Does crop diversification reduce downside risk in maize yield enhancing investments? Evidence from Ethiopia using panel data

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Abstract:

Using a unique household level panel data collected from the major maize producing regions of Ethiopia, this study assesses the role of crop diversification in minimizing the downside risks associated with the use of improved seed and chemical fertilizer in maize production. Empirical results show that maize-legume intercropping and rotation increases the average maize yield and reduces downside risk as captured by the estimated yield distribution using Endogenous Switching Regression models and quintile moment approaches. Controlling for plot and household level characteristics that may induce selection bias in technology adoption, maximum yield was obtained on plots with maize-legume rotation or intercropping sequences. The contribution of crop diversification in reducing downside risk in maize yield was higher when diversification was applied to plots that received improved seed and chemical fertilizers. In addition to the technical support provided to smallholder farmers on the use of improved seed and chemical fertilizer in maize production, the existing agricultural extension program in Ethiopia may also need to give due emphasis to both spatial and temporal crop diversification practices to enhance crop productivity further and reduce the potential downside risk hampering smallholder farmers' initiatives in investing in purchased agricultural inputs in maize production.

Acknowledegment: The authors would like to acknowledge two projects financially supported the collection of panel data used in this study: Sustainable Intensification of Maize-Legume cropping systems for food security in Eastern and Southern Africa (SIMLESA) project funded by the Australian Center for International Agricultural Research (ACIAR) and Diffusion and Impact of Improved Varieties in Africa (DIIVA) project funded by Bill and Melinda Gates Foundation (BMGF) through Bioversity International which collaborated with the Standing Panel for Impact Analysis (SPIA) in the CGIAR and CIMMYT. Views in this paper are of the authors. The usual disclaimer also works here.

JEL Codes: C34, Q12

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Keywords: downside risk, maize, sustainable intensification, impacts, Ethiopia.

JEL codes: C31, C34, Q12.

1. Introduction

Farming in general and cereal production under rain-fed systems in most sub-Sahara African countries is susceptible to a wider range of production risks (Barrios et al., 2008; Schlenker and Lobell, 2014; Kassie et al., 2015) than is true in irrigated systems. These include weather calamities like droughts, heat stress, hailstorm, excessive rain causing water logging on flat farmlands, pests and diseases under humid and hot temperature (Kamanga et al., 2010; Cairns et al., 2013). These and other biotic and abiotic shocks reduce crop productivity and expose smallholder farmers to downside risk where the crop productivity distribution becomes more skewed to the left. Increasing downside risk means increasing the asymmetry or skewness of the risk distribution towards low outcome, holding both mean and variance constant (Di Falco and Chavas, 2006). Such a change in the distribution of outcomes puts a downside risk-averse farmer at a considerable disadvantage.

The severity of crop failure associated with any of the sources of production risk is higher for the resource poor smallholder farmers who have limited ability to buffer/absorb the shocks. There are many practices used by smallholder farmers in managing production risks among which crop rotation (temporal diversification) and intercropping (spatial diversification) are most commonly and widely used in maize production. Rotating crops after one another (especially legumes after cereals) helps in maintaining soil fertility and also break the life cycle of some pests and diseases. Intercropping also helps to increase the harvest per unit area of land from different crops grown at the same time and secure some harvest in case one crop fails.

Studying the role of crop diversification in reducing the downside risk in maize production systems of Ethiopia is relevant due to several factors. First, among the cereal crops grown in the country, maize stands first in production and second in terms of area coverage (CSA, 2017). Thus, any reduction in maize productivity could easily be reflected in the national agricultural production too. Second, though maize has shown a positive trend in terms of both production and productivity growth in Ethiopia (Abate et al., 2015; CSA, 2017), there is a considerable yield variability across years due to weather factors (Kassie et al. 2014). Third, maize is one of the leading cereal crops in terms of using purchased agricultural inputs, specifically improved seeds and chemical fertilizers through the support of strong government-backed agricultural extension system (Alene et al., 2000; Fufa and Hassan, 2006; Spielman et al., 2012; Abate et al., 2015). Any production risk in maize could put smallholder farmers' income and consumption in jeopardy as maize growers directly depend on maize for consumption and cash income. Moreover, production risks also discourage smallholder farmers from investing in purchased agricultural inputs. Overall, any biotic or abiotic stress that induce production risk in maize crop has a direct effect on the consumption and livelihoods of more than 10 million smallholder farmers producing maize in Ethiopia (Chavas and Di Falco, 2012; CSA, 2017).

With the above understanding, this paper is focusing mainly on assessing the role of crop diversification on the downside risk in maize productivity at a plot level. Emphasis will be given to plots treated with and without improved variety and chemical fertilizer, and how both spatial and temporal diversification of maize plots could contribute towards reducing the downside risk in maize productivity. The remaining parts of the paper are structured as follows. In section 2, conceptual framework used for the analysis is discussed. Methodologies used in the analysis are presented in Section 3. Section 4 describes data used for the analysis and Section 5 discusses analysis results. Conclusions and implications are dealt with in Section 6.

2. Conceptual Framework

Use of improved technologies (specifically improved varieties and chemical fertilizer) in maize production could enhance maize yield. Variability in maize yield also increases with the use of improved technologies as these technologies lift up the yield frontier under normal circumstances and face lower yield or complete lose when any sort of production risks happened. The only exception is when the improved technologies are directed towards tackling specific risks induced through biotic and/or abiotic factors, like in the cases of drought or stress tolerant varieties, and the use of herbicides and pesticides. Thus, investment in improved maize technologies (improved seed and fertilizer) is subject to risk and farmers need to design some sort of insurance mechanism that could minimize the effects of these risk sources. Under the absence of crop insurance schemes, smallholder farmers use agronomic practices like temporal (crop rotation) and spatial (intercropping) types of crop diversification strategies to replenish soil fertility, break the life cycle of pests and diseases, and withstand other shocks. These non-cash agronomic practices could be combined with cash-based improved technologies to boost productivity and at the same time help in reducing exposure to downside risk.

Plots with different input use and associated agronomic practices are disaggregated to evaluate their respective average maize yield and associated variance and skewness towards the left side of yield distribution in putting the variability more to the undesirable side. A package of technologies and practices may help in enhancing the average productivity but if the variation is higher than the normal circumstances, and particularly, if the associated loss due to any downside risk is higher, smallholder farmers may not be encouraged to invest in such purchased inputs. Thus, farmers consider any crop management mechanism that could reduce their risk of crop failure and losses on investment.

