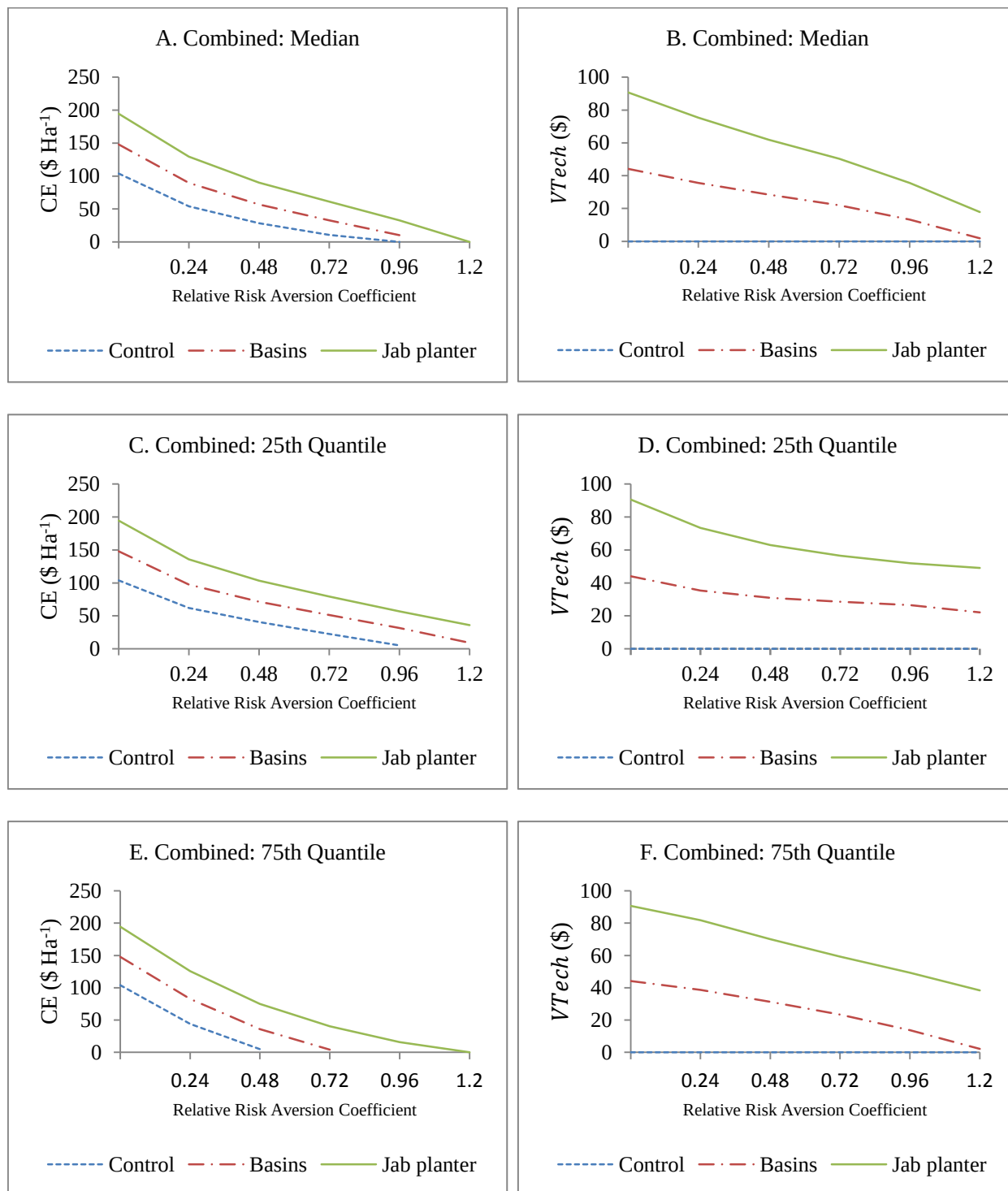


Figure 6 Certainty equivalent and risk premium relative to conventional initial wealth 25th, median and 75th quantile using power utility function.

Note: $VTech(A, B, r_r) = CE(A, r_r) - CE(B, r_r)$

the conventional farming system. On the other hand, an extremely risk averse farmer attributes US\$ 22 ha⁻¹ to the jab planter system compared to the basin technology.

a. Certainty Equivalent and Value of Technology: 25th and 75th Quantile Initial Wealth

At the 25th quantile of $w_0 = \text{US\$ } 18$, the CE curves remained the same as those evaluated at the median wealth level, except that the CE of the basins approached more quickly zero at $r_r = 1.2$ (Figure 6 C). The value of technology increased almost 30% from the same level of r_r (at 0.96) of the median initial wealth level. An extremely risk averse farmer values jab planter at US\$ 51.90 ha⁻¹ and basins at US\$ 26.50 ha⁻¹ relative to conventional method (Figure 6 D).

At the 75th quantile level of $w_0 = \text{US\$ } 200$, the coefficient of risk aversion decreased by almost one half for the farming system associated with relatively low net returns, one third for the next alternative and remained the same for the risk preferred technology. Figure 6 E shows the certainty equivalent of the conventional farming technology (CE = 0 at $r_r = 0.48$) approaches zero more quickly compared to the basins (at $r_r = 0.72$) and jab planter (at $r_r = 1.18$). The value of technology curve declines from the risk neutral level sharply and remains nearly the same compared to the same level of r_r evaluated at the median initial wealth value (Figure 6 F). An extremely risk averse farmer values jab planter at US\$ 49.35 ha⁻¹ and basin at US\$ 13.66 ha⁻¹ relative to the conventional farming system.

b. Certainty Equivalent and Value of Technology Analysis: Elevation > 800m

In elevations exceeding 800 m, the certainty equivalent is higher for the jab planter technology for both risk neutral ($r_r = 0$, US\$ 406 ha⁻¹), and risk averse producers ($r_r = 1.2$, US\$ 174 ha⁻¹). This is followed by the conventional farming system for risk neutral (US\$ 346 ha⁻¹), and risk averse producers ($r_r = 1.2$, US\$ 164 ha⁻¹). Finally, the basin technology exhibits the

same CE value with the conventional risk neutral producers (US\$ 346 ha⁻¹), but a lower CE for risk averse producers ($r_r = 1.2$, US\$ 139 ha⁻¹) (Appendix A Figure A1 A).

