Green Growth Knowledge Platform (GGKP)
Fourth Annual Conference on
Transforming Development Through Inclusive Green Growth
6-7 September 2016
Jeju International Convention Center, Republic of Korea

IMPACT OF MULTIPLE CLIMATE SMART PRACTICES IN THE CLIMATE RESILIENT GREEN ECONOMY: EMPIRICAL EVIDENCE FROM THE NILE BASIN OF ETHIOPIA

Hailemariam Teklewold[1], Alemu Mekonnen[2], Gunnar Kohlin[3] and Salvatore Di Falco[4]

[1]Environment and Climate Research Center, Ethiopian Development Research Institute, Ethiopia, e-mail: hamtekbel@yahoo.com
[2]Department of Economics, Addis Ababa University and Environment and Climate Research Center, Ethiopian Development Research Institute, Ethiopia, e-mail:alemu_m2004@yahoo.com
[3]Department of Economics, University of Gothenburg, e-mail: gunnar.kohlin@economics.gu.se
[4]Department of Economics, University of Geneva, e-mail: salvatore.difalco@unige.ch

GREEN GROWTH
Knowledge Platform

ABSTRACT
The Ethiopian government has recently launched a vision to build a climate resilient green economy (CRGE) by 2025. One of the pillars for the CRGE strategy in the agricultural sector is the adoption and diffusion of various climate smart strategies for improving crop and livestock production for higher food security and farmer income while reducing emissions. However, there is a paucity of information on the conditions under which multiple climate-smart practices are adopted and on the synergies among such practices in increasing household resilience by improving agricultural income. This study analyzes how heat, rainfall, and rainfall variability affect farmers' choices of a portfolio of potential climate-smart practices – agricultural water management, improved crop seeds and fertilizer – and the impact of these practices on farm income in the Nile Basin of Ethiopia. A primary result of this study is that farmers are less likely to adopt fertilizer (either alone or in combination with improved varieties) in areas of higher rainfall variability. However, even when there is high rainfall variability, farmers are more likely to adopt these two yield-increasing inputs when they choose to include the third part of the portfolio: agricultural water management. Net farm income responds positively to agricultural water management, improved crop variety and fertilizer when they are adopted in isolation as well as in combination. But this effect is greater when these practices are combined. Simulation results suggest that a warming temperature and decreased precipitation in future decades will make it less likely that farmers will adopt practices in isolation but more likely that they will adopt a combination of practices. Hence, a package approach rather than a piecemeal approach is needed to maximize the synergies implicit in various climate-smart practices.

Key words: *Multinomial Endogenous Switching, multiple climate smart practice, farm income, Ethiopia.*

1. **INTRODUCTION**

The Ethiopian government has recently launched a vision to build a climate resilient green economy (CRGE) by 2025 (FDRE 2011). This is an economy that would be middle-income, resilient to the negative impacts of climate change and would be achieved with no net increase in greenhouse gas emissions relative today. One of the pillars for the CRGE strategy in the agricultural sector is the adoption and diffusion of various climate smart strategies for improving crop and livestock production for higher food security and farmer income while reducing emissions (FDRE 2011). However, there is a paucity of information on the conditions under which multiple climate-smart practices are adopted and on the synergies among such practices in increasing household resilience by improving agricultural income. While individual climate-smart practices (CSA) provide multiple benefits, there are complementarities and synergies when more than one practice is adopted together. For instance, in smallholder farming , one of the major sources of risk is moisture stress, where fertilizer will not be applied if application to a crop is perceived as too risky (Rockström et al., 2002). Under these circumstances, agricultural water management can reduce the risk created by moisture stress and thus make farmers more confident about applying fertilizer. Treating farmers' adoption choices as bundle of practices, rather than as isolated decisions, is important in order to better understand the synergistic effect of inter-related practices. This will enable policy makers and development practitioners to promote combinations of technologies/practices that perform well together.

In this study, we consider three CSA practices. The first is the adoption of agricultural water management practices. This is one of the "best bet" strategies for adapting agricultural production to climate change and variability, because agricultural water management practices improve water balance and availability, infiltration and retention by the soil, reduce water loss due to runoff and evaporation, and improve the quality and availability of ground and surface water (Arslan et al., 2013). Agricultural water management works best when it is accompanied by other crop management practices such as modern crop varieties and fertilizer that can use moisture more efficiently. Thus, we next consider two other technologies: improved crop varieties and inorganic fertilizer. Food security in an era of climate change may be possible if farmers transform agricultural systems via the use of improved crop seed and fertilizer (Bryan et al., 2011). Appropriate use of fertilizer is required both to enhance crop productivity and to produce sufficient crop residues to ensure soil cover under smallholder conditions.