3. Empirical Models

In capturing the plot level yield difference due to different combination of purchased inputs and crop diversification, we use self-selection corrected endogenous switching regression model and obtain the average treatment effects on treated (ATT) and untreated plots (ATU) controlling for plot, household, farm and village level observed characteristics. This approach helps in capturing both the observed and unobservable characteristics influencing the level of crop yield. Then, yield estimates from the actual and counterfactual groups are arranged in ascending order and a quintile-based moment approach is applied to estimate the cost of risk, the contribution of variance and skewness of maize yield distribution to the cost of risk, and the contribution of downside risk to the overall cost of risk under the different combinations of purchased inputs used and crop diversification practices on maize plots. The empirical procedure we followed is discussed as follows.

Assuming farmer i growing maize on plot j chooses combination k of the three technologies, i.e. diversification (D), improved variety (V) and chemical fertilizer (F), if the expected benefit from combination k is better than any of the other combinations m, i.e., $u_{ijk} > u_{ijm}$ for $K = 1,2, \dots ,8$ and $m \neq k$. Thus, considering plot, household, farm, and village level characteristics (X_{ij}) affecting the choice of technology combinations on a specific maize plot j, the probability that plot j is treated with combination k by household i is specified using a multinomial logit model as:

$$p_{ijk} = pr\left(u_{ijk} > u_{ijm} \middle| X_{ij}\right) \ = \frac{\exp(\beta_k X_{ij})}{\sum_{m \neq k}^{K} \exp(\beta_m X_{ij})} \tag{1}$$

Then, after deriving the household and technology combination specific Inverse Mill's Ratios ($\hat{\lambda}$) from the above multinomial logit model, the self-selection bias controlled maize yield estimate (Y) from the K possible combinations of technologies/practices is specified as:

$$\begin{cases} Regime\ 1: & Y_{ij1} = \theta_1 X_{ij1} + \sigma_1 \hat{\lambda}_{ij1} + \varepsilon_{ij1} \\ \quad . & \qquad . \\ \quad . & \qquad . \\ \quad . & \qquad . \\ Regime\ K: & Y_{ijK} = \theta_K X_{ijK} + \sigma_K \hat{\lambda}_{ijK} + \varepsilon_{ijK} \end{cases} \tag{2}$$

The conditional expected maize yield under different regimes with and without adoption of combination k is given as:

If a plot is treated with a desired combination of practice, k=1; (adopter plots, actual):

$$E\left[Y_{ijk}\middle|k=1, X_{ijk}, \hat{\lambda}_{ijk}\right] = \theta_1 X_{ij1} + \sigma_1 \hat{\lambda}_{ij1} \tag{4}$$

If a plot is not treated with a combination k=1; (non-adopter plots without adoption, actual):

$$E\left[Y_{ijm}\middle|k=m, X_{ijm}, \hat{\lambda}_{ijm}\right] = \theta_m X_{ijm} + \sigma_m \hat{\lambda}_{ijm} \tag{5}$$

If a plot treated with combination k=1 would have been not treated (adopter plots had they not adopted, counterfactual)

$$E\left[Y_{ijm}\middle|k=1, X_{ijk}, \hat{\lambda}_{ijk}\right] = \theta_m X_{ij1} + \sigma_m \hat{\lambda}_{ij1} \tag{6}$$

If a non-treated plot would have been treated with combination k=1; (non-adopter plots had they been treated with combination k=1, counterfactual)

$$E\left[Y_{ijk}\middle|k=m, X_{ijm}, \hat{\lambda}_{ijm}\right] = \theta_1 X_{ijm} + \sigma_1 \hat{\lambda}_{ijm} \tag{7}$$

Equations (4) and (5) are the actual maize yield estimates from plots treated and non-treated with the specific combination of technologies/practices, respectively. The average treatment effect on treated (ATT_k) for k=1 is given as the difference of Equation (4) and (6) and specified as:

$$\begin{aligned} ATT_k &= E\left[Y_{ijk}\middle|k=1, X_{ijk}, \hat{\lambda}_{ijk}\right] - E\left[Y_{ijm}\middle|k=1, X_{ijk}, \hat{\lambda}_{ijk}\right] \\ &= (\theta_1 - \theta_m) X_{ij1} + (\sigma_1 - \sigma_m) \hat{\lambda}_{ij1} \end{aligned} \tag{8}$$

Similarly, the average treatment effect on the untreated (ATU_m) is computed from the difference between Equations (5) and (7) and specified as:

$$\begin{aligned} ATU_m &= E\left[Y_{ijm}\middle|k=m, X_{ijm}, \hat{\lambda}_{ijm}\right] - E\left[Y_{ijk}\middle|k=1, X_{ijm}, \hat{\lambda}_{ijm}\right] \\ &= (\theta_m - \theta_1) X_{ijm} + (\sigma_m - \sigma_1) \hat{\lambda}_{ijm} \end{aligned} \tag{9}$$

Table 1 gives how the average maize yield estimates from the actual and counterfactual maize plots are presented and evaluated to get the average treatment effects on treated (ATT) and untreated (ATU) maize plots.

< Table 1 here >

A quintile moment approach is applied to evaluate the role of crop diversification in reducing the downside risk of investments on yield enhancing purchased inputs in maize production. Following earlier studies that used the Arrow-Pratt relative coefficient of risk in measuring the cost of risk proxied with risk premium (Kim and Chavas, 2003; Kassie, et al, 2015; Di Falco and Chavas, 2006, 2009; Kim et al., 2014), the cost of risk considering both the variance and skewness components is given as:

$$R \cong 0.5 * [F(b_k) - F(b_{k-1})] * \left\{ \frac{b(m_{k1})^{-b-1}}{\sum_{i=1}^{k}\{[F(b_k) - F(b_{k-1}) * (m_{k1})^{-b}]\}} * m_{k2} + [b(M_1)^{-1}] * [m_{k1} - M_1]^2 \right\} +$$
$$(1/6) * [F(b_k) - F(b_{k-1})] * \left\{ - \frac{b(1+b)(m_{k1})^{-b-2}}{\sum_{i=k}^{k}\{[F(b_k) - F(b_{k-1}) * (m_{k1})^{-b}]\}} * m_{k3} - [b(1+b)(M_1)^{-2}] * [m_{k1} - M_1]^3 \right\} \tag{10}$$

Where $[F(b_k) - F(b_{k-1})]$ is the probability of each partial central moment to be in the quintile k; m_{k1}, m_{k2}, and m_{k3} are referring to the partial mean, variance and skewness of maize yield distribution in the specific quintile k, respectively; M is the overall central moment. All terms before (1/6) in Equation (10) are referring to the variance component of cost of risk whereas the terms starting from (1/6) are referring to the skewness component.