The value of jab planter compared to conventional farming systems for risk neutral farmer is US\$ 61 ha⁻¹ and for an extremely risk averse farmer is US\$ 10.23 ha⁻¹ (Appendix A Figure A1 B). An extremely risk averse farmer attributes \$25 ha⁻¹ to the conventional farming system compared to the basin technology (Appendix A Figure A1 B). The value of technology for the jab planter is always positive in comparison to the conventional system, whereas the value of technology of the basins is negative compared to the conventional farming method. For farmers in higher elevations the risk preferred technology is the jab planter followed by the conventional and basins farming system (Appendix A Figure A1 B).

CE and Value of Technology: Elevations > 800 m at 25th and 75th Wealth level

In high elevations communities, the different levels of initial wealth do not affect the shape of the CE curve evaluated at the median initial wealth level. The CE curves are never negative (Appendix A Figure A1 C and E). The conventional farming technology is risk preferred over the basins at the different wealth levels evaluated and across all the r_r range. An extremely risk averse farmer values jab planter at US\$ 72 and US\$ 59 ha⁻¹ relative to conventional farming system at the 25th and 75th wealth quantiles, respectively (Appendix A Figure A1 D and F). These values are relatively high compared to the CE evaluated at the median initial wealth.

c. Certainty Equivalent and Value of Technology: Elevation 350 – 800 m

In the mid-range elevation of 350 m and 800 m communities, the certainty equivalent is higher for the jab planter technology for both risk neutral ($r_r = 0$, US\$ 300 ha⁻¹), and risk averse

producers ($r_r = 1.2$, US\$ 30 ha⁻¹). This is followed by the basin technology for the risk neutral US\$ 236 ha⁻¹, and risk averse producers ($r_r = 1.2$, US\$ 36 ha⁻¹). Finally, the conventional method exhibit a CE value for risk neutral producers of US\$ 139 ha⁻¹, and for risk averse producers ($r_r = 1.2$) US\$ 27 ha⁻¹ (Appendix A Figure A2 A).

In the mid-range elevation of 350 m and 800 m, risk neutral farmers values the jab planter technology at US\$ 161 and the basins technology at US\$ 97 relative to the conventional farming method (Appendix A Figure A2 B). At the $r_r = 0.96$, farmers in mid-range altitude communities value the jab planter technology at US\$ 60, and the basins at US\$ 38 relative to the conventional farming system. The plots of the value of technology of CAP technologies are positive compared with the conventional farming method across a range of r_r (Appendix A Figure A2 B).

CE and Value of Technology: Elevations 350 – 800 m at 25th and 75th wealth levels

In middle elevations communities, the shapes of the certainty equivalent curves evaluated at different initial wealth levels remained similar to the curves generated at the median initial wealth level (Appendix A Figure A2 C and E). However, for 75th wealth quantile, ($w_0 = \text{US\$ } 200.00$) the CE of the conventional method drops quickly to zero at $r_r = 0.72$. The CE of the CAP technologies, evaluated at the 25th quantile, cross each other at $r_r = 1.2$, suggesting the basin technologies risk preferred by highly risk averse farmers. Hence, for risk averse farmers the value of technology for basins (US\$ 65), is higher than the jab planter (US\$ 53) (Appendix A Figure A2 D). At the 75th initial wealth quantile, risk averse farmer value the jab planter technology at US\$ 53 and the basin technology at US\$ 85, compared to the conventional farming method (Appendix A Figure A2 F).

d. Certainty Equivalent and Value of Technology: Elevation < 350 m

In low altitude communities, the CAP technologies outperform the conventional farming system up to certain range of r_r . The CE curves of the basin and jab planter technologies cross the CE curve of the conventional system at $r_r = 0.72$ and 0.96 , with CE values -131 and -124 , respectively (Appendix A Figure A3 A). Hence risk neutral to moderately risk averse producers would prefer the basin and jab planter technologies. In these low elevation communities, risk neutral farmers value the jab planter technology at US\$ 54 and the basin technology at US\$ 32, compared to conventional farming method. At $r_r = 0.48$, farmers in low altitude communities would value the jab planter technology at US\$ 22 and the basin technology at US\$ 8, compared to the conventional farming method (Appendix A Figure A3 A). The plots of the technology values relative to conventional method, ($VTech(A, B, r_r) = CE(A, r_r) - CE(B, r_r)$), are positive up to $r_r = 0.72$ for basins and $r_r = 0.96$ for jab planter (Appendix A Figure A3 B).

CE and Value of Technology: Elevations < 350 m at 25th and 75th Wealth level

In low elevations communities, the shape of the CE curves evaluated at different initial wealth levels are similar to the CE curves generated at the median initial wealth level of US\$ 70, except the CE curves of the conventional farming method cross the CEs of the CAP technologies at different r_r levels (Appendix A Figure A3 C and E). At $w_0 = \text{US\$ } 18$, the CE of the conventional farming method crosses the CE of the basin technology at $r_r = 0.96$. As the initial wealth is increased to $w_0 = \text{US\$ } 200$, the CE curve of the conventional technology crosses that of the basins at $r_r = 0.72$ and the jab planter CE curve at $r_r = 0.96$ (Appendix A Figure A3 C and E). The premium associated with different initial wealth levels and the varying r_r influenced amount of US\$ required to change the ranking of the technologies.

At the 25th quantile of wealth, an extremely risk averse farmer values the jab planter technology at US\$ 16 and the basin technology at US\$ 2 ha⁻¹, compared to the conventional farming method. Whereas, at the 75th wealth quantile, a moderately risk averse farmer values the jab planter technologies at US\$ 15 ha⁻¹ and the basin technology at US\$ 6 ha⁻¹, compared to conventional farming method (Appendix A Figure A3 D and F).

5.3.3 Risk Premium

Figure 7 shows graphical representation in a 3-dimensional surface by contour plotting the constant values risk premium in a 2 dimensional format. That is, given a value for a risk premium, lines are drawn by connecting the risk aversion coefficient and initial wealth level coordinates where that risk premium value occurs. The contour of the risk premium changes as a function of risk aversion coefficient and initial wealth. To the extent that the risk premium represents the value attributed to a technology in terms of reducing return risk, clear differences emerge comparing the conventional tillage returns with those from the CAP technologies. Initial wealth levels play a role in determining curvature of the risk premium contours. As the risk premium associated with a technology increases, the tradeoff between wealth and risk increases. Higher initial wealth levels and higher risk premium appear to translate into lower levels of risk aversion. The finding suggests that relatively wealthy smallholder farmers may be more willing to try new technologies.

