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EFFECTIVENESS OF TECHNOLOGICAL OPTIONS FOR MINIMISING PRODUCTION RISKS UNDER VARIABLE CLIMATIC CONDITIONS IN EASTERN UGANDA

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ABSTRACT

This study employed the Just and Pope stochastic production frontier to assess the effectiveness of farmer-preferred technologies in reducing production risk related to climate variability in Eastern Uganda. Data for this study were obtained from 315 households, 9 focus group discussions and 23 key informants drawn from Mbale, Pallisa and Sironko districts. Results show that farmers employed a number of technologies/practices strategically in response to seasonal variations in climatic conditions. Most of the technologies showed significant positive impacts on mean yield, but had different risk-reducing effects on yield. Changing sowing dates and crop varieties, soil bunds, compost manure, cover crops, crop rotation and intercropping showed significant ($P<0.05$) risk-reducing effects on yield. However, their effects varied across agro-ecological zone, except soil bunds and compost manure whose use consistently exhibited both yield-increasing and risk-reducing effects across all the agro-ecologies. Farmer perceptions of technology effectiveness, to some extent, agreed with econometric evidence from this study. Study results have two implications: firstly, the need to develop and disseminate location specific adaptation technologies to reduce production risks, instead of blanket recommendations of similar adaptation measures across locations; and secondly, the need to focus not only on the technical aspects of technologies, but also the social dimensions such as perceptions of smallholder farmers of technology effectiveness, if adoption and retention of adaptation technologies is to be enhanced. Development and research organisations promoting adaptation options should involve farmers in technology evaluation so as to recommend the most feasible options given farmers' situations and local perceptions.

Key Words: Adaptation, climate variability, Just and Pope Framework

RÉSUMÉ

Cette étude a utilisé la méthode « frontière de production stochastique » de Just et Pope pour évaluer l'efficacité des technologies préférées par les agriculteurs pour réduire les risques de diminution de la production agricole liés à la variabilité climatique à l'Est de l'Ouganda. Les données de cette étude étaient obtenues à partir de 315 ménages, 9 groupes de discussion focalisés et 23 informateurs clés sélectionnés dans les districts de Mbale, Pallisa et Sironko. Les résultats ont montré que les fermiers utilisent stratégiquement un bon nombre de technologies en réponse aux variations climatiques saisonnières. Laplupart de ces technologies ont montré des impacts positifs significatifs sur les rendements moyens, mais présentaient des différences au niveau de leur effets sur les risques de diminution des rendements. Le changement des dates de semis et des variétés des cultures, du billonnage, de l'utilisation du compost, descultures de couverture, de la rotation et des cultures intercalaires ont manifesté des effets significatifs ($P<0.05$) sur le risque de diminution des rendements. Par ailleurs, leurs effets variaient en fonction des zones agro-écologiques, sauf pour le billonnage, et le compost dont l'utilisation a induit une augmentation des rendements et une réduction de risques à travers toutes les zones agro-écologiques. Les perceptions des agriculteurs sur l'efficacité de ces technologies sont en accord avec l'évidence économétrique de cette étude. Les résultats de cette recherche ont deux implications : premièrement, le besoin de développer et diffuser les technologies spécifiquement adaptés aux conditions locales pour réduire les risques au lieu de formuler des recommandations générales pour diverses localités, et deuxièmement, le besoin de se focaliser non seulement sur les aspects techniques des technologies, mais aussi sur les les dimensions sociales telles que les perceptions des petits exploitants sur l'efficacité des technologies, si on veut s'assurer d'une adoption durable des technologies d'adaptation par les expoloitants. Les organisations de recherche et de développement engagés dans la promotion des options d'adaptation devraient dès lors impliquer les fermiers dans l'évaluation des technologies afin de recommander les options les plus appropriées compte tenu de la situatiion réelle des agriculteurs et de leurs perceptions au niveau local.

Mots Clés: Adaptation, variabilité climatique, structure de Just et Pope

INTRODUCTION

Among the many risks agricultural stakeholders face especially in Sub-Saharan Africa (SSA), production or yield risk is the most important (Chuku and Okoye, 2009). Rainfall variability influenced by large scale inter-seasonal and inter-annual variability resulting in frequent extreme weather events, is among the major risk factors affecting agricultural production and food security in SSA (Haile, 2005; Christensen *et al*., 2007; Easterling *et al*., 2007). This variability in rainfall has also been directly linked to decline in economic activity in most SSA countries, as measured by Gross Domestic Product (GDP) (Brown *et al*., 2011).