4. Data

In this analysis, we used two waves of panel data collected in 2010 and 2013 from major maize growing areas across five regional states in Ethiopia (Tigray, Amhara, Oromia, Benishangul-Gumuz, and SNNPR[1]). The survey covered a total of 39 maize growing districts randomly selected from the five regional states considering their maize production potential as '*high*', '*medium*' and '*low*' based on average maize productivity and standard deviation as a cut-off points. Then, from each district, four maize growing *kebeles* (the lowest administrative unit) were randomly selected. From each

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[1] Southern Nations Nationalities and Peoples Regional State.

selected PA, 16 to 18 sample farmers growing maize were selected for interview. In case any selected sample household happened to be non-producer of maize during the specific survey season, the household was replaced by another randomly selected maize producing household. Table 2 gives the detailed overview of the sample households and number of maize plots surveyed across the two waves. Accordingly, in 2010 and 2013 respectively, a total of 2887 and 2853 maize plots operated by a sample of 1751 and 1774 farm households were surveyed and used in this analysis. Data from Tigray regional state was not collected in 2013 due to logistic problem.

< Table 2 here >

The data are panel at a household level and each year details of maize plots for each sample households were collected. However, due to crop rotation and change in plot size resulting from splitting and merging of plots each season, the datasets we have could not be a panel at a plot level. The survey had details of plot level physical characteristics (soil type, color, slope, and soil depth), farmer specific subjective judgment on plot level soil fertility, inputs used and production from all maize plots operated by each sample household. In addition, for all the surveyed plots, the amount of labor, seed and fertilizer used, herbicide and pesticides applied, whether the production was exposed to any kind of biotic or abiotic stresses (like drought, flood, disease, pest, etc.) were documented. Finally, maize and beans productivity accounting for the type of harvest (whether harvested when green/fresh or dry) were collected. Using a standard conversion factor, the green harvests were converted to dry weight equivalent for yield accounting purpose.

Table 3 gives summary of plot level characteristics and average maize yield for the two survey years. Accordingly, there was a slight improvement in the average maize productivity of the sample households from 2.3 to 2.5 tons/ha. The increase in the level of maize productivity is in line with the nationally representative data released by the Ethiopian Central Statistical Agency for these specific cropping seasons. There were some improvements on the rate of fertilizer use in maize production between the two survey years. Pesticide and labor use in maize production have shown some increment between the two survey years. More interesting is that the proportion of plots treated with improved hybrid maize varieties has shown increment from 54 to 63%.

< Table 3 here >

During both years, the major stress farmers had reported was the prevalence of drought, reported for 15% and 12% of the maize plots in 2010 and 2013, respectively. The occurrence of drought at any stage of maize production discourages smallholder farmers from use of purchased inputs in maize production but it encourages crop diversification, particularly intercropping of maize with legumes or shifting to beans to reduce a complete loss from maize plots in case the drought is severe as some crops like beans could provide some yield under limited available moisture level.

Table 4 gives the number of maize plots under different combinations of purchased inputs use (improved variety, V, and chemical fertilizer, F) and crop diversification, D. During both survey years, most of the maize plots were treated with both improved varieties and chemical fertilizer ($D_0V_1F_1$ and $D_1V_1F_1$). Interestingly, the data also show that these combinations of technology use have shown better maize productivity. The level of skewness is higher when maize plots were not treated with improved varieties and chemical fertilizer regardless of diversification ($D_0V_0F_0$ and $D_1V_0F_0$).

< Table 4 here >

5. Results and Discussions

5.1. *Explaining variations in maize yield*

Controlling for the potential variations at district level, Table 5 presents estimation results explaining variations in maize yield for the total sample and the two survey years. Accordingly, household head characteristics and key inputs in maize production (seed rate, fertilizer rate and use of seeds of improved hybrid and openly pollinated maize varieties) have explained the variation in maize yield as expected. Considering the total sample (pooled data) and controlling for other factors, estimated maize yield is higher for male headed households by 164.7 kg/ha. In addition, the estimated maize yield per ha decreased with the age of household head and increased with the level of education of the household head. Plots with common bean intercropped with maize have shown higher and significant yield increment (638.1 kg/ha for the pooled data). The rate of maize seed and chemical fertilizer used in maize production during both survey years have shown significant and positive effect on maize yield. On the other hand, the effects of both biotic and abiotic factors reported by farmers had significant negative effect on maize yield. Compared to other stress factors, water logging and drought effects were relatively larger. These are extreme cases related to the amount of rainfall received at a given time and its distribution across the cropping season exposing maize producing farmers to yield reduction.

< Table 5 here >

5.2. Average treatment effects on maize yield

Results from the conditional expected maize yield derived from endogenous switching regression analysis for the actual and counterfactual maize plots under different treatments are presented in Table 6. Results show that the largest average treatment effect on maize yield (1.36 t/ha) was observed when plots treated with diversification under the presence of investments both in improved seed and chemical fertilizer ($D_1V_1F_1$) and had these plots were only treated by diversification but with no improved seed and chemical fertilizer use ($D_1V_0F_0$). On the other hand, plots with no diversification and no use of improved seed and chemical fertilizer ($D_0V_0F_0$) would have attained higher returns in maize yield (average increment of 0.28 t/ha) if they had been treated with diversification and the two purchased inputs ($D_1V_1F_1$). Moreover, if plots treated with both improved variety and chemical fertilizer but no diversification ($D_0V_1F_1$) would have been treated with the combination of these three technologies/practices ($D_1V_1F_1$), the average maize yield increases by 0.1 t/ha. Overall, the association of diversification with either of the two purchased inputs or both have shown better increment in average maize yield. This confirms the assertion that smallholders' investment in these two purchased inputs is more secured in terms of average maize yield obtained if plots treated with these two technologies also receive some sort of crop diversification, i.e., either intercropping maize with legumes or rotating maize with legumes.

< Table 6 here >

Figures 1a and 1b also show the actual and estimated maize yield distribution from the sub-set of plots treated with three different combinations of technologies/practices ($D_1V_1F_1$, $D_0V_1F_1$., and $D_0V_0F_0$). It is apparent that maize yield is lower for plots treated with maize-after-maize and at the same time not receiving improved seeds and chemical fertilizer. For those received improved seed and chemical fertilizer, better yield distribution is observed for those treated with crop diversification.