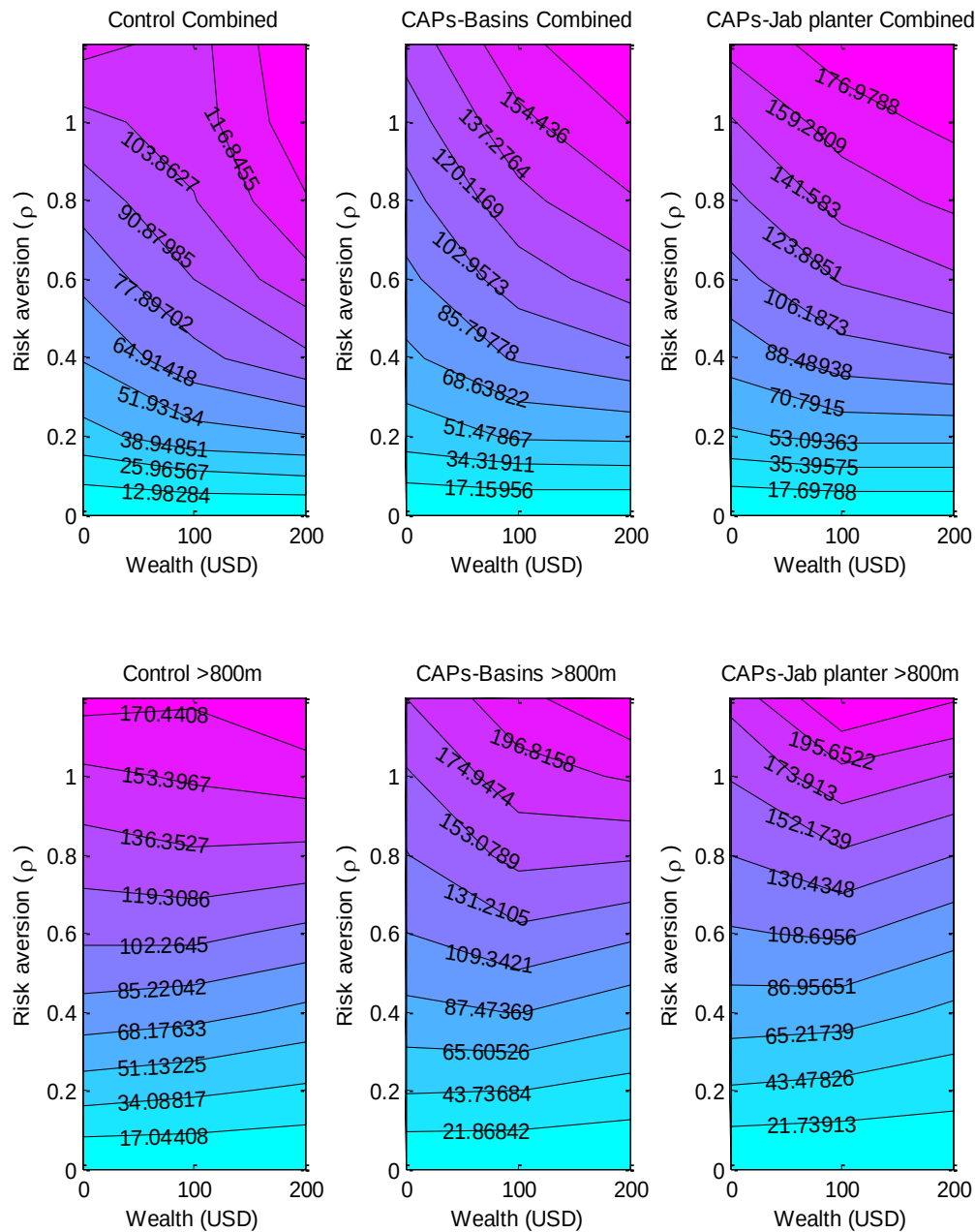


Figure 7 Sensitivity analysis of the risk premium associated with conventional and CAP farming technologies, Mozambique 2008 - 2011.

Note: Contours are risk premium (US\$ ha⁻¹)

CHAPTER VI – CONCLUSION AND FURTHER RESEARCH

The primary goal of this thesis was to evaluate the maize yields and economic profitability associated with three farming systems – basin planting, jab planting and conventional planting system – based on on-farm experimental data using statistical approaches and determining when risk is involved. The basins and jab planter practices are components of more general soil management conservation practices (CAP). Univariate and multivariate analysis of variance as well risk analysis were used for ranking the conventional farming system, basins and jab planter technologies using data from 4 years (2008 – 2011) collected from n = 632 farmers of the Central region of Mozambique by CIMMYT. A sensitivity analysis using a power utility function which allowed for certainty equivalents (CE) to vary depending on wealth endowments of producers was used. Results suggest that on average, residue cover and seeding maize using CAP basin or jab planter technologies generate higher ha^{-1} net returns and yields than conventional tillage practices across the study region.

The CAP technologies generated higher net returns and maize yields than the conventional farming systems at different elevation levels. In the Manica district, maize yields from the conventional farming system performed well compared to the CAP technologies, but the difference was not significant. In the Buzi district, maize yields of the conventional farming system were higher than the basins technology. In the remaining 8 study regions, farming systems associated with CAP technologies generated higher maize yields than the conventional farming system. However, the significant advantage of the CAP technologies over the conventional practice does not follow the same pattern across different elevations. This suggests further research is required to analyze the performance of CAP at village levels.

The mean net returns of maize production associated with the CAP technologies were higher than the conventional farming systems. The Buzi district exhibited negative net returns

across the three farming systems, whereas the districts of Tsangano and Angonia enjoyed higher net returns from the three farming systems. The highest maize net return was obtained by the jab planter treatment in the Barwe district. Overall, the maize net return generated from the jab planter technology is highest in the three different elevations. At elevations higher than 800 m, the net returns generated from the CAP basin technology and the conventional farming systems are similar. The higher altitude zones of Mozambique registered higher yield and net returns compared to the mid-range altitudes and low altitude zones. The higher altitudes are characterized by high rainfall levels, and favorable soil types for maize growing. This research also suggests that, overall, the CAP technologies studied enhanced yield and net returns, but these results vary consistently in different agro-ecological zones.

The CAP technologies were risk preferred over the conventional farming method in all the different altitudes by the mean-variance criteria. However, in elevations higher than 800 meters, the conventional farming system is preferred over basins by the mean-variance criteria. CAP technologies stochastically dominate the conventional farming method in the combined data and in mid-range altitudes. In the lower and higher altitudes the distributions of the basins, jab planter and conventional farming systems cannot be ranked.