This study, therefore, has two objectives: to examine the effect of both climate-related and socio-economic factors on the probability that farmers will adopt climate-smart practices, individually and in combination, in the Nile Basin of Ethiopia; and to quantify the impact of adopting various combinations of these practices on crop net income (net of fertilizer, seed, labor and pesticide costs), as an outcome indicator. We do this by controlling for selection bias using a multinomial endogenous switching treatment effects approach. Our study adds to the literature in the following ways. First, we contribute to the limited literature on adoption of a portfolio of CSA practices under climate change. Second, we investigate whether adoption of a combination of CSA practices will provide more economic benefits than individual adoption. For Ethiopia, a country that has a vision of building a climate-resilient economy, identifying a combination of CSA that deliver the highest payoff is a valuable contribution to help to design effective extension policies.

2. STUDY AREAS AND SAMPLING

Our basic data come from the farm household survey conducted in five regions of the Ethiopian part of the Blue Nile Basin: Amhara, Oromia, Tigray, Benshangul-Gumuz and SNNP. The data collected during March – May, 2015 on a randomly selected 929 farm households with 4702 farming plots. The basin covers about two thirds of the country's land mass and contributes nearly 40% of its agricultural products (Erkossa et al., 2014).

3. DATA DESCRIPTION AND EMPIRICAL SPECIFICATION

The CSA practices considered in this study include agricultural water management, improved crop seeds and inorganic fertilizer; providing eight mutually exclusive combinations of practices (2^3). Table 1 presents the proportions of area cultivated under the different combination of practices. Of all the 4702 farming plots, about 28% did not receive any of the adaptation practices ($Va_0Fe_0Aw_0$); while all the three practices were simultaneously adopted on only 9% of the plots ($Va_1Fe_1Aw_1$).

Table 1.Package of CSA practices used on farming plots in the Nile Basin of Ethiopia

Choice	Package of CSA	Improved crop varieties (Va)		Fertilizer (Fe)		Water management (Aw)		
(j)	practices$^{\Psi}$	Va_1	Va_0	Fe_1	Fe_0	Aw_1	Aw_0	Frequency (%)
1	$Va_0Fe_0Aw_0$		√		√		√	28.25
2	$Va_1Fe_0Aw_0$	√			√		√	2.72
3	$Va_0Fe_1Aw_0$		√	√			√	17.50
4	$Va_0Fe_0Aw_1$		√		√	√		14.50
5	$Va_1Fe_1Aw_0$	√		√			√	10.36
6	$Va_1Fe_0Aw_1$	√			√	√		1.83
7	$Va_0Fe_1Aw_1$		√	√		√		16.16
8	$Va_1Fe_1Aw_1$	√		√		√		8.57

$^{\Psi}$Each element in the CSA combinations consist of a binary variable for a practice /Improved crop varieties (Va), Inorganic fertilizer (Fe) and Agricultural water management (Aw)/, where the subscript refers 1= if adopted and 0 = otherwise.

Table 2 shows the interdependence of CSA practices. Water management, improved seeds and fertilizer is used on 41, 24 and 53% of the plots, respectively. The sample unconditional and conditional probabilities presented in Table 2 also highlight the existence of interdependence across the three CSA practices. For instance, the probability of adopting water management increased by 3 and 6% conditional on adoption of crop variety and fertilizer, respectively. The conditional probability of household adopting fertilizer and crop varieties is significantly increased from 52% to 60% and from 23% to 25%, respectively, when farmers practiced water management. The result indicates complementarity between the three CSA practices.