< Figure 1a and 1b here >

5.3.Cost of risk

Subdividing the estimated maize yield distribution from the actual and counterfactual estimates under the different combinations of technologies/practices in to four quintiles, the level of average maize yield, skewness, risk premium at randomly considered coefficient of relative risk factor (CRRA), and the contribution of downside risk to the risk premium are evaluated. As shown below in Table 7, both the risk premium farmers are willing to pay to avoid the associated yield reduction and the contribution of downside risk to the cost of risk are higher for the lowest quintile (quintile 1) in both survey years. This implies that, the cost of risk (proxied by the level of maize yield loss) is higher on the left side of the maize yield distribution. Smallholder farmers at the stated quintile are mainly resource poor and they need any sort of cushion (crop management practices or risk reducing or sharing arrangements) while encouraging them to adopt improved maize technologies demanding any cash outlay (like purchased improved seeds and chemical fertilizers).

< Table 7 here >

Comparing $D_1V_1F_1$ and $D_0V_1F_1$, where the difference is mainly the diversification component, both at moderate (b=2) to low (b=1) constant relative risk aversion coefficients (CRRA), the proportion of risk emanating from variance and skewness of maize yield distribution at the lower quintile (i.e., 1st quintile) ranges between 55 to 64% and 73 to 82% for plots with and without diversification (Table 8). Looking at the skewness component alone, the risk premium is positive for plots without diversification whereas plots treated with diversification have negative risk premium which indicates that the level of risk from diversified plots not a challenge. However, the risk premium from the skewness component when looked at the specific quintiles is not the same. Though smaller than the risk premium of plots without diversification, plots treated with diversification also have some positive premium at the lower quintiles (1st and 2nd quintiles).

< Table 8 here >

In Figure 2, the risk premium from plots treated with diversification and purchased inputs ($D_1V_1F_1$) is lower than the risk premium of other plots with different combination of practices for all ranges of constant relative risk aversion coefficients (from the lowest 0.5 to the highest 3). The cost of risk is higher for plots with no diversification ($D_0V_1F_1$) compared to any of the other combinations of purchased inputs used with crop diversification ($D_0V_1F_1$, $D_0V_1F_1$, or $D_0V_1F_1$).

< Figure 2 here >

6. Conclusions

Biotic and abiotic stress factors put smallholder farmers' production under risk. The resulting consequence on income, food and nutrition security is detrimental when farmers have no or limited weather-related information to make informed decisions in production and inputs use in god time. Moreover, resource poor farmers mainly relying on their own production for home consumption and livelihoods are seriously affected due to crop failure or any reduction in yield associated to these risks. In situations where there are no functional insurance markets to buffer smallholder farmers from production risks, the introduction of sustainable intensification practices could help at least in reducing production and consumption shocks associated to crop production risk. This paper, using a unique two years of household panel data collected at both plot and household level from maize-based systems in Ethiopia, assessed the contribution of crop diversification in improving average maize yield, and reducing the potential left-side move of maize yield distribution, i.e., reducing the skewness of maize yield distribution to the left and associated downside risk in maize production.

Estimation results confirmed the role of crop diversification in increasing the average maize productivity and the effects are higher when diversification practices were used with yield enhancing purchased agricultural inputs, i.e., improved maize varieties and chemical fertilizer in this specific study. In addition, the cost of risk, as measured by the possible maize yield farmers are willing to pay to ensure their production under different combinations of practices/technologies, is higher for plots with no diversification but treated with both improved seed and chemical fertilizer.

Results from this study imply that while the current agricultural extension system in Ethiopia is encouraging smallholder farmers to intensify production through use of purchased inputs in maize production (improved seed and chemical fertilizer), emphasis also needs to be given to training and encouraging smallholder farmers in using maize-legume intercropping and/or crop rotation to reduce farmers' challenges emanating from down-side risks in maize production. Sustainable intensification and innovative crop management practices are key in improving both the short and long-term crop productivity and in reducing the effects of biotic and abiotic stresses that increase farmers' exposure to downside risk. Moreover, the application of these practices could encourage smallholder maize producing farmers to invest more in maize yield enhancing externally purchased inputs like improved seed and chemical fertilizer.

Acknowledgements

The authors would like to acknowledge two projects financially supported the collection of panel data used in this study: Sustainable Intensification of Maize-Legume cropping systems for food security in Eastern and Southern Africa (SIMLESA) project funded by the Australian Center for International Agricultural Research (ACIAR) and Diffusion and Impact of Improved Varieties in Africa (DIIVA) project funded by Bill and Melinda Gates Foundation (BMGF) through Bioversity International which collaborated with the Standing Panel for Impact Analysis (SPIA) in the CGIAR and CIMMYT. Views in this paper are of the authors and do not represent the donors or the institutes that the authors are affiliated to. The usual disclaimer also works here.

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Tables

Table 1. Expected conditional and average treatment effects (considering $D_1V_1F_1$ and $D_0V_1F_1$ as an example)

	Treated plots	Non-treated plots	Average treatment effect on treated (ATT) and untreated (ATU)
Adopted D ($D_1V_1F_1$)	(a_{111}) $E\left[Y_{ijk} \middle\| k = 1, X_{ijk}, \hat{\lambda}_{ijk}\right]$	($c_{111,\,011}$) $E\left[Y_{ijm} \middle\| k = m, X_{ijk}, \hat{\lambda}_{ijk}\right]$	ATT=a-c
Not adopted D ($D_0V_1F_1$)	($d_{011,\,111}$) $E\left[Y_{ijk} \middle\| k = 1, X_{ijm}, \hat{\lambda}_{ijm}\right]$	(b_{011}) $E\left[Y_{ijm} \middle\| k = m, X_{ijm}, \hat{\lambda}_{ijm}\right]$	ATU=b-d

a_{111} = Actual maize yield from plots treated with $D_1V_1F_1$.
b_{011} = Actual maize yield from plots treated with $D_1V_1F_1$.
$c_{111,\,011}$ = Estimated maize yield if the counterfactual plots ($D_0V_1F_1$) were treated with $D_1V_1F_1$.
$d_{011,\,111}$ = Estimated maize yield if the counterfactual plots ($D_1V_1F_1$) were treated with $D_0V_1F_1$.