The certainty equivalents suggest the CAP technologies are risk preferred over the conventional farming system across a range of risk aversion levels and at different levels of wealth. The results also suggest as the level of initial wealth increases, the certainty equivalent curves of the conventional farming system approaches zero very quickly compared to those of the CE of CAP technologies. The value of the technologies evaluated at different levels of initial wealth decreases as the relative risk aversion coefficient increases. However, the above situation does not hold at different altitude levels. All the CE values associated with the three farming

practices of the low elevation farmers are negative, implying risk neutral and risk averse farmers have a negative net returns ha^{-1} .

Development of the agricultural sector in Mozambique remains constrained by a number of factors such as low soil fertility, climate change impacts (especially more frequent droughts), and limited input availability. CAP adoption by small-holder farmers is also capacity-constrained because of weak or nonexistent institutions (Gowing and Palmer 2008). Other adoption constraints include problems accessing inputs, inaccurate information about improved technologies, and weak credit markets. Yield increases from CAP systems may result after soil quality improves. Without reliable durable and self-sustaining social capital networks (Silici 2010), adoption patterns will probably languish or level off (Gowing and Palmer 2008; Mazvimavi and Twomlow 2009) as producers struggle to balance the risk associated with adopting new ways to produce food.

This thesis demonstrates that using economic and risk analysis (using a partial budget) to examine net return and yield risk can be useful in analyzing farming systems. However, the difference in farming systems may be difficult to determine in terms of risk because of household demographic differences, income sources, agricultural inputs and output markets, and availability of labor can cause one farming system to be selected over another. This is an area where further research is also required.

In this thesis, I illustrated the use of the CE analysis for the problem of selecting an alternative farming method. The only behavioral characteristic considered was risk attitude. However, farmers may have other objectives like food self-sufficiency and socio-economic needs, and marketing risk, which also require assessment using household survey information.

Future research could also consider alternative utility functions such as the negative exponential and expo-power utility functions or a combination. A shift from Conventional farming methods to CAP is often supplemented by farm restructuring and behavioral changes, which include farming practices, tools purchase like a jab planter, application of herbicides and pesticides and a shift in seed variety, the analyses of which are beyond the scope of this study.

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APPENDICES

Appendix A

Table A1 Non-parametric comparison of empirical distributions of yield kg ha⁻¹ for conventional, basin and jab planter technologies, Mozambique, 2008 - 2011

Technologies	D-statistic*	Pr(D ≥ 0)
Combined:		
Conventional vs. Basins	0.0997	0.0037
Conventional vs. Jab planter	0.1313	<0.0001
Basins vs. Jab planter	0.0459	0.5188
≤ 350 m:		
Conventional vs. Basins	0.0827	0.3504
Conventional vs. Jab planter	0.0827	0.3504
Basins vs. Jab planter	0.0748	0.476
Between 350 and 800 m:		
Conventional vs. Basins	0.1019	0.2347
Conventional vs. Jab planter	0.1456	0.0253
Basins vs. Jab planter	0.0728	0.6457
> 800 m:		
Conventional vs. Basins	0.2384	00.0001
Conventional vs. Jab planter	0.2558	<0.0001
Basins vs. Jab planter	0.064	0.8733

Note: Distance statistic, Kolmogorov-Smirnoff test of equality between empirical distributions

Table A2 Conventional planting, basin planting and jab planting on - farm trial expected maize profit (US\$ ha⁻¹), Mozambique, 2008 – 2011

District Name	n	Conventional	Basins	Jab planter
Angonia	85	385	368	453
Barwe	153	213	295	391
Buzi	162	-77	-159	-113
Gondola	16	27	148	244
Gorongosa	20	-117	310	145
Guro	10	-358	-133	-114
Manica	10	75	142	-42
Nhamatanda	72	-107	72	92
Sussundenga	19	-138	-40	-59
Tsangano	85	327	350	378
Weighted mean		104	148	195
Standard error (weighted mean)		18	19	20

Table A3 Mean yield (kg ha⁻¹) regression model comparing CAP yields with conventional yields of on – farm trial mean yield for maize, Mozambique, 2008 - 2012

Explanatory variable	Coefficient	t Value
Intercept†	2320.60**	8.27
Basins technology	270.68	1.39
Jab planter technology	236.4	1.22
2008 harvest year	-1363.88**	-6.73
2009 harvest year	-350.53*	-1.91
2010 harvest year	-1457.21**	-16.71
Area nao variety	-619.09**	-3.83
Matuba variety	452.78**	2.7
Pan 67 variety	1829.25**	3.96
SC 627 variety	2167.20**	3.81
ZM 309 variety	430.03**	2.66
ZM 401 variety	498.52**	3.09
ZM 523 variety	529.07**	3.28
ZM 625 variety	526.82**	3.26
Basins × Area n	-150.71	-0.66
Basins × Matuba	-3.65	-0.02
Basins × Pan 67	159.85	0.41
Basins × SC 627	-649.87	-1.35
Basins × ZM 309	61.93	0.27
Basins × ZM 401	-54.91	-0.24
Basins × ZM 523	12.91	0.06
Basins × ZM 625	65.97	0.29
Jab planter × Area n	88.08	0.39
Jab planter × Matuba	-33.21	-0.15
Jab planter × Pan 67	330.06	0.84

Table A3 continued

Explanatory variable	Coefficient	t Value
Jab planter × SC 627	-623.19	-1.3
Jab planter × ZM 309	161.62	0.71
Jab planter × ZM 401	79.07	0.35
Jab planter × ZM 523	91.36	0.4
Jab planter × ZM 625	283.82	1.25

Note: *significant at the 0.05 confidence level, ** significant at the 0.01 confidence level.

Note: † Intercept contains the reference categories of conventional farming technology, 2011 of harvest year, and local seed variety.