Table 2. Sample conditional and unconditional adoption probabilities of CSA practices in Ethiopia

	Improved varieties (Va)	Fertilizer (Fe)	Water management (Aw)
$P(Y_k = 1)$	23.5	52.6	41.1
$P(Y_k = 1 \mid Y_{Va}= 1)$	100.0	80.6***	44.3***
$P(Y_k = 1 \mid Y_{Fe}= 1)$	35.9***	100.0	47.0***
$P(Y_k = 1 \mid Y_{Aw} = 1)$	25.3***	60.2***	100.0
$P(Y_k = 1 \mid Y_{Va}= 1, Y_{Fe} = 1)$	100.0	100.0	45.3***
$P(Y_k = 1 \mid Y_{Va}= 1, Y_{Aw} = 1)$	100.0	82.4***	100.0
$P(Y_k = 1 \mid Y_{Fe}= 1, Y_{Aw}= 1)$	34.7***	100.0	100.0

Y_k is a binary variable representing the adoption status with respect to choice k (k = Improved crop varieties (Va), Inorganic fertilizer (Fe) and Agricultural water management (Aw).

*, ** and *** indicate statistical significance difference at 10, 5 and 1% respectively. The comparison is between unconditional probability and conditional probabilities in each practice.

Table 3 presents the description and summary statistics of the control variables used in the empirical analysis for the full sample and the eight sub-groups. The specification of our empirical model is based on a review previous related (see Teklewold et al., 2013 for detail references). According to these literatures, factors affecting adaptation and net crop income include natural capital, social capital and network, shocks, physical capital, access to services and constraints, access to credit, extension service and climate information, human capital, geographic location and climate variables. Below we focus on describing those variables that are not common in the adoption literature. See Teklewold et al., 2013 for discussion on other variables.

This study includes self-reported rainfall shocks and plot level crop production shocks. We followed Quisumbing (2003) to construct the rainfall disturbance variable based on respondents' subjective rainfall satisfaction in terms of timeliness, amount, and distribution. The individual rainfall index was constructed to measure the farm-specific experience related to rainfall in the preceding seasons, based on such questions as whether rainfall came on time at the start of the growing season, whether there is enough rain at the beginning and during the growing season, whether the rain stops on time and whether there is no rain at harvest time. Responses to each of these questions (either yes or no) were coded as favorable or unfavorable rainfall outcomes. Then, the index provides a value close to one for the favorable outcome and zero for the worst outcome. The plot level disturbance is captured by five most common shock affecting crop production such as pest and disease pressure; drought, flood, hailstorm and erratic rainfall.

Table 3. Explanatory variables by combination of climate smart practices

Variable	Description	$Va_0Fe_0Aw_0$	$Va_1Fe_0Aw_0$	$Va_0Fe_1Aw_0$	$Va_0Fe_0Aw_1$	$Va_1Fe_1Aw_0$	$Va_0Fe_0Aw_0$	$Va_0Fe_0Aw_0$	$Va_0Fe_0Aw_0$	All Mean
Household features										
Gender	Sex of the head (1=if male)	0.872	0.867	0.855	0.890	0.930	0.872	0.876	0.916	0.882
Age	Age of the head. years	51.39	48.62	52.64	51.39	51.81	49.55	53.15	51.23	51.81
Education	Education level of the head. years	1.80	2.35	1.24	1.95	2.11	2.87	1.76	1.98	1.80
Famlysize	Family size	8.07	8.45	8.27	8.03	8.55	8.29	8.10	8.55	8.21
Resource constraints										
Farmsize	Farm size. ha	1.74	2.28	1.90	1.80	1.84	2.04	1.90	1.83	1.84
Tlu	Livestock size	4.71	4.84	4.84	4.68	5.13	4.79	4.85	5.13	4.83
Credit	Credit constraint (1=if yes)	0.485	0.492	0.408	0.440	0.419	0.558	0.417	0.404	0.442
Expend	Annual household expenditure. '000 Birr	14.69	16.23	16.97	13.18	19.10	14.79	16.14	19.36	16.00
Extension. information and market										
Distmkt	Walking distance to main market. minutes	68.65	65.51	69.05	69.55	57.96	62.97	67.84	59.49	66.64
Extcont	1=if contact extension agents	0.959	0.992	0.968	0.972	0.979	1.000	0.971	0.983	0.970
Extconfd	1=if confident with the skill of extension agents	0.952	0.984	0.959	0.955	0.964	0.957	0.961	0.957	0.958
Infoclimat	1=if farmer has access to climate information	0.496	0.539	0.447	0.595	0.575	0.547	0.503	0.620	0.524
Social capital and network										
Member	1=if the household is member of groups	0.923	0.938	0.983	0.969	0.994	0.977	0.978	0.973	0.962
Agrigroup	Number of agricultural groups where a farmer is a member	0.789	0.953	0.656	0.802	0.951	1.105	0.807	1.097	0.824
Socgroup	Number of social groups where a farmer is a member	2.428	2.508	2.495	2.567	2.669	2.384	2.607	3.017	2.566
Spillover effects on neighbors' plots										
Vapos	1=if perceived positive effects of improved variety	0.258	0.336	0.337	0.189	0.359	0.291	0.228	0.395	0.282
Fepos	1=if perceived positive effects of fertilizer	0.336	0.328	0.396	0.306	0.374	0.349	0.379	0.412	0.360
Awpos	1=if perceived positive effects of water management	0.593	0.688	0.652	0.818	0.630	0.733	0.822	0.779	0.698
Shocks										
Rainindex	Rainfall disturbance index (1=best)	0.706	0.706	0.683	0.695	0.727	0.630	0.731	0.673	0.702
Plotindex	Plot level disturbance index (1=worst)	0.185	0.150	0.200	0.184	0.157	0.165	0.199	0.215	0.188
Relygovt	1=if rely on government support in case of crop failure	0.364	0.359	0.482	0.334	0.437	0.360	0.434	0.479	0.409
Farm features										
Plotdist	Walking distance of the plot from home. minutes	14.64	14.20	14.50	16.05	13.41	16.88	15.08	14.35	14.77
Tenure	1=if own the plot	0.867	0.898	0.814	0.897	0.850	0.919	0.832	0.849	0.855
Highfert	1=if highly fertile soil plot	0.349	0.305	0.367	0.384	0.386	0.488	0.393	0.427	0.376
Midfert	1=if medium fertile soil plot	0.516	0.578	0.490	0.515	0.509	0.453	0.508	0.469	0.506
Flatslop	1=if flat slope plot	0.580	0.492	0.683	0.565	0.602	0.709	0.617	0.613	0.607
Midslop	1=if medium slope plot	0.392	0.445	0.279	0.389	0.366	0.267	0.367	0.347	0.360
Depdepth	1=if deep depth soil plot	0.464	0.484	0.482	0.479	0.478	0.558	0.501	0.467	0.480