Table 2. Distribution of sample households and number of surveyed maize plots across the two waves

	Region										Total	
	Tigray		Amhara		Oromia		B/Gumuz		SNNPR			
Year	Sample HHs	Maize plots	Sample HHs	Maize plots	Sample HHs	Maize plots	Sample HHs	Maize plots	Sample HHs	Maize plots	Sample HHs	Maize plots
2010	27	30	259	446	992	1666	55	72	418	673	1751	2887
2013	*nd*	*nd*	235	369	1068	1802	64	78	407	604	1774	2853
Total	27	30	494	815	2060	3468	119	150	825	1277	3525	5740

nd=Data was not collected from Tigray region in 2013 due to logistic problem.

Table 3. Plot level characteristics and maize yield statistics (kg/ha)

	2010 *(N=2887)*		2013 *(N=2853)*		Total *(N=5740)*	
Variables	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Maize yield *(kg/ha)*	2325.2	1532.7	2496.3	1512.7	2410.2	1525.1
Seed *(kg/ha)*	26.92	15.58	25.80	12.69	26.36	14.23
Fertilizer *(kg/ha)*	87.29	105.07	109.47	114.11	98.31	110.21
Pesticide *(Birr/ha)*	2.55	14.96	1.40	25.40	1.98	20.83
Herbicide *(Birr/ha)*	6.48	69.58	11.32	90.52	8.89	80.71
Labor *(AE/ha)*	72.41	31.60	79.26	32.06	75.81	32.01
Improved hybrid variety *(1=Yes)*	0.53	0.50	0.64	0.48	0.59	0.49
Improved OPV variety *(1=Yes)*	0.08	0.27	0.03	0.18	0.06	0.23
Soil fertility *(1=Good, 2=Medium, 3=Poor)*	2.40	0.60	2.48	0.62	2.44	0.61
Soil slope *(1=Flat, 2=Medium, 3=Steep)*	2.65	0.53	2.67	0.55	2.66	0.54
Soil Depth *(1=Shallow, 2=Medium, 3=Deep)*	2.23	0.77	2.40	0.77	2.31	0.77
Plot distance from homestead *(Minutes)*	12.20	23.31	11.04	19.82	11.63	21.65
Dummy_ plot under rotation *(1=Yes)*	0.43	0.49	0.29	0.46	0.36	0.48
Dummy_ intercrop with common bean *(1=Yes)*	0.06	0.24	0.12	0.33	0.09	0.29
Dummy_ rotation and HB intercrop *(1=Yes)*	0.02	0.14	0.02	0.15	0.02	0.14
Stress effect reported on the plots						
Pest *(1=Yes)*	0.04	0.20	0.06	0.23	0.05	0.22
Disease *(1=Yes)*	0.05	0.21	0.05	0.23	0.05	0.22
Water logging *(1=Yes)*	0.03	0.18	0.05	0.22	0.04	0.20
Drought *(1=Yes)*	0.15	0.35	0.12	0.32	0.13	0.34
Hailstorm *(1=Yes)*	0.03	0.17	0.03	0.17	0.03	0.17
Other stresses *(1=Yes)*	0.02	0.13	0.06	0.24	0.04	0.20
Regional dummy						
Dummy_Tigray *(1=Yes)*	0.01	0.10	0	0	0.01	0.07
Dummy_Amhara *(1=Yes)*	0.15	0.36	0.13	0.34	0.14	0.35
Dummy_Oromia *(1=Yes)*	0.58	0.49	0.63	0.48	0.60	0.49
Dummy_B/Gumuz *(1=Yes)*)	0.03	0.16	0.03	0.16	0.03	0.16
Dummy_SNNPR *(1=Yes)*	0.23	0.42	0.21	0.41	0.22	0.42

Table 4. Maize yield distribution by combination of practices (kg/ha)

Technology combinations	2010 *(N=2887)*				2013 *(N=2853)*				Total *(N=5740)*			
	Obs	Mean	*Std. Dev*	Skewness	Obs	Mean	*Std. Dev*	Skewness	Obs	Mean	*Std. Dev*	*Skewness*
$D_0V_0F_0$	461	1630.5	1113.7	1.65	400	1751.1	1098.3	1.49	861	1686.5	1107.6	1.57
$D_0V_1F_0$	232	1888.8	1227.7	0.79	239	2005.4	1238.5	1.06	471	1947.9	1233.3	0.93
$D_0V_0F_1$	120	2094.3	1452.0	1.51	147	2102.5	1285.7	0.75	267	2098.8	1360.3	1.17
$D_0V_1F_1$	621	2714.3	1515.4	0.81	798	2804.5	1501.5	0.77	1419	2765.1	1507.7	0.79
$D_1V_0F_0$	395	1721.3	1232.7	1.65	255	1652.0	1016.2	1.43	650	1694.1	1152.3	1.62
$D_1V_1F_0$	185	2140.4	1397.0	1.05	154	2176.5	1376.6	0.95	339	2156.8	1385.8	1.01
$D_1V_0F_1$	157	2309.4	1424.5	1.42	119	2450.9	1598.1	1.31	276	2370.4	1500.6	1.38
$D_1V_1F_1$	716	2999.4	1700.9	0.87	741	3167.4	1593.0	0.69	1457	3084.9	1648.5	0.78