Table A4 Mixed model results for on - farm trial mean net return (US\$ ha⁻¹) for maize,
Mozambique, 2008 - 2011

Covariance Parameter	Estimate	Standard Error	Z Value	Pr > Z
Village	72576	29459	2.46	0.0069
Farmer (Village)	55107	7778	7.08	<0.0001
Village × Technology	3774	1607	2.35	0.0094
Residual	62201	2157	28.84	<0.0001
Effect			F Value	Pr > F
Technology			2.04	0.1419
Harvest Year			120.60	<0.0001
Variety			37.21	<0.0001
Technology × Variety			0.67	0.8568

Note: Covariance parameter estimates: are the square roots of the diagonal elements of the observed inverse Fisher information matrix, which equals $2\mathbf{H}^{-1}$

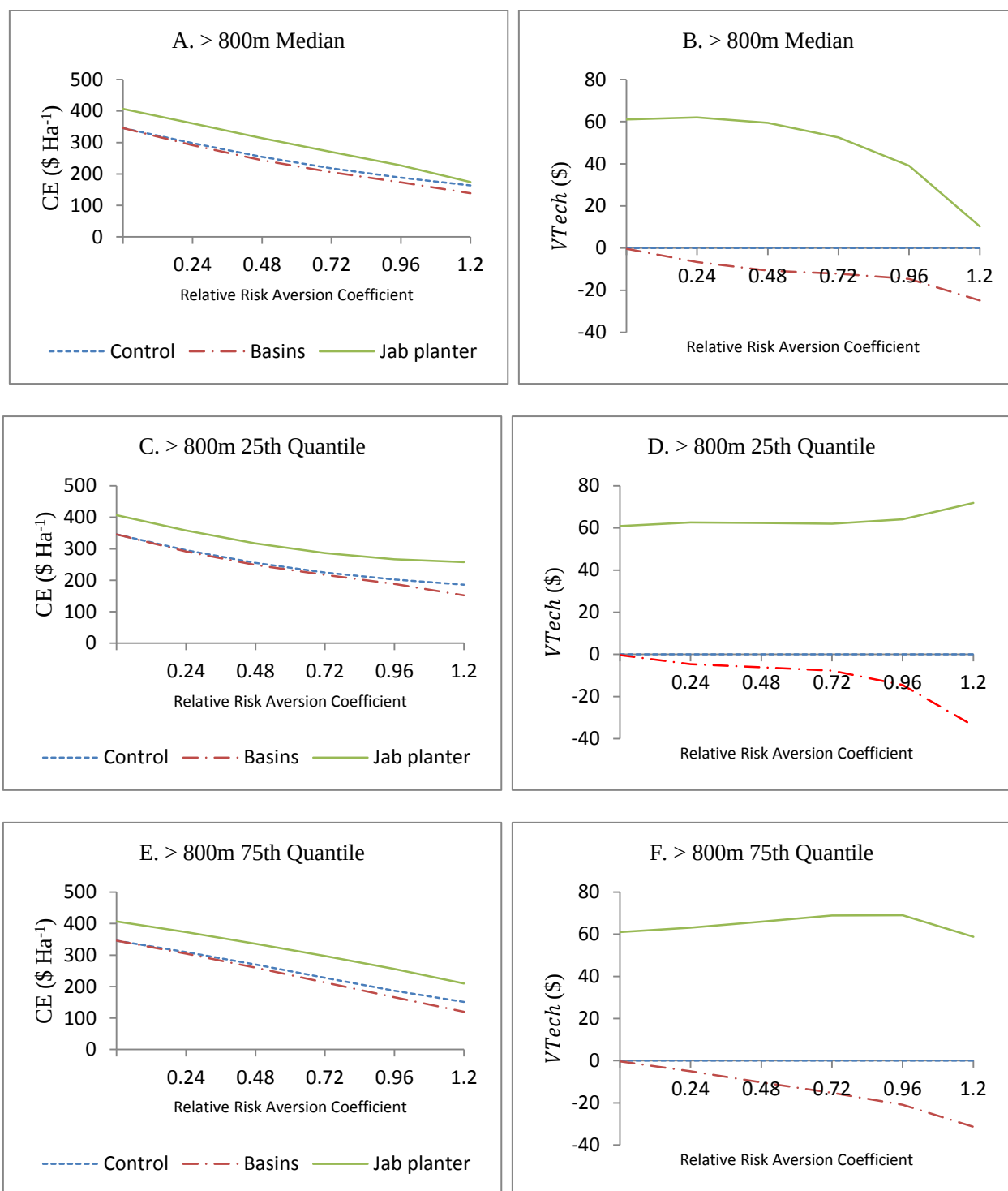


Figure A1 Certainty equivalent and value of technology relative to conventional with initial wealth 25th, median and 75th quantile using power utility function at altitude higher than 800m