Middepth	1=if medium depth soil plot	0.408	0.414	0.405	0.411	0.394	0.337	0.417	0.400	0.406
Manure	1=if manure was applied in the plot	0.260	0.414	0.283	0.330	0.298	0.523	0.292	0.385	0.303
Cereal	1=if cereal crops grown	0.593	0.758	0.871	0.588	0.938	0.593	0.820	0.871	0.742
Legume	1=if legume crops grown	0.283	0.148	0.064	0.220	0.031	0.221	0.064	0.037	0.148
Climate										
Rain	Amount of rainfall in the growing season in mm (2000-2013)	698.39	790.70	616.24	775.88	719.19	818.02	695.72	694.97	701.38
PCI	Precipitation concentration index	20.09	21.02	19.39	20.79	19.62	21.66	19.56	19.86	19.97
Temperature	Average temperature in ^{0}C (2000-2013)	27.36	26.34	26.04	28.19	24.31	27.20	29.35	29.14	27.38
Elevation	Location of the household with respect to altitude.m.a.s.l	2218	1979	2279	2251	2211	2001	2250	2214	2227
Number of observations		1333	128	823	682	487	86	760	403	4702

We also merge the household survey data with the novel set of climate variables based on geo-referenced historical temperature and precipitation data at household level for the period of 2000 – 2013. Monthly rainfall and temperature data were collected from all the meteorological stations in the country. Then, the Thin Plate Spline method of spatial interpolation was used to impute the household specific rainfall and temperature values using the geo-referenced information such as elevation, longitude and latitude. The Thin Plate Spline is a physically based two-dimensional interpolation scheme for arbitrarily spaced tabulated data. In order to identify the monthly pattern of rainfall heterogeneity in our study areas, we used the Oliver's (1980) Precipitation Concentration Index (PCI)[1] analyzed at supra-seasonal scale (April-September). Similarly, in order to assess farmers' perception on climate change, in the survey instruments, farmers have asked to reveal their perceptions whether they have noticed changes in climate over their life time.