Note: D=Diversification, V= Improved variety, F= Chemical fertilizer

Table 5. Factors explaining the variations in maize yield *(kg/ha)*

	Total		2010		2013	
Explanatory variables	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
Sex of HH head *(1=male, 0=female)*	164.70**	71.82	244.79**	102.87	133.76	97.71
Age of HH head *(years)*	-5.02***	1.41	-4.97**	1.98	-3.50*	1.96
Education of HH head *(years)*	39.44***	5.68	38.19***	8.20	39.98***	7.67
Seed *(kg/ha)*	9.31***	1.29	9.18***	1.74	7.71***	1.94
Fertilizer *(kg/ha)*	4.58***	0.21	5.04***	0.32	4.08***	0.27
Pesticide *(Birr/ha)*	0.95	0.80	2.45	1.70	0.15	0.87
Herbicide *(Birr/ha)*	0.00	0.21	-0.19	0.34	0.23	0.25
Labor *(AE/ha)*	6.96***	0.56	5.25***	0.81	9.01***	0.79
Improved hybrid variety *(1=Yes)*	292.03***	48.05	261.89***	70.45	348.71***	65.96
Improved OPV variety *(1=Yes)*	192.94**	84.48	303.80***	107.90	185.02	146.31
Soil fertility *(1=Good, 2=Medium, 3=Poor)*	127.25***	29.37	37.25	43.40	189.59***	39.61
Soil slope *(1=Flat, 2=Medium, 3=Steep)*	50.03	34.40	48.74	49.62	36.51	47.91
Soil Depth *(1=Shallow, 2=Medium, 3=Deep)*	-24.14	22.43	11.19	32.09	-40.28	31.45
Plot distance from homestead *(Minutes)*	-1.29	0.81	-2.12*	1.10	-0.82	1.17
Dummy_ plot under rotation *(1=Yes)*	78.15**	37.10	69.98	51.56	34.66	53.70
Dummy_ intercrop with common bean *(1=Yes)*	638.07***	73.66	890.72***	129.68	578.45***	88.64
Dummy_ rotation and HB intercrop *(1=Yes)*	-127.56	134.45	-397.28*	215.83	-21.05	170.97
Stress effect reported on the plots						
Pest *(1=Yes)*	-372.90***	77.96	-377.27***	121.31	-300.07***	99.43
Disease *(1=Yes)*	-464.78***	77.73	-376.77***	116.26	-399.82***	102.51
Water logging *(1=Yes)*	-631.68***	84.21	-575.98***	133.60	-652.08***	105.27
Drought *(1=Yes)*	-587.44***	53.84	-651.94***	79.82	-516.33***	74.10
Hailstorm *(1=Yes)*	-402.84***	100.93	-385.18***	141.92	-335.67**	142.27
Other stresses *(1=Yes)*	-533.17***	87.03	-398.45**	180.80	-552.97***	97.00

Dummy_ survey year *(1= if 2013)*	12.52	35.56				
Districts _Dummy ^{a}						
Guangua	371.46	274.01	556.61*	306.29		
Dangila	134.89	264.68	553.04*	289.29	-526.75**	209.12
Fogera	420.48	270.41	641.34*	299.62	10.13	221.27
Dawa Chefa	1050.13***	276.63	1205.81***	300.01	571.61**	268.65
Gonder	727.65**	307.47	1350.43***	371.42	-103.27	291.97
Sekela	-58.98	288.33	121.43	323.85	-570.62**	275.38
Merawi	573.89**	269.33	885.09***	298.87	15.958	221.32
Omo Nada	111.13	270.59	704.74**	308.95	-518.75**	220.37
Kersa/Jimma	210.04	266.85	606.87**	304.27	-268.09	210.02
Gutu Wayo/gidda	1425.92***	270.46	1030.32***	316.42	1475.79***	212.83
Jimma Rare	412.01	278.26	791.15**	333.72	41.60	230.47
Hagere Maryam	999.10***	283.30	850.39**	398.64	758.42***	221.89
Arero	632.07**	288.35	902.02**	363.21	281.18	244.88
Kersa/EH	1479.94***	282.17	1319.60***	312.55	1631.35***	266.03
Kuni	1557.59***	280.77	1108.19***	306.34	2272.48***	278.01
Chole	1243.00***	293.60	864.21**	365.31	1353.24***	257.34
Ada'a Chukala	646.34**	285.40	487.87	340.61	635.52**	247.42
Darimu	190.10	267.02	26.54	292.03	99.20	227.24
Mana	91.82	274.51	350.99	307.03	-420.05*	241.71
Setema	83.25	274.36	207.13	303.58	-239.47	244.18
Limu Kosa	691.68**	274.54	919.55***	321.29	322.88	223.60
Nono	2312.33***	271.39	2469.19***	300.06	1985.17***	226.94
Dano	891.88***	264.59	584.98**	295.11	963.09***	206.58
Sayyo	490.49*	271.47	814.85***	301.10	-77.26	229.42
Gimbi	298.26	278.14	337.15	311.94	29.17	248.51
Meskanena Mareko	859.39***	267.76	947.00***	295.92	582.28***	216.52

Kacha Bira	-24.72	281.32	189.81	318.01	-432.21*	253.15
Shebedino	1123.11***	271.80	1503.84***	304.51	475.00**	222.82
Damot Weyde	-2.50	279.59	185.14	320.97	-391.10*	235.00
Gubu Sayyo	842.14***	263.16	939.42***	284.79	394.75*	214.83
Bako Tibbe	730.28***	254.42	449.36*	271.60	756.78***	187.96
Shalla	1298.43***	258.75	1156.75***	277.84	1265.29***	192.36
Misrak Badawacho	581.58**	260.18	553.18**	280.86	389.59**	198.27
Meskan	1022.33***	259.59	840.68***	281.49	975.81***	195.43
Hawassa Zurya	1106.18***	261.81	977.61***	283.37	1020.77***	205.62
Dugda	828.93***	264.70	820.08***	293.51	648.61***	204.69
Adami Tulu	842.69***	259.81	1041.89***	280.04	486.82**	193.89
Pawe	839.38***	267.43	941.74***	295.77	557.76**	217.36
Constant	-96.18	289.75	24.70527	338.60	-57.54	283.01
Number of Obs.	*5,620*		*2,842*		*2,778*	
F(k, n-k)	*48.59*		*23.78*		*32.26*	
Prob > F	*0.000*		*0.000*		*0.000*	
R-square	*0.3515*		*0.3429*		*0.4161*	
Adj R-square	*0.3443*		*0.3285*		*0.4032*	

****, **, and * are significant at 1%, 5%, and 10%, respectively.*

[a] *Tahtay Maychew is a reference district for the total sample 2010 estimation as Guangua is for 2013. There was no survey data from Tahtay Maychew in 2013. References were selected randomly.*

Table 6. Average treatment effects (ATT and ATU) moving from untreated ($D_0V_0F_0$) to fully treated ($D_1V_1F_1$) plots and vice versa.