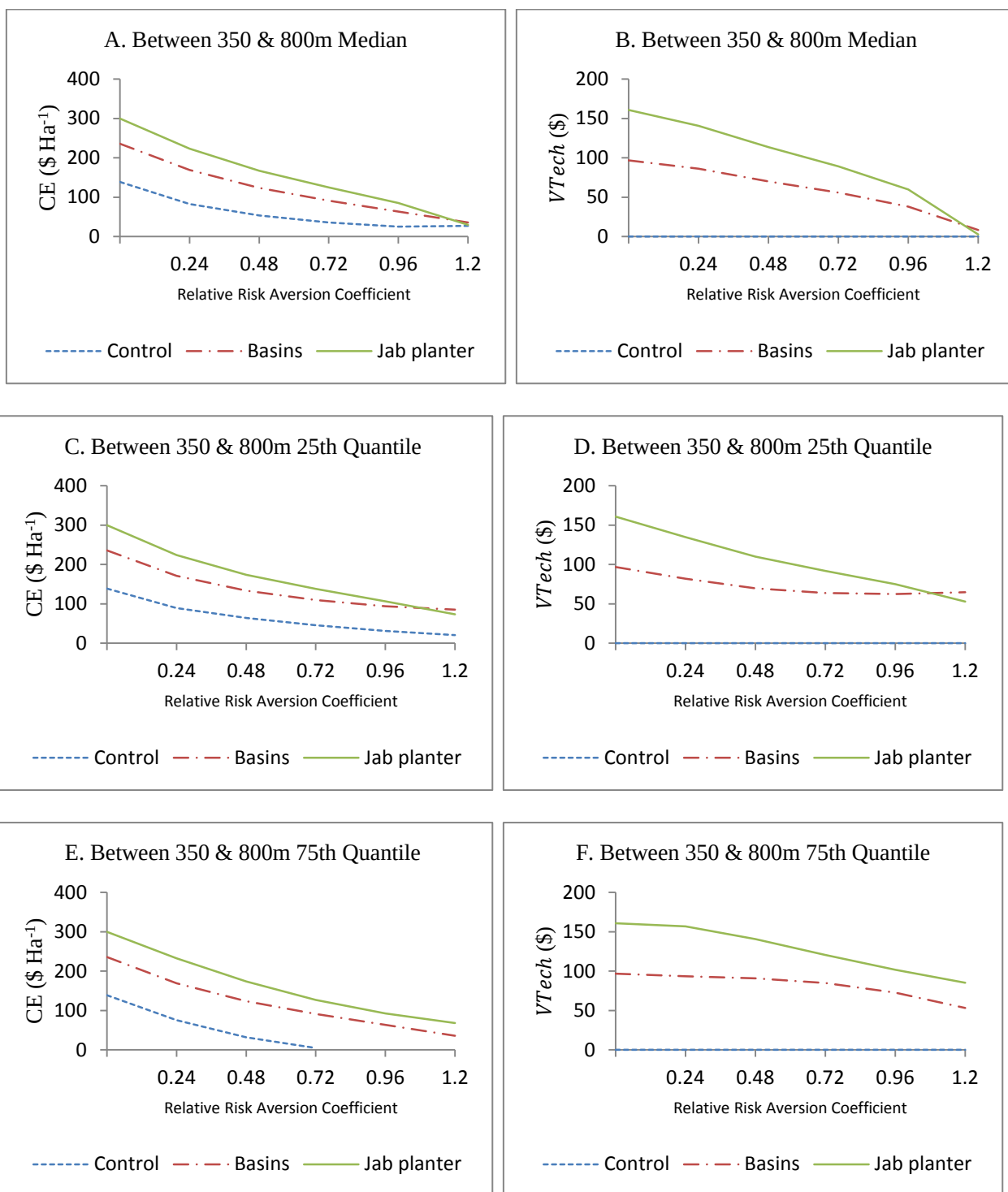


Figure A2 Certainty equivalent and value of technology relative to conventional with initial wealth 25th, median and 75th quantile using power utility function at medium altitude between 350 and 800m

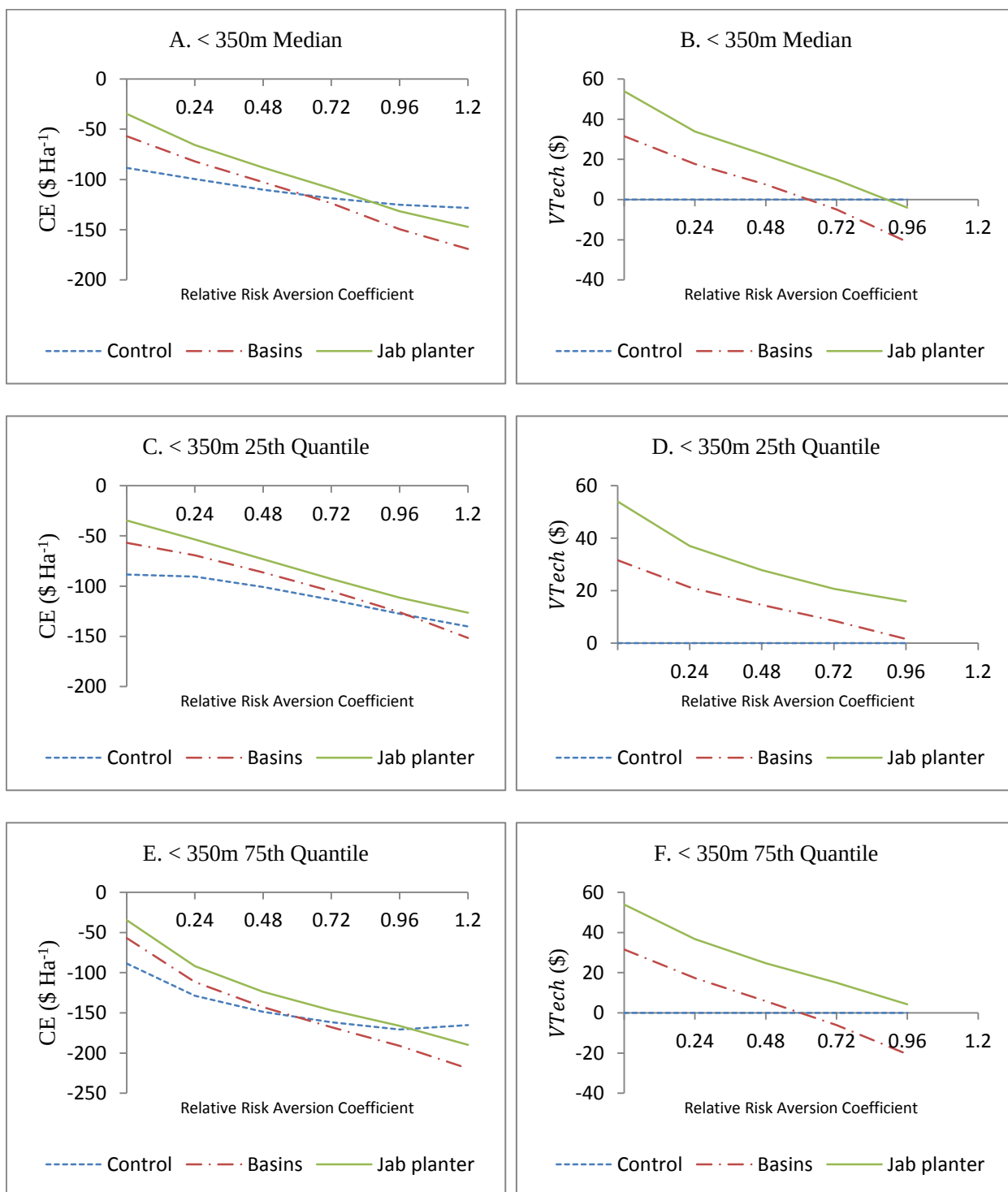


Figure A3 Certainty equivalent and value of technology relative to conventional with initial wealth 25th, median and 75th quantile using power utility function at altitude below 350m