4. CONCEPTUAL FRAMEWORK AND ECONOMETRIC SPECIFICATION

As discussed above farmers' adoption of water management, modern seeds and fertilizers leads to eight (2^3) possible combinations of CSA practices. Adoption of these combinations may not be random; instead farmers may endogenously self-select into using or not-using decisions, so decisions are likely to be influenced by unobservable characteristics (for example expectation of yield gain from adoption, managerial skills, motivation) that may be correlated with the outcomes of interest, farm income. We model farmers' choice of combinations of CSA practices and impacts of adoption in a setting of a multinomial endogenous switching regression framework (Bourguignon et al., 2007).This framework has also the advantage of evaluating both individual and combinations of practices while capturing the interactions between alternative practices choice (Teklewold et al., 2013). The estimation is done in two-steps. In the first stage, farmers' choice of individual and combined practices is modeled using a multinomial logit selection model. In the second stage, we estimate Ricardian models conditional on the impacts of the types of combination of CSA on the outcome variables with selectivity correction terms. The probability that farmer *i* with characteristics *X* will choose combination of practices *j* can be specified by a multinomial logit model (MNL) (McFadden, 1973):

(1)

In the second stage, the relationship between the outcome variables and a set of exogenous variables Z (farm, household and location characteristics) is estimated for the chosen combination of practices. This yields eight conditional specifications, one for each combination of practices. The conditional Ricardian specification for each possible regime *j* for j=1, . . ., 8 is given as:

$$\text{Regime j: } Q_{ij} = Z_i\alpha_j + \sigma_{j\varepsilon}\hat{\lambda}_{ij} + \omega_{ij} \quad \text{if } U = j \tag{2}$$

where $Q'_{ij}s$ are the outcome variables of the i^{th} farmer in regime j σ_j is the covariance between error terms between selection and outcome equations, λ_j is the inverse Mills ratio computed from the estimated probabilities in (1) and ω's are error terms with an expected value of zero.

Estimation of average adoption effects: the estimands that are most commonly of interest are the average adoption effect on the adopter (ATT), The ATT answers the question of how the average outcome would change if everyone who received one particular treatment had instead received another particular treatment. The ATT is used to compare expected net farm income of adopters

[1]The PCI is described as: $PCI = 50X\left[\sum r_m^2 / \left(\sum r_m\right)^2\right]$ where r_m is amount of rainfall of the m^{th} month. The PCI is a powerful indicator of temporal distribution of precipitation, as the value increases, the more concentrated the precipitation. PCI values of less than 10 indicate uniform monthly distribution of rainfall (low precipitation concentration); values between 11 and 15 indicate moderate precipitation concentration; PCI between16-20 indicates irregular distribution, and values above 21 indicate very high precipitation concentration (strong irregularity) Oliver (1980).

with the counterfactual hypothetical case that adopters did not adopt. The expected net farm income under the actual and counterfactual hypothetical cases is computed as follows by applying equations (2):

Adopters with adoption (actual):

$$E(Q_{ij} \mid I = j) = Z_{ij}\alpha_j + \sigma_j\lambda_{ij} \quad (3)$$

Adopters had they decided not to adopt (counterfactual):

$$E[Q_{i1} \mid I = j] = Z_{ij}\alpha_1 + \sigma_1\lambda_{ij} \quad (4)$$

The average CSA adoption effect on the adopters (ATT) is defined as the difference between equations (3) and (4):

$$ATT = [Q_{ij} \mid I = j] - E[Q_{i1} \mid I = j] = Z_i(\alpha_j - \alpha_1) + \lambda_{ij}(\sigma_j - \sigma_1) \quad (5)$$

5 ESTIMATION RESULTS

5.1 Adoptions of multiple climate smart practices[2]

As expected there is significant and positive association between education level of the household head and adoption of modern crop seeds when combined with inorganic fertilizers ($Va_1Fe_1Aw_0$) or water management practices ($Va_1Fe_0Aw_1$). The result reveals a significant wealth or liquidity constraint effect for the adoption of the combination of climate smart practices. This indicates modern seeds and inorganic fertilizer, an externally purchased inputs, is not adopted by resource poor farmers. Similarly, adoption of $Va_0Fe_1Aw_0$ (only fertilizer) or $Va_0Fe_0Aw_1$ (only agricultural water management practice) is less likely for credit constrained farm households. The results also reveal that households with confidence in the skills of extension agents are more likely to adopt improved variety or fertilizer. It is also found that access to climate information is important for farmers to use water management practices ($Va_0Fe_0Aw_1$). With regards to the importance of rainfall and plot level shocks in determining the adoption of combination of adaptation practices, the result indicates that in areas/years where rainfall is worst in terms of timing, amount and distribution, it is more likely that household shifts in to a combination of practices that are more climate smart. This finding suggests that smallholder farmers who realized rainfall variability are using water management practices in combination with modern seeds and ($Va_1Fe_0Aw_1$) and inorganic fertilizer ($Va_1Fe_1Aw_1$) as adaptation strategies to mitigate the risk of climate variability. This is important evidence on the synergy between climate smart practices as climate change adaptation.