Managing risks paused by climate variability is important in agriculture not only for the direct impact it has on production, but also for the tendency of most farmers to be risk-averse (Cabrera *et al*., 2009). An increasing body of observations has emphasized the importance of managing production risks to optimise crop/ varietal choice, especially in marginal areas (Di Falco *et al*., 2006; Kurukulasuriya and Mendelsohn, 2006), and farm income (Jones *et al*., 2000; Kumar *et al*., 2004). Kassie *et al*. (2009) and Kato *et al*. (2009) demonstrated the importance of organic farming and, soil and water conservation techniques, as adaptation strategies to climate variability in specific farming systems. Other technologies that have been promoted include, new crop varieties, agronomic management adjustments, reforestation of fragile landscapes, response agriculture, down-scaled forecasting, and investment in low level irrigation infrastructure in watersheds (Goddard *et al*., 2001; Iglesias, 2005; Nzuma *et al*., 2010). In Eastern Uganda, some of these and other crop and land management practices have been observed at farm level (Kansiime, 2012).

As the role of technology continues to become more ingrained in strategic thinking of agricultural adaptation to climate variability and change (Smithers and Blay-Palmer, 2001), there is a need for systematic, location specific assessment of the technologies to improve adoption through unravelling their effectiveness, constraints, opportunities and synergies under variable climatic conditions. This will lead to better understanding of their effects on risks in agricultural production and facilitate decisions on which technologies to promote and where in particular.

Some assessments have been done linking technology adoption to production risks. For example, Kurukulasuriya and Mendelsohn (2006), Kassie *et al*. (2008), Kassie *et al*. (2009), and Sileshi *et al*. (2010) indicated positive relationships between technology adoption and production risk reduction. However, the performance of technologies was only judged based on mean yields, except Kato *et al*. (2009) who considered technology effects on both the mean and variance of crop production. Inference based on the means alone can be misleading if the variance around the mean, and hence the probability distribution of the risk is not known.

Other studies have used agricultural simulation models to capture these complex interactions. A range of methods for linking crop simulation models to seasonal climate forecast models have been advanced in Africa, Australia and USA (Hansen and Indeje 2004; Hansen *et al*., 2006; Cabrera *et al*., 2009). Multiple regression models have also been developed to represent process-based yield responses to these environmental and management variables (Di

Falco *et al*., 2006; Pender and Gebremedhin, 2006; Iglesias and Quiroga, 2007; Cabas *et al*., 2010; Sileshi *et al*., 2010), and could be used to estimate the risk associated with climate variability.

A major challenge facing these evaluations is the inclusion of both biophysical and socioeconomic aspects in the methodology (Iglesias and Quiroga, 2007). The present study used an integrated approach to assess the effectiveness of various farmer-preferred technologies in reducing production risks associated with climate variability across three agro-ecologies in Eastern Uganda. Specifically, this study addressed three open questions: (i) How do various farmer-preferred adaptation technologies affect mean and variance (as an index of risk) of crop yield in Eastern Uganda given actual and perceived variability in rainfall? (ii) How do the effects of these technologies on crop yield vary across agro-ecological zones in eastern Uganda? (iii) What is the perception of farmers regarding technology effectiveness in reducing production risks, and how do these perceptions compare with statistical evidence?

MATERIALS AND METHODS

Research design. The research used a cross sectional survey design and qualitative research approaches, including description of historical weather variability events. This allowed establishment of facts about actual and perceived climate variability, which were used as inputs in explaining factors underlying farmers' practices under variable climatic conditions based on descriptive research data.

Study area and sampling procedure. The study was conducted in Eastern Uganda, covering three distinct agro-ecological zones (AEZs) namely; the Lake Victoria Crescent, South East Lake Kyoga and Mount Elgon (Wortmann and Eledu, 1999). From each of the agro-ecological zones, one district was selected from which respondents were drawn. Sampled districts included, Mbale, Pallisa and Sironko; representing L. Victoria Crescent, SE L. Kyoga and Mt. Elgon agro-ecologies, respectively.

A sample size of 315 households, was obtained using probability proportional to size method. In addition, nine focus group discussions (FGDs) involving 104 community members, and 23 key informant interviews (KIIs) were conducted.

Further, observational rainfall data for the 40-year period; extending from 1971 to 2010 were obtained from the Uganda Meteorological Department, Ministry of Lands and Environment. Data were obtained for three meteorological stations, namely Tororo, Soroti and Sipi, representing the three sample districts of Mbale, Pallisa and Sironko, respectively. Each of the AEZs had one weather station, and data from these were used to generalise for the sample districts and the AEZs. Table 1 shows the study agro-ecological zones, their biophysical characteristics sampled districts and sample size.