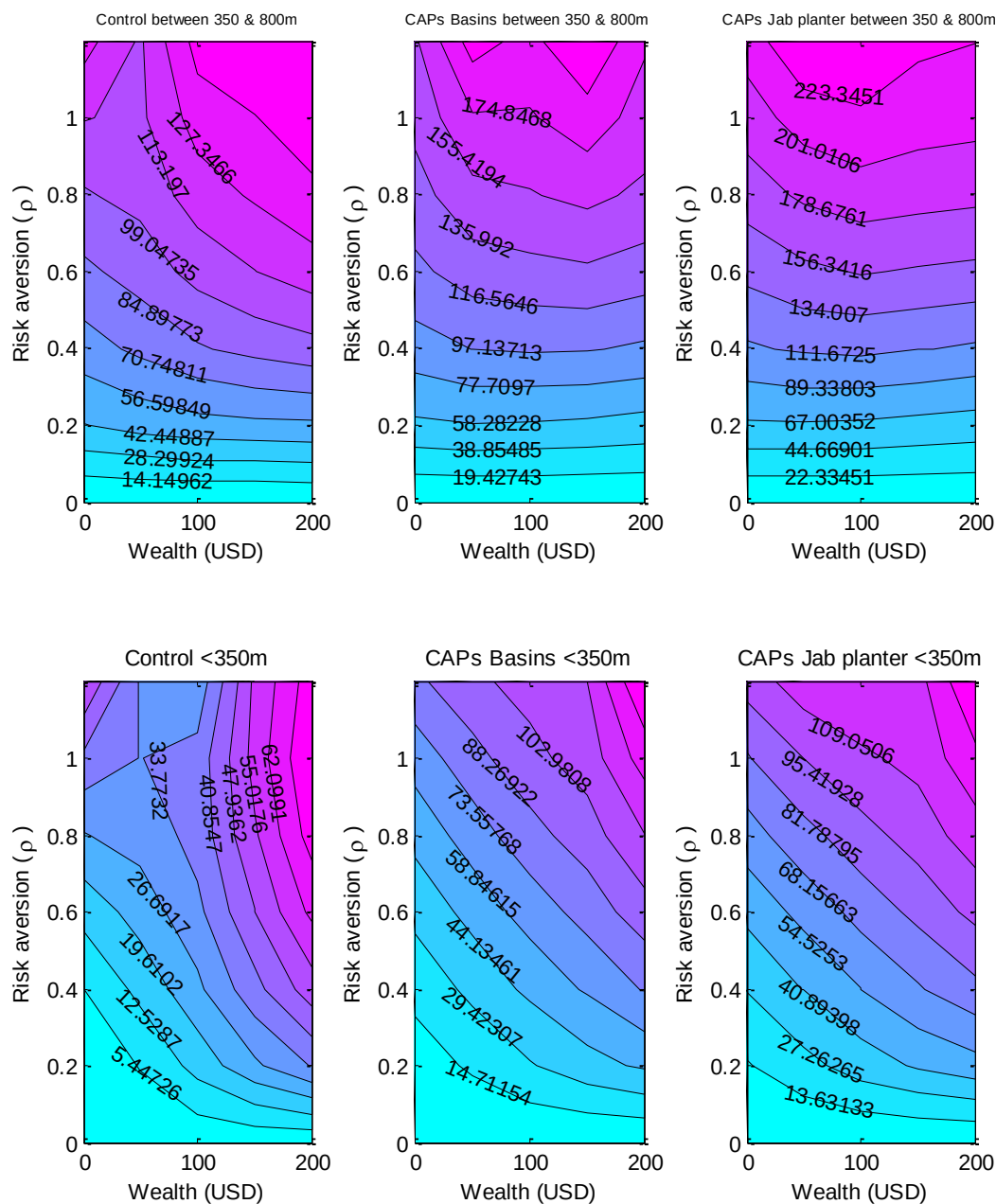


Figure A4 Sensitivity analysis of the risk premium associated with conventional and CA farming system, Mozambique 2008 – 2011

Note: Contour are risk premium (US\$ ha⁻¹)

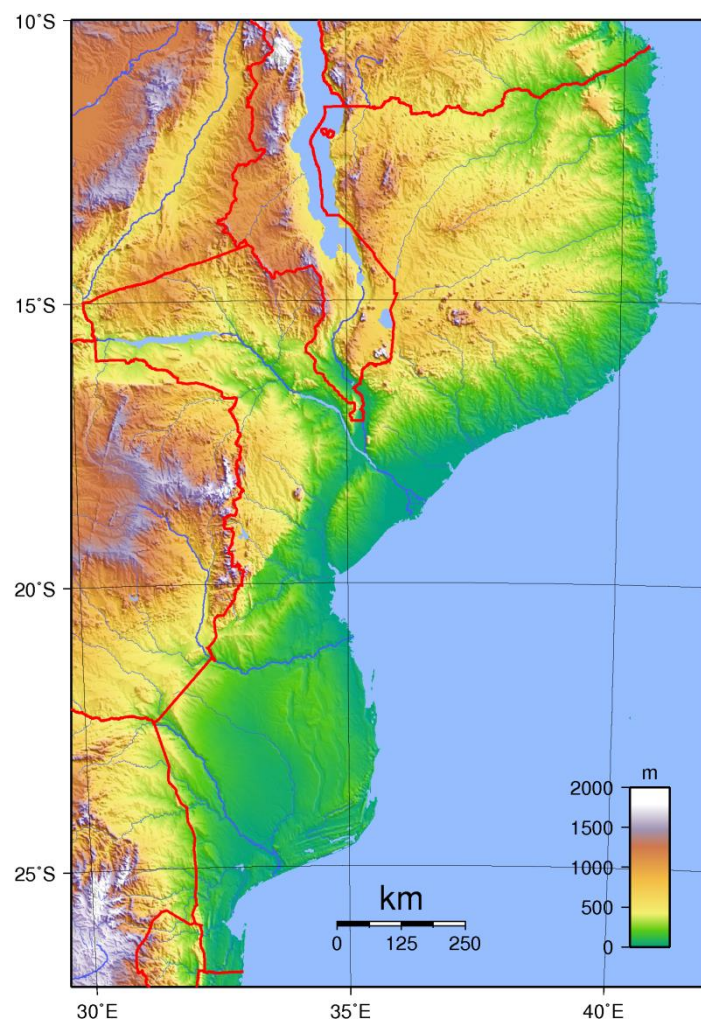


Figure A5 Mozambique map showing altitudes in meters above sea level

Source: National Institute for Disaster Management – Study on the impact of climate change on disaster risk in Mozambique, February 2009