Not all individual climate variables are statistically significant. However, the set of climate variables are jointly highly significant determinant of the choice of a combination of climate smart practices. We found that growing season rainfall amount is important for the choice of fertilizer ($Va_0Fe_1Aw_0$) and a combination of water management practices with improved seed ($Va_1Fe_0Aw_1$) or fertilizer ($Va_0Fe_1Aw_1$).The positive first degree and negative second degree terms for growing season precipitation indicate an inverted U-shaped response to the likelihood of these combinations of climate smart practices. However, the non-significance of the quadratic term coefficients of ($Va_1Fe_0Aw_1$) and ($Va_0Fe_1Aw_1$) suggests that adoption of modern seeds and fertilizer might be quite resilient to changes in precipitation when they are combined with water management practices. The result suggests the need for careful agro-ecological targeting when developing, promoting and scaling up of adaptation practices. The main reason seems to be that farmers seek to minimize the downside risk a yield shortfall arising from application of these practices in unfavorable seasons (Monjardino et al., 2013).

---

[2]The result is not reported here for the sake of space.

The study also recognized agricultural water management in combination with modern seeds ($Va_1Fe_0Aw_1$) or inorganic fertilizer ($Va_0Fe_1Aw_1$) as important options for adapting agricultural production under warmer climate. Agricultural water management is a risk reducing option, so that increased frequency of unfavorable weather conditions favors its adoption. Agricultural water management as adaptation techniques is thus key to ensuring agricultural production and reduction of risks, whilst at the same time improving resilience to drought and dry spells. Increasing rainfall variability significantly decreases the likelihood of adoption of fertilizer both in isolation and in combination with modern seeds, thus reflecting the adverse effects of rainfall variability on adoption of risk increasing inputs. In high rainfall variability condition, agricultural water management in isolation ($Va_0Fe_1Aw_1$) or in combination with inorganic fertilizer ($Va_0Fe_1Aw_1$) or modern seeds ($Va_1Fe_0Aw_1$) or both ($Va_1Fe_1Aw_1$) are more responsive and considered as important adaptation strategies for smallholder farming system. As a risk decreasing practice, the adoption of water management is considered as the most common response to rainfall variability and strengthens farmers' resilience when adopted in combination with modern seeds and/or inorganic fertilizer.

Finally, we tested an interaction term between amounts of growing season precipitation and growing season rainfall variability and found important lesson for climate change adaptation. The result shows that in low rainfall areas adoptions of improved crop seeds and/or fertilizer in combination with agricultural water management is more likely under high variable rainfall condition. More variable rainfall and low amount of rain could bring challenges to agricultural production such as adoption of risk increasing externally purchased inputs, modern seeds and fertilizer. However, agricultural water management can be combined with modern seeds and inorganic fertilizers to present opportunities for farmers to make the farming system more resilient to decreased rain intensity and increased variability.

5.2 Impacts of multiple adaptation practices

Table 5 shows that the adoption of any of the climate smart practice in isolation or a combination of them provides higher net crop income compared with non-adoption..

Table 5. Average expected net crop income ('000 Birr/ha) with adoption of combination of CSA effects

Outcome	Descriptions	Adopter sample farm households		
		(A) Actual Net crop income if farm households did adopt (Birr/ha)	(B) Counterfactual Net crop income if farm households didn't adopt (Birr/ha)	(C) Adoption Effects (Birr/ha)
$Va_1Fe_0Aw_0$	Varieties	12.19 (0.56)	7.32 (3.15)	4.88(3.19)***
$Va_0Fe_1Aw_0$	Fertilizer	12.87 (0.13)	5.99 (0.39)	6.89 (0.41)***
$Va_0Fe_0Aw_1$	Water management	12.83 (0.20)	9.58 (0.11)	3.24 (0.23)***
$Va_1Fe_1Aw_0$	Varieties & Fertilizers	13.42 (0.16)	5.84 (0.47)	7.58 (0.49)***
$Va_1Fe_0Aw_1$	Varieties & Water management	17.34 (1.08)	10.39 (0.48)	6.94 (1.19)***
$Va_0Fe_1Aw_1$	Fertilizer & Water management	15.06 (0.12)	5.99 (0.71)	9.06 (0.72)***
$Va_1Fe_1Aw_1$	Varieties, Fertilizer & Water management	20.55 (0.20)	10.04 (1.45)	10.51 (1.46)***

Note: figures in parenthesis are standard errors; *. ** and *** indicate statistical significance at 10%, 5% and 1% level.