Model specification. This study employed the Just and Pope stochastic production frontier framework (Just and Pope, 1979). Just and Pope Framework focuses on production risks measured by the variance of output, allowing yield enhancing inputs to have either a negative or a positive effect on the variance of yield by relating the variance of output to explanatory variables in a multiplicative heteroskedastic regression model (Kato *et al*., 2009). The study specified a single equation joint production function, which summarises the relationship among aggregate outputs and aggregate inputs in order to circumvent the problem of estimating production functions in the absence of activity-specific input data. Single equation approach has been used in several previous studies (Smale *et al*., 1998; Koundouri *et al*., 2006; Kato *et al*., 2009; Barnwal and Kotani, 2010). The stochastic production function is represented as:

$$Y = f(X, \beta) + \mu = f(X, \beta) + h(X, \alpha)^{0.5} + \varepsilon$$

Where:

Y = the yield, X = a vector of explanatory variables, f(.) denotes the deterministic component, the mean function of yield and relates X to average yield with β representing the set of estimated coefficients, μ = the heteroskedastic disturbance term with a zero mean, h(.) = the stochastic component i.e. variance function of

TABLE 1. Characteristics of the areas selected for the study

AEZ (weather station[a])	Biophysical characeristics	Sampled district (sub counties)	Respondents
Lake Victoria Crescent (Tororo)	Bimodal high rainfall, 1971-2010 mean annual rainfall is 1503 mm; main crops include banana, Arabica coffee, maize, beans, sweet potato and rice; mean altitude is 1174 m.a.s.l., Petric Plinthosols (Acric) soils, and population density of 166.3 km^2	Mbale (Bungokho, Mutoto and Bumbobi)	105 household surveys, 35 participants in FGDs and 7 KIIs
South East Lake Kyoga (Soroti)	Bimodal high rainfall, 1971-2010 mean annual rainfall is 1368 mm; main crops include cotton, finger millet, sorghum, groundnuts, sweet potato, cassava, beans and maize; mean altitude is 1075 m.a.s.l.; Gleysols soils; population density of 252 km^2; livestock rearing, especially indigenous cattle important	Pallisa (Olok, Apopong and Pallisa Rural)	105 household surveys, 36 participants in FGDs and 8 KIIs
Mount Elgon (Sipi)	Bimodal high rainfall, 1971-2010 mean annual rainfall is 2058 mm; main crops include; banana, Arabica coffee, maize, beans, rice, potato, sweet potato and vegetables; mean altitude of 1299 – 1524 m.a.s.l.; Vertisols soils and population density of 770 km^2	Sironko (Bumasifa, Buhugu, and Bumalimba)	105 household surveys, 33 participants in FGDs and 8 KIIs

[a] Observational rainfall data were obtained from these weather stations to generalise for the study districts. In each of the AEZs, only one weather station existed, indicated in parenthesis in the Table after AEZ. Source: Adapted and modified from Wortmann and Eledu (1999), Komutunga and Musitwa (2001) and Kansiime *et al*. (2013)

yield and relates X to the standard deviation of yield with α representing the corresponding set of estimated coefficients, and ε = a random error term with a mean of zero and variance of σ^2.

Thus this specification shows mean yield and yield variance as two separate components being explained by change in input variables, i.e. rainfall and other derived variables (Just and Pope, 1979; Chen *et al*., 2004).

The stochastic production function given above can be estimated using maximum likelihood estimation (MLE) or a three-step estimation procedure involving feasible generalised least squares (FGLS) under heteroskedastic disturbances (Cabas *et al*., 2010). Though most empirical studies have used the FGLS approach, MLE is considered more efficient and unbiased than FLGS estimation in the case of small samples (Saha *et al*., 1994).

Given the large sample in this study, the three stage estimation procedure as described in Judge *et al*. (1988) was used for analysis. In the first stage, Y was regressed on f(X, β) using Ordinary Least Squares (OLS); in the second step, least square residuals were calculated as $\hat{\mu}$ = y - f(X, β), where $\hat{\mu}$ is a consistent estimate of μ, a heteroskedastic disturbance term with zero mean. In the third step, squared residuals were used as the dependent variable for the variance function estimation h(X, α) using OLS, where h(.) is assumed to be in exponential form. The focus was on the coefficients for the variance function, where a positive coefficient implies risk-increasing effects, and a negative coefficient implies a risk-decreasing effect of the input on yield. Technologies that showed risk-reducing effects were, therefore, considered effective in reducing risks associated with climate variability.