Combinations compared	Adopted plots	Non-adopted plots	Adoption Effect (a-c) (b-d)	Rank in Impacts (ATT)	Rank in Impacts (ATU)
$D_1V_1F_1$ - $D_0V_1F_1$	(a_{111}) 3083.8(25.7)	$(c_{111,011})$ 2262.3(31.8)	821.5***	4	
	$(d_{011,111})$ 2848.4(23.3)	(b_{011}) 2748.3(21.8)	100.1***		6
$D_1V_1F_1$ – $D_0V_0F_1$	(a_{111}) 3083.8(25.7)	$(c_{111,001})$ 2415.6(26.0)	668.2***	6	
	$(d_{001,111})$ 2312.3(80.0)	(b_{001}) 2084.8(56.6)	227.6***		4
$D_1V_1F_1$ – $D_0V_1F_0$	(a_{111}) 3083.8(25.7)	$(c_{111,010})$ 1979.9(26.4)	1103.9***	3	
	$(d_{010,111})$ 2219.1(36.4)	(b_{010}) 1953.5(31.5)	265.6***		2
$D_1V_1F_1$ – $D_0V_0F_0$	(a_{111}) 3083.8(25.7)	$(c_{111,000})$ 1760.4(16.6)	1323.4***	2	
	$(d_{000,111})$ 1965.1(31.5)	(b_{000}) 1685.1(19.0)	279.9***		1
$D_1V_1F_1$ – $D_1V_0F_1$	(a_{111}) 3083.8(25.7)	$(c_{111,101})$ 2643.9(26.5)	439.9***	7	
	$(d_{101,111})$ 2512.7(79.2)	(b_{101}) 2382.0(60.0)	130.6*		5
$D_1V_1F_1$ – $D_1V_1F_0$	(a_{111}) 3083.8(25.7)	$(c_{111,110})$ 2299.8(29.0)	784.0***	5	
	$(d_{110,111})$ 2092.8(45.3)	(b_{110}) 2149.0(41.6)	(56.2)		7
$D_1V_1F_1$ – $D_1V_0F_0$	(a_{111}) 3083.8(25.7)	$(c_{111,100})$ 1718.9(16.2)	1364.9***	1	
	$(d_{100,111})$ 1944.9(36.3)	(b_{100}) 1688.0(22.6)	256.9***		3

a-c, reduction in yield if plots treated by $D_1V_1F_1$ *would have been treated by their counterfactuals*

b-d, yield gain if plots not fully treated would have been fully treated by $D_1V_1F_1$*.*

****, **, and * are significant at 1%, 5%, and 10% level, respectively.*

Table 7. Comparison of risk premium (cost of risk) by quintile of yield distribution (with and without diversification on plots treated with both improved seed and chemical fertilizer)

	$D_1V_1F_1$					$D_oV_1F_1$				
Quintile	Obs.	Mean Yield (kg/ha)	Skewness	Risk Premium (at 2 CRRA)	Contribution of downside risk to the premium	Obs.	Mean Yield (kg/ha)	Skewness	Risk Premium (at 2 CRRA)	Contribution of downside risk to the premium
1	355	1932.3	-1.288	188.0	21.3	337	990.6	-0.365	494.6	24.8
2	356	2704.5	-0.103	15.8	9.1	338	2147.7	-0.238	11.4	6.7
3	356	3324.7	0.155	6.5	-5.6	338	2792.7	0.280	14.0	-17.6
4	356	4362.8	1.147	85.6	-64.7	336	3705.2	0.882	82.9	-113.1
Total	1423	3083.8	0.395	295.9	63.5	1349	2408.2	-0.181	602.9	82.1

Table 8. Risk premium (R) and its decomposition by quintiles (comparing V_1 and F_1 use with and without diversification, D)

CRRA Coefficient	Total		1st Quintile		2nd Quintile		3rd Quintile		4th Quintile	
(b)	$D_1V_1F_1$	$D_0V_1F_1$	$D_1V_1F_1$	$D_0V_1F_1$	$D_1V_1F_1$	$D_0V_1F_1$	$D_1V_1F_1$	$D_0V_1F_1$	$D_1V_1F_1$	$D_0V_1F_1$
Variance + Skewness components										
2	295.90(1.00)	602.85(1.00)	187.97(0.64)	494.64(0.82)	15.80(0.05)	11.36(0.02)	6.50(0.02)	13.98(0.02)	85.58(0.29)	82.88(0.14)
1	148.10(1.00)	273.74(1.00)	82.15(0.55)	200.44(0.73)	7.72(0.05)	6.38(0.02)	3.65(0.02)	7.87(0.03)	54.58(0.37)	59.05(0.22)
Variance component										
2	310.13(1.00)	575.54(1.00)	147.91(0.48)	371.92(0.65)	14.37(0.05)	10.60(0.02)	6.91(0.02)	16.43(0.03)	140.94(0.45)	176.60(0.31)
1	152.84(1.00)	264.64(1.00)	68.79(0.45)	159.54(0.60)	7.25(0.05)	6.12(0.02)	3.77(0.02)	8.69(0.03)	73.03(0.48)	90.29(0.34)
Skewness component										
2	-14.23(1.00)	27.31(1.00)	40.06(-2.82)	122.72(4.49)	1.43(-0.10)	0.76(0.03)	-0.37(0.03)	-2.46(-0.09)	-55.35(3.89)	-93.72(-3.43)
1	-4.74(1.00)	9.10(1.00)	13.52(-2.85)	40.91(4.50)	0.48(-0.10)	0.25(0.03)	-0.12(0.03)	-0.82(-0.09)	-18.45(3.89)	-31.24(-3.43)

Note: Ratios of risk premium in each quintile are in parenthesis.

Figures

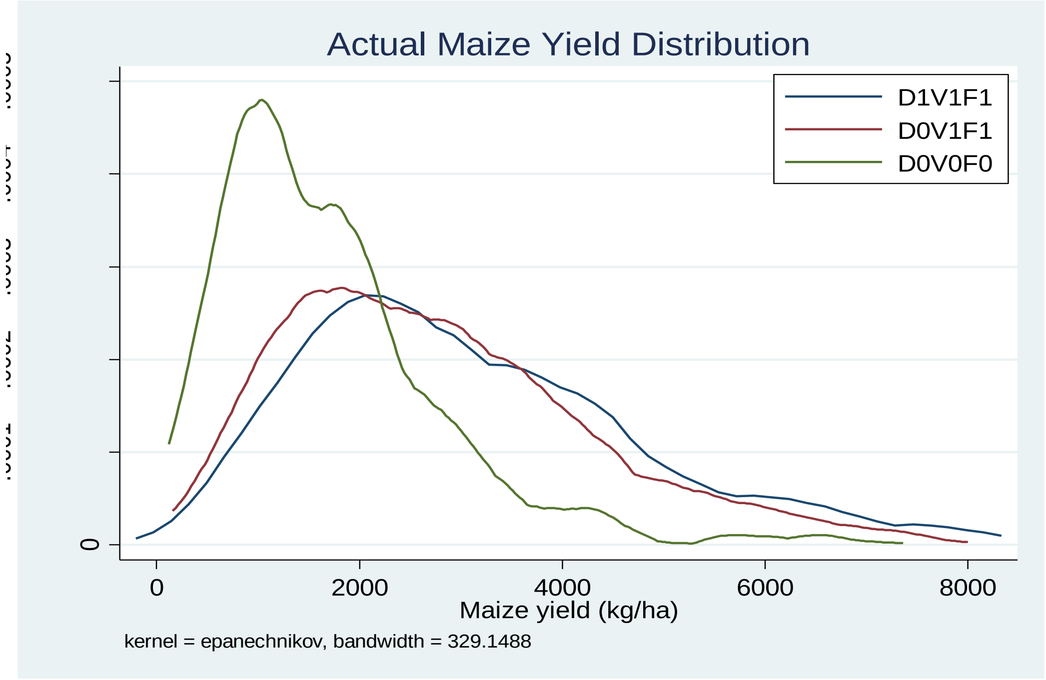

Figure 1a. Actual maize yield distributions under different combination of practices