In all counterfactual cases, farm households who actually adopted would have earned less if they did not adopt. The largest farm income (10.5 thousands Birr/ha) is obtained from adoption of water management practices jointly with fertilizers and modern seeds ($Va_1Fe_1Aw_1$). Adoption of fertilizers in isolation provides the highest net income than adoption of other practices in isolation. Adoption of fertilizers in combination with water management practices ($Va_0Fe_1Aw_1$) or in combination with modern seeds ($Va_1Fe_1Aw_0$) also provides the highest farm income compared with income obtained from a combination of water management and modern crop seeds ($Va_1Fe_0Aw_1$).

5.3 Simulation of future combination of practices and income

We use a climate scenario predicted by the regional climate model BCM.2 to get estimates using the A2 emission scenario from the special report on emission scenarios (SRES) of the IPCC (2000). At the district level, the SRES A2 emissions scenario predicts an annual warming with an average annual temperature increase of 1.8^0C (+8% from the 1980-99 period) and an average total annual rainfall declines of 34 mm (-2%) by 2060. We summarize the potential behavior of combination of climate smart practices in the adaptation model by calculating the scenario-predicted probabilities which are cross tabulated against the base fitted ones (Table 6). Based on our parameter results and the A2 storyline, adoption of combination of CSA by 2060 would be expected to change in about 40% of the farming plots (around 1840 plots – the sum of the off-diagonal components of Table 6).While plots with none of the climate smart practices is predicted to decrease by about 22% (38% vs 16%), adoption of CSA practices in isolation as well as in combination would be expected to increase up to 18% half a century later.

Table 6. Changes in the choice probabilities (%) of combinations of CSA for future decades

Baseline (model-fitted)	Scenario simulated combinations of CSA								
combinations of CSA	$Va_0Fe_0Aw_0$	$Va_1Fe_0Aw_0$	$Va_0Fe_1Aw_0$	$Va_0Fe_0Aw_1$	$Va_1Fe_1Aw_0$	$Va_1Fe_0Aw_1$	$Va_0Fe_1Aw_1$	$Va_1Fe_1Aw_1$	Sum
$Va_0Fe_0Aw_0$	40.09	1.01	18.47	21.51	6.19	0.73	9.74	2.25	37.77
$Va_1Fe_0Aw_0$	0.00	94.74	0.00	0.00	5.26	0.00	0.00	0.00	0.40
$Va_0Fe_1Aw_0$	1.33	0.00	76.48	2.42	6.06	0.00	11.52	2.18	17.55
$Va_0Fe_0Aw_1$	3.16	0.53	2.63	85.44	0.35	0.18	4.91	2.81	12.12
$Va_1Fe_1Aw_0$	0.25	0.49	11.03	0.98	74.51	0.00	8.82	3.92	8.68
$Va_1Fe_0Aw_1$	0.00	0.00	0.00	6.25	6.25	81.25	6.25	0.00	0.34
$Va_0Fe_1Aw_1$	0.00	0.00	22.25	7.42	3.01	0.00	64.19	3.13	18.35
$Va_1Fe_1Aw_1$	0.00	0.00	21.78	1.33	5.33	0.89	7.11	63.56	4.79
Sum	15.78	0.87	26.80	20.44	10.76	0.62	19.20	5.53	100.00

Under the SRES A2 scenario, the net crop income for farms without CSA would be expected to decline compared to the baseline levels but the profit of the farm with water management practices increases (Table 7). Similarly, although the net crop income from farms with modern seeds alone or in combination with inorganic fertilizer falls, but the profit increases when these two externally purchased inputs are combined with water management practices. Although profit from farms with water management increases, the increase from farms with a combination of water management with modern seeds and inorganic fertilizer are overwhelming. The overall conclusion that the net income changes in Table 7 confirm the hypothesis that farms with a combination of CSA are more resilient under climate change than farms with CSA in isolation.