The Semi-logarithmic functional form specification was used in the model and this helped to improve normality of the dependent variable and residuals, thus reducing problems of nonlinearity, heteroskedasticity and sensitivity to outliers (Kato *et al*., 2009). The data were tested for multicollinearity using the variance inflation factors (VIF) and also by pair-wise correlations. Multicollinearity was not a serious problem; the VIFs were less than 3.0 and the pair-wise correlations were less than 0.5, indicating that the standard errors were not being affected by collinearity problems.

Data and empirical specifications of model variables. Data for this study were made available as part of a larger study investigating determinants of crop and land management practices, and effects on production risks under variable climatic conditions in Eastern Uganda. The study was conducted during August - September 2011. Data were obtained on both the dependent and independent variables (Table 2). The dependent variable for the model Y was expressed as value of crop production per hectare (van de Steeg *et al*., 2010).

Value of production per hectare was preferred because some plots were intercrops, making estimation of single crop-production functions difficult. This approach has been used in many previous plot-level-based microeconometric studies in sub-Saharan Africa (Jansen *et al*., 2006; Pender and Gebremedhin, 2007; Nkonya *et al*., 2008; Kato *et al*., 2009). In estimating value of crop production at plot level, average market prices were used based on historical and current data from cross sectional survey and other qualitative research methods.

The model explanatory variables included farmer-preferred adaptation technologies. Rainfall variables were included in the model to capture effects of rainfall variability on the mean and variance of crop production. These included the rainfall satisfaction index of the preceding main agricultural season (August–November 2010), and the mean and standard deviation of monthly precipitation for the August-November growing season over a 40-year period, similar to the approach used by Cabas *et al*. (2010). The analysis also controlled for other variables that were hypothesized to be correlated with the observed plot-level crop outputs such as sex, age and education of household head, household size, use of chemical fertilisers, land size, and local agro-ecology.

RESULTS

Descriptive results. An inventory of farmer preferred management practices was made based

TABLE 2. Summary of variables used in the empirical model

Variable	Description	Mean	SD
Dependent variable			
Crop production (expressed as VOP)	Value of crop production measured as output x price (UGX '000' per hectare)[a]	894	719
Explanatory variables			
Technology adoption	Set of technological options employed by farmers to reduce climate-induced production risk. Dummy = 1 if farmer reported utilisation of given technology	0.71	0.46
Rainfall index	Rainfall satisfaction index constructed from a set of questions relating to rainfall adequacy during the season of August – November 2010 [b]	0.19	0.11
Mean rainfall	Mean monthly rainfall (mm) for the second season (September – November) over a 40 year period [b]	655.75	277.82
SD rainfall	Standard deviation of monthly rainfall for the second season (September – November) over a 40 year period [b]	193.84	95.90
Age	Age of the household head in years	44.93	14.89
Education	Level of education of the household head measured on a scale where 1 = none, 2 = Primary, 3 = Secondary, 4 = Tertiary	2.14	1.13
Household size	Household size measured by number of members in who contribute to farming operations	7.05	3.75
Gender	Gender of household head (1 = Male, 0 = Female)	0.84	0.36
Farm size	Total farm size measured in acres	1.33	1.22
Inorganic fertiliser	Use of chemical fertiliser	0.27	0.45
Local agro-ecology	Local agro-ecology represented by the study districts. District dummy 1 = 1 if Mbale, 0 otherwise; District dummy 2 = 1 if Sironko, 0 otherwise		

* Conversion rate used is 1USD = UGX 2470 (The New Vision, June 11, 2012, Vol. 27 No.116). [b] Kansiime *et al.* (2013)

on responses obtained from the survey. For each of the technologies or management practices on farm, adoption was dichotomised, where a value of one was given if a farmer reported to use a particular technology, and zero otherwise. Farmers employed a number of crop and land management practices on their farm, either singly or in combination (Table 3). It should be noted that there were multiple responses on farmers using more than one management practice.

A majority of farmers changed sowing dates to coincide with onset of rain or planted as and when it rained. Another important crop management practice was intercropping, practiced by 72% of the respondents. Other crop management practices included changing crop varieties, changing crop density and crop rotation. Farmers changed crop varieties to include early maturing ones particularly maize, beans and ground nuts. In Sironko, farmers introduced non - traditional crops such as paddy rice and coco yam to cope with increased incidence of soil water logging, while in Pallisa, farmers were moving back to local varieties of finger millet and sorghum, which they perceived to be more hardy and tolerant to dry spells as compared to improved varieties.