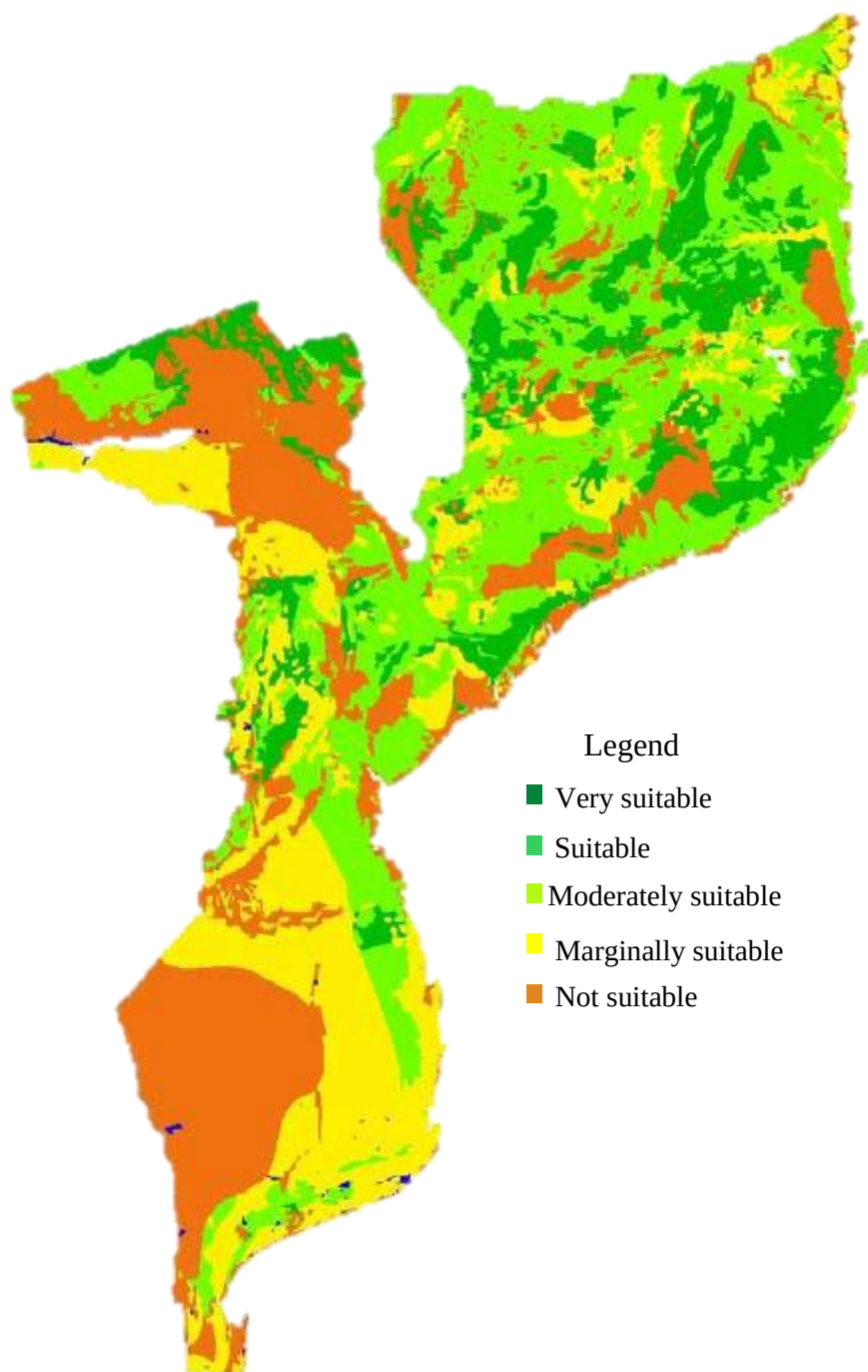


Figure A6 Land suitability for rain fed maize production Mozambique

Source: National Institute for Disaster Management – Study on the impact of climate change on disaster risk in Mozambique, February 2009

Appendix B

Derivation of the Risk Aversion Coefficient

A decision-maker with a starting position of wealth, w is presented with a risk whose expected value is zero. His/her final position is a random variable $w + z$, where z has zero expectation, $E[z] = 0$. z may take values z_i for $i = 1, 2, \dots, n$ with probabilities p_i , and such that

$\sum_{i=1}^n p_i z_i = 0$. The certainty equivalent is defined as the solution CE to the equation

$$u(CE) = \sum_{i=1}^n p_i u(w + z_i)$$

and the risk premium is $RP = E(w) - CE$. Applying the Taylor approximation for small risk produces an expression of an Arrow-Pratt approximation.

$$u(w - RP) = \sum_{i=1}^n p_i u(w + z_i)$$

Expand both sides in Taylor series around w :

$$\begin{aligned} u(w) - RPu'(w) + \dots &= \sum_{i=1}^n p_i u[(w) + z_i u'(w) + \frac{1}{2}(z_i)^2 u''(w) + \dots] \\ &= u(w) \sum_{i=1}^n p_i + u'(w) \sum_{i=1}^n p_i z_i + \frac{1}{2} u''(w) \sum_{i=1}^n p_i (z_i)^2 + \dots \\ &= u(w) \times 1 + u'(w) \times 0 + \frac{1}{2} u''(w) \text{var}[z] + \dots \\ &= u(w) + \frac{1}{2} u''(w) \text{var}[z] + \dots \end{aligned}$$

where ... indicates higher order terms in the expansion.

Canceling $u(w)$ from both sides and equating the leading terms that remain on each side gives

$$-RPu'(w) = \frac{1}{2}u''(w)\text{var}[z]$$

Or

$$RP = \frac{1}{2}\text{var}[z]\frac{-u''(w)}{u'(w)}$$

Intuitively, the risk premium is proportional to the variance of the random component w , which is a measure of the magnitude of the risk, and also proportional to a measure of the extent of curvature of the utility function. The decision maker's risk aversion for small risks around w

$$r_a(w) = -\left[\frac{wU''(w)}{U'(w)}\right]$$

This is the coefficient of absolute risk aversion (Eeckhoudt et al. 2005).

Computation of the Certainty Equivalent

The expected utility of risky prospect is $EU(w_0 + \tilde{z})$ and the value of the certainty equivalent $U(CE + w_0)$ (Baker 2003). Conceptually the solution is as follows

$$U(CE + w_0) = EU(w_0 + z)$$

$$CE^* + w_0 = U^{-1}(EU(w_0 + z))$$

$$CE^* = U(CE) - w_0 \text{ since } U(w) = \frac{z_i^{1-r_r(w)}}{1-r_r(w)}$$

$$= EU\left(\frac{z_i^{1-r_r(w)}}{1-r_r(w)}\right)^{-1} - w_0$$

$$= EU\left(\frac{1-r_r(w)}{z_i^{1-r_r(w)}}\right) - w_0$$

$$= ((1-r_r(w))EU(z_i))^{\frac{1}{1-r_r(w)}} - w_0$$

VITA

Simon Mesfin Kidane was born in 1971 in Asmara, Eritrea to the late Mesfin Kidane and Mehret Kidane. He completed his school from Santa Ana Secondary School of Asmara in 1989 and joined University of Asmara for undergraduate studies. He graduated with bachelor's degree of Economics in 1995. Since then, he worked with different national and international organizations as an assistant researcher and researcher in development projects before he was conscripted in the national service. Simon Kidane attended the University of Tennessee where he completed a Master of Science degree in Agricultural and Resource Economics.