Table 7. Changes in conditional net farm income ('000 Birr/ha) for future decades

Mean net income	$Va_0Fe_0Aw_0$	$Va_1Fe_0Aw_0$	$Va_0Fe_1Aw_0$	$Va_0Fe_0Aw_1$	$Va_1Fe_1Aw_0$	$Va_1Fe_0Aw_1$	$Va_0Fe_1Aw_1$	$Va_1Fe_1Aw_1$
Simulated	8.87	9.94	13.04	14.03	12.90	18.79	16.10	23.09
	(1.46)	(5.33)	(2.38)	(2.73)	(3.03)	(10.89)	(2.09)	(4.78)
Baseline	9.44	12.07	12.87	12.85	13.43	16.99	15.09	20.57
	(2.03)	(6.05	(3.09)	(4.58)	(3.21)	(6.92)	(3.16)	(4.04)
Absolute change	-0.56***	-2.12**	0.17	1.18***	-0.54***	1.79	1.01	2.52***
Percentage change	-5.40	-17.94	1.33	9.18	-3.99	10.55	6.69	12.20***

Note: numbers in parenthesis are standard deviation; ** and *** indicate statistical significance at 10%. 5% and 1% level.

6. CONCLUSIONS

In this article, we contribute to the existing empirical literature on whether a combination of multiple CSA practices is more resilient against climate change. The results indicate that the current choices of alternative combinations of practices and related farm income in the Nile basin of Ethiopia are heavily influenced by climate. When the climate is hot and the rainfall is variable, farmers more often prefer a combination of practices over a practice in isolation. The results also revealed that the likelihood of adoption of water management, modern seeds and fertilizers is influenced by plot-level shocks, soil characteristics, social capital and extension services. The effect of these variables can be used to target policies aimed at increasing adoption rates of different types of practices. For example, the significant role of social capital and extension services suggests the need for establishing and strengthening local institutions, service providers and extension systems to accelerate climate change adaptation.

Acknowledgments
The household survey for this research is supported by the International Development Research Centre (IDRC) under the project "Adaptation to increase Resilience to Climate Change in Ethiopian Agriculture (IDRC Project Number: 107745-001)". Logistic support for this study from the Environment and Climate Research Center (ECRC) of the Environment and Development Initiative (EfD) at the Ethiopian Development Research Institute (EDRI) is also gratefully acknowledged.

References

Arslan A., McCarthy N., Lipper L., Asfaw S. and Cattaneo A. 2013.Adoption and intensity of adoption of conservation farming practices in Zambia. *ESA Working paper* No. 13-01. FAO.

Bourguignon, F., Fournier, M., Gurgand, M., 2007. Selection bias corrections based on the multinomial logit model: Monte-Carlo comparisons. *Journal of Economic Surveys* 21, 174–205.

Bryan E., Ringler C., Okoba B., Koo J., Herrero M. and Silvestri S. 2011. Agricultural management for climate change adaptation, greenhouse gas mitigation, and agricultural productivity: insights from Kenya. International Food Policy Research Institute (IFPRI) Working paper 01098. Washington DC.

Erkossa T., Haileslassie A., and MacAliste C.. 2014. Enhancing farming system water productivity through alternative land use and water management in vertisol areas of Ethiopian Blue Nile Basin (Abay). *Agricultural Water Management* 132: 120– 128

FDRE 2011. Ethiopia's Climate-Resilient Green Economy: Green Economy Strategy. Federal and Democratic Republic of Ethiopia, Addis Ababa.

Monjardino M., Mc Beath T.M., Brennan L, Llewellyn R.S. 2013. Are farmers in low-rainfall cropping regions under-fertilising with nitrogen? A risk analysis. *Agricultural Systems* 116: 37–51.

Oliver J.E., 1980. Monthly precipitation distribution: a comparative index, Professional Geographer, 32, 300–309.

Quisumbing A. 2003. 'Food aid and child nutrition in rural Ethiopia', *World Development*, 7: 1309-1324.

Rockstrom J., Barron J. and Fox P. 2002. Rainwater management for increased productivity among smallholder farmers in drought environments. *Physics and Chemistry of the Earth* 27: 949-959.

Teklewold, H., Kassie, M., Shiferaw, B. Köhlin G. 2013. Cropping system diversification, conservation tillage and modern seed adoption in Ethiopia: Impacts on household income, agrochemical use and demand for labor. *Ecological Economics*.93:85-93.