A majority of farmers reported to have increased crop density, particularly in Pallisa. Increasing crop density was linked to continuous planting, mixed cropping and re-planting or gap filling, which were commonly practiced and aimed at increasing chances of getting harvest even under climatic stresses. There were also cases of farmers increasing the number of seeds per planting hole, which they claimed increased chances of seed survival when soil temperatures increased immediately after planting, as narrated by Akol Pricilla (68 years), one of the participants in a focus group discussion conducted during this study in Komolo village, Pallisa district:

"When we plant more seeds in each planting hole, chances of seed survival are increased. The seeds that are in the middle, not in direct contact with soil retain the moisture, while the ones in contact with the soil are burnt away when it gets very hot. Therefore, we still have some seeds germinating even when there has been a dry spell immediately after planting. If we are lucky and the rain is normal, then we may remove the extra plants."

Cover crops, compost manure and crop rotation were the most common land management practices employed by farmers in the sampled

TABLE 3. Proportion of respondents using various adaptation technologies by district

Production technologies	% of respondents using technology			Pearson χ^2 (2)	P- value
	Mbale	Pallisa	Sironko		
Crop management					
Changed sowing date	63	100	74	45.251	0.000
Changed crop density	35	75	34	50.194	0.000
Changed crop varieties	39	27	30	3.808	0.149
Crop rotation	6	94	29	176.472	0.000
Intercropping	55	82	83	27.082	0.000
Land management					
Soil bunds	48	48	19	24.283	0.000
Mulching	13	50	30	34.123	0.000
Grass strips	15	43	36	19.786	0.000
Compost manure	36	55	50	8.379	0.015
Cover crops	11	76	58	95.382	0.000
Inorganic fertiliser	7	8	67	126.816	0.000

villages in that order. Other land management practices included, soil bunds, terraces, mulching, grass strips and inorganic fertiliser. The observed differences in adoption of production technologies per district were significant ($P < 0.05$) in the three sample districts. The strongest differences were observed for crop rotation, inorganic fertiliser and cover crops ($ChiSq > 95$, $P = 0.000$).

The study also included response variables measuring the reasons for farmers' change in farming practices in response to climate variability. In particular, the study primarily examined whether farmers made on-farm changes due to other reasons, and not only changes that were specifically in response to weather and climate patterns. The data reflect only reported changes, and not whether a change was adaptive, a concept implying that a change confers some benefit to the farmer that made that change.

Farmers' reasons for using various production technologies ranged from weather, to land and cost related issues (Table 4). Overall, climate related reasons (rainfall pattern, increase yield, reduce risk, reduce erosion and reduce flooding/water logging) were the commonly mentioned across the study districts. Limited land was a big factor in Mbale and Sironko rating 19 and 11%, respectively.

Effects of farmer-preferred adaptation technologies on the mean and variance of crop yield. Econometric results of the Just and Pope Production function are presented in Table 5 for the mean and variance functions of crop production in general. Changed crop varieties, soil bunds, and inorganic fertilizer showed positive and significant impacts on the mean of crop output. Soil bunds showed the largest production elasticity among the technologies. Technology effects on yield variability also differed with changing sowing dates and crop varieties, soil bunds, compost manure, cover crops, crop rotation and intercropping all showing significant negative coefficients on yield variability. On the other hand, changing crop density and mulching had significant positive coefficients, implying that they are risk-increasing.

Examination of effects of other non-technological variables on the mean and variance of crop production indicated that rainfall subjective index and rainfall standard deviation significantly and positively affected the mean yield, and negatively affected yield variability. Household and socio-economic characteristics such as age of household head, education level, household size, gender of household head and farm size did not show any significant impacts

TABLE 4. Farmers' reasons for adopting various production technologies

Change drivers	Percent of respondents			
	Mbale	Pallisa	Sironko	Average
No change [a]	60	0	25	28
Change	40	100	75	72
Reasons for change [b]				
Poor rainfall pattern	43	33	27	33
To increase crop yield	29	17	18	20
Limited land	19	2	11	8
To spread risk	2	30	6	17
Reduce soil erosion	2	5	24	11
Reduce flooding/water logging	0	8	14	8
Limited labour	5	2	0	2
Low cost	0	3	0	1

[a] No change is the total number of farmers who reported making no crop or land management related change; [b] Reasons for change are proportionately computed from only those who indicated to have changed their farming practices, irrespective of the technology they employed