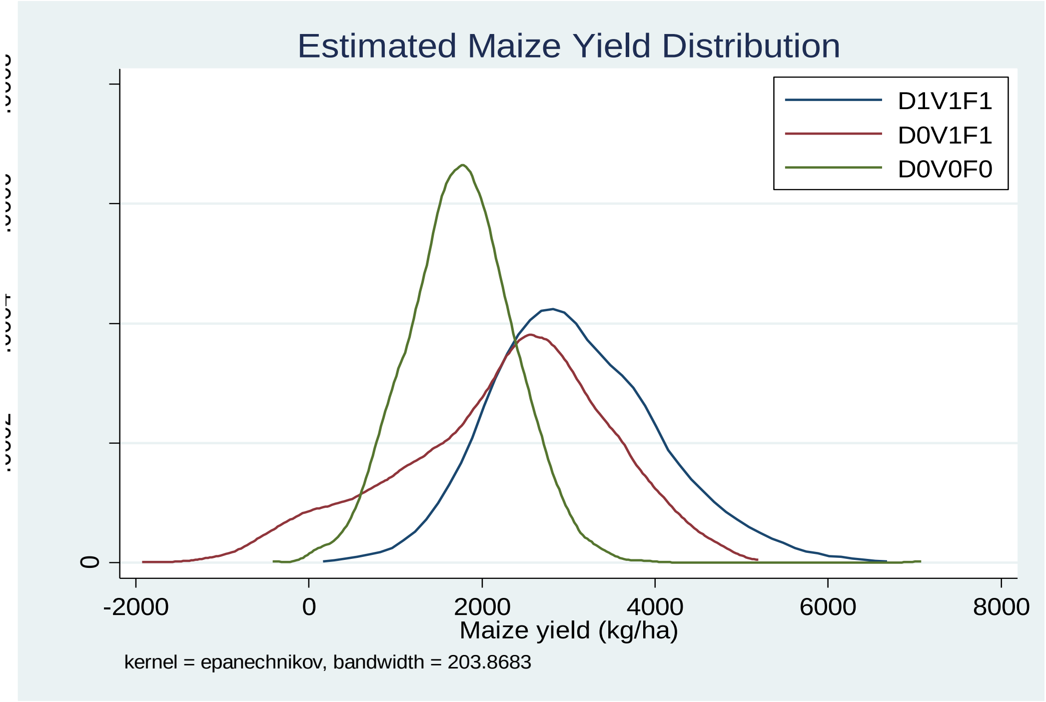

Figure 1b. Estimated maize yield distributions under different combination of practices

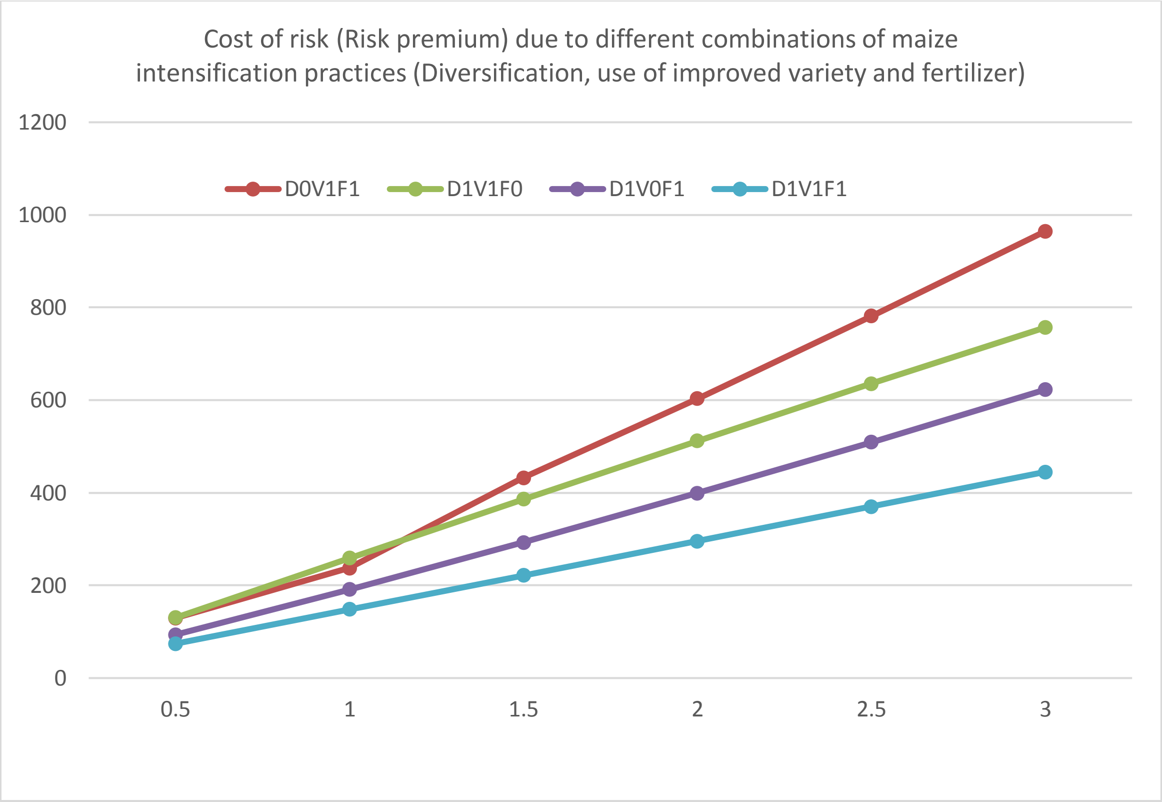

Figure 2. Risk premium (cost of risk) due to selected combinations of maize intensification practices (diversification, use of improved seed and chemical fertilizer)