TABLE 5. Effects of technologies on mean and variance of crop yield

Variables	Log VOP for mean		Log VOP for variance	
	Coef.	Std. Err.	Coef.	Std. Err.
Technologies				
Changed sowing date	0.110	0.246	-0.481*	0.753
Changed crop density	-0.093	0.128	0.340*	0.582
Changed crop varieties	0.456**	0.207	-0.951**	0.633
Soil bunds	0.971***	0.197	-2.865***	0.607
Mulching	-0.149	0.232	0.765*	0.704
Grass strips	-0.222	0.224	0.107	0.690
Compost manure	0.217	0.192	-0.824*	0.591
Cover crops	0.257	0.242	-1.444*	0.744
Crop rotation	0.209	0.301	-0.573*	0.921
Intercropping	0.259	0.211	-0.462*	0.642
Rainfall variables				
Rainfall index	0.507**	0.584	-1.252	1.797
Mean rainfall	-0.516	0.003	0.000*	0.009
SD rainfall	2.412*	1.518	-0.008*	0.017
Household characteristics				
Age	-0.002	0.006	0.004	0.019
Education	-0.121	0.091	0.581	0.353
Household size	0.009	0.091	0.006	0.079
Gender	0.099	0.294	-0.398	0.885
Land variables				
Farm size	0.071	0.101	-0.296*	0.308
Inorganic fertiliser	0.164*	0.152	-0.697*	0.808
Local agro-ecology (cf. Pallisa)				
Mbale	-2.561*	0.401	0.234	1.205
Sironko	3.713**	1.620	-0.856	4.871
Intercept	4.573	1.826	6.833*	5.490
R^2	0.250		0.211	
Adjusted R^2	0.189		0.151	
F	4.14		3.491	
Pr > F	0.000		< 0.0001	

VOP = value of crop production; Coef = Coefficient; Std Err = Standard Error; Statistical significant at the 0.01 (***), 0.05 (**), 0.1 (*) level of probability

on mean yield. Only farm size showed significant risk-reducing effects on crop variability.

The effect of agro-ecology on mean and variance of yield was such that location in Mbale decreased the mean yield by about 25%, while location in Sironko increased the mean yield by 37% as compared to Pallisa. Yield variability followed the opposite trend, with location in Mbale having positive effects and location in Sironko negative effects in comparison with Pallisa. That means that location in Mbale and Sironko were more and less risk–reducing, respectively, compared to location in Pallisa.

Yield effects and risk of farmer-preferred technologies by district. Results by district

TABLE 6. Effects of technologies on mean and variance of crop yield by district

Variables	Mbale Log VOP		Pallisa Log VOP		Sironko Log VOP	
	Mean	Variance	Mean	Variance	Mean	Variance
Technologies						
Changed sowing date	0.305	-0.554	-1.671	3.866	-0.261*	0.534
Changed crop density	-0.037	-0.845	-0.125	1.339	-0.429***	0.732**
Changed crop varieties	0.995**	-0.192	-0.126	0.833	0.328*	-0.264
Soil bunds	1.508***	-4.812***	0.337*	-0.619*	0.395**	-0.191*
Mulching	-0.377	1.404	0.035	0.341	0.019	0.038
Grass strips	-0.424	2.556	-0.106	0.320	-0.400**	0.348
Compost manure	0.146	-0.697	0.817**	-3.225**	0.267*	-0.321
Cover crops	0.681	-0.407	0.695*	-1.243	0.111	-0.557
Crop rotation	0.539	-2.144	0.759	0.204	0.043	0.072
Intercropping	0.432	-1.068	-0.463	0.377	0.571***	-1.300***
Rainfall variables						
Rainfall index	1.260	0.623	1.731	-5.786	0.417	-0.693
Mean rainfall	0.343	-2.574	-0.022	0.147	-0.001	0.003
SD rainfall	-0.002	-0.020	0.004	-0.016	-0.825	1.568
Household variables						
Age	-0.010	0.019	0.005	-0.006	0.004	-0.011
Education	-0.713**	0.495	-0.059	0.203	-0.014	0.168
Household size	-0.018	0.059	0.009	-0.034	-0.045*	0.131**
Gender	0.619	-2.678	-1.323	-1.343	-0.097	-0.309
Land variables						
Farm size	0.101	0.325	0.108	-0.531*	0.010	0.046
Inorganic fertiliser	0.736	-1.508	-0.475	0.535	0.531***	-0.614*
Intercept	-174.428	1351.872	15.113	-74.123	276.29	-515.2
Observations	104		102		104	
R^2	0.290	0.272	0.272	0.280	0.414	0.244
Adjusted R^2	0.119	0.097	0.092	0.102	0.273	0.061
F value	1.698	1.552	1.510	1.571	2.936	1.337
Pr > F	0.050	0.086	0.101	0.081	0.000	0.180

VOP = value of production; Statistical significant at the 0.01 (***), 0.05 (**), 0.1 (*) level of probability

(Table 6) showed varying effects of the various technologies by district. In Mbale, changed crop varieties and soil bunds showed significant positive effects on the mean of crop yield. In Pallisa, the technologies that showed positive impact on mean yield were, soil bunds, compost manure, and cover crops; while in Sironko, crop varieties, soil bunds, compost manure, intercropping and inorganic fertiliser use showed significant positive impacts on yield. Of the yield-enhancing technologies, only soil bunds showed significant risk-reducing effects on crop yield across all the districts.

Inorganic fertiliser use also had significant risk-reducing effect on crop yield in Sironko. Rainfall variables showed positive effects on yield across the locations, though not significant. Mean seasonal rainfall showed negative effects on the variability of yield in Mbale, while in Pallisa and Sironko, it showed positive impacts. This implies that mean rainfall generally increased risk in Pallisa and Sironko areas. Standard deviation of rainfall generally increased risks in Sironko as opposed to Mbale and Pallisa.

Effectiveness scale of farmer-preferred technologies. Using the subjective effectiveness scale, farmers rated the various production technologies they employed according to their judgement of their effectiveness in reducing risk of crop failure associated with rainfall variability. Subjective effectiveness analysis was done per technology and by district. In Mbale, compost manure was rated as the most effective by the users. At least 73% rated it as either effective or very effective. Other technologies rated as effective in Mbale included, altering sowing date, changing crop density, changing crop varieties, mulching and cover crops. However, intercropping, crop rotation, grass strips and soil bunds were rated as either not effective or farmers were not certain about their effectiveness in reducing production risks.

In Pallisa, farmers rated changing crop varieties (82%), changing sowing date (74%), compost manure (68%) and mulching (64%) as either effective or very effective in reducing production risks. Changing crop density on the other hand, though practiced by a majority of farmers in Pallisa compared to Mbale and Sironko, about 62% of farmers in Pallisa rated it either as ineffective or they could not establish its effectiveness in reducing production risks. Other practices considered to be less effective in Pallisa were, mulching, grass strips, cover crops, and intercropping. In Sironko, most of the management practices were rated as effective or very effective by over 65% of the respondents (on average). Management practices considered least effective were, changing sowing date and changing crop density.

There was also a high proportion of farmers that were not able to assess the effectiveness of the management practices they employed on their farms for reducing production risks, especially in Mbale and Pallisa. A majority of farmers in Mbale using crop rotation, grass strips and soil bunds were not sure of their effectiveness in reducing production risks. It is no wonder that these management practices were employed by a very small proportion of farmers. On the contrary, in Pallisa, the management practices where farmers were not sure of their effectiveness were practiced by a majority of farmers. For example, intercropping, crop rotation, cover crops and grass strips.

Overall, across the study districts, changing crop varieties, compost manure use and changing sowing date were rated the most effective by 80, 72 and 62% of respondents (Table7). Changing crop density was generally rated less effective. A Kruskal-Wallis test was conducted to evaluate

TABLE 7. Subjective effectiveness scale of farmer-preferred technologies

Production technology	Sample space [a]	Effectiveness scales (subjective) (%) [b]					Kruskal-Wallis $\chi^2(2)$	Probability
		Not effective	Somehow effective	Not sure	Effective	Very effective		
Changed sowing date	244	19	-	18	13	49	42.300	0.0001
Changed crop density	148	37	3	17	20	24	24.364	0.0001
Changed crop varieties	100	3	3	14	17	63	2.665	0.2639
Soil bunds	119	2	1	46	27	24	9.638	0.0081
Mulching	95	2	-	52	7	39	5.624	0.0601
Grass strips	97	1	1	57	9	32	7.750	0.0208
Compost manure	145	4	1	23	19	53	21.706	0.0001
Cover crops	149	2	3	55	10	30	24.790	0.0001
Crop rotation	132	2	-	60	11	27	5.195	0.0744
Intercropping	227	1	3	42	22	32	51.455	0.0001

[a] Sample space is total response across the study districts; [b] Percentage is computed from only those respondents who indicated to have used the particular technology, not from the total respondents

differences among the three study districts on their rating of technology effectiveness (Table 7). The test results were significant for all technologies, except for changed crop varieties, mulching and crop rotation.

DISCUSSION

Farmers employed a number of technologies/ practices strategically in response to seasonal variations in climatic conditions (Table 3). Most of the technologies showed significant, positive impacts on yields (Table 5), but they had different risk-reducing effects on yield. The different effects on yield variability could be attributed to technology characteristics and their intention in farming systems. Changing crop varieties ensured that farming households introduced crops that were best suited to the current climatic and other biophysical conditions peculiar to the site. In most cases, farmers introduced new crop varieties, however, this strategy was limited by resources for purchasing improved seed, hence the few farmers using it. It was mainly used in Mbale and Sironko, with better access to markets and less constraining pedoclimatic conditions than Pallisa. In a similar way, Kurukulasuriya and Mendelsohn (2006) demonstrated that crop selection is an important adaptation strategy to climate variability.

Innovations in soil and water conservation such as soil bunds, compost manure and cover crops address the risk of soil moisture deficits associated with shifting precipitation patterns besides controlling soil degradation, which would otherwise render the crops prone to unfavourable climatic conditions. Soil bunds were effective in increasing yields and reducing risk in all agro-ecologies because they minimised runoff, thus increasing infiltration of water into the soil. In this way, the soil bunds facilitated recharge of soil water storage capacity for the benefit of the crops against drought stress, apart from controlling soil degradation through erosion. This is in line with the observation that soil bunds were particularly effective in Mbale, which had rugged terrain prone to soil erosion.

Compost manure was particularly effective in Pallisa (Table 6). This is because the area receives less rainfall yet it has light-textured soils with poor soil moisture storage capacity and low cation exchange capacity for holding nutrients against leaching loss. Application of manure may have improved the available soil water storage capacity through increase in soil organic matter, which may have also contributed towards increased basic cation nutrient retention against leaching loss due to increase in cation exchange capacity of the soil. Empirical evidences from other studies also confirmed effectiveness of manure in reducing production risks in low rainfall zones (Wahba and Darwish, 2008; Kassie *et al*., 2009; Kato *et al*., 2009).

Cover crops can also achieve the same effects (Table 6) since their biomass ultimately ends up contributing to soil organic matter, hence their yield-increasing and yield stability effects in Pallisa. The effects of crop rotation and intercropping are mainly on the ability of these innovations to break the pest cycle, ensure crop diversification and thus reduce the risk of crop failure. For example, Di Falco *et al*. (2006) reported that variety richness increases farm productivity, and reduces yield variability. Dixon *et al*. (2001) showed that mixed cropping systems reduce crop losses due to pests and diseases and make more efficient use of farm labour.

Changed sowing dates had risk-reducing effects, though it did not show significant effects on mean yield. Changed sowing dates ensures more effective use of precipitation available during the season such that yields are optimised. This is in agreement with Chiotti *et al*. (1997), de Loë *et al*. (1999) and Smit and Skinner (2002) who reported that changing the timing of farm operations had the potential to maximise farm productivity during the growing seasons and to avoid heat stresses and moisture deficits during times of increased climate perturbations. The observed risk-increasing effects of changing crop density, particularly in Sironko are attributed to the fact that increasing crop density increased crop competition and subsequently reduced productivity.

The observed variability of technology effects by agro-ecological zone is attributed to the different biophysical characteristics and farming systems in these areas that define the farming potential (Table 1). Sironko is generally high rainfall zone, with higher variability both of annual and seasonal rainfall (Kansiime *et al*., 2013) compared to Pallisa and Mbale, thus the possibility that location in Sironko would increase crop production risks. Gebremedhin *et al*. (1999), Bekele (2005), Kassie *et al*. (2008) and Kato *et al*. (2009) indicated significant variations in the effect of technologies in low and high rainfall zones. The effect of farmers' perception of rainfall on yield variability could be due to the fact that farmers' perception determines the timing of operations as well as the type of crops to grow. It is anticipated that if farmers' perception of rainfall adequacy is correct, adjustment in their farming operations should give risk-reducing effects on the variance of crop yield. Similarly, farmers' perceptions of technology effectiveness have a strong bearing on the decisions of what adaptations to employ.

The subjective assessment of technology effectiveness by farmers indicated that changed crop varieties, compost manure use and changed sowing dates were considered effective practices across the three study districts. This is in agreement with results obtained on effect of these production technologies on variance of yield (Table 7). The difference in rating technology effectiveness by districts is related to the differences in biophysical characteristics. For example in Sironko, land management practices were ranked most important. The high rainfall amounts and steep slopes make it vulnerable to water logging, erosion and mud slides. As such, land management practices such as soil bunds, mulching and cover crops are more relevant to farmers there. Pallisa, on the other hand, is generally flat with lower rainfall amounts. Thus, interventions in crop management were more appreciated by farmers and, thus ranked more effective than land management practices.

Study results have two implications: first, the need to develop and disseminate location specific adaptation technologies to reduce production risks, instead of blanket recommendations of similar adaptation measures across locations. For instance, in high-rainfall, highland areas (e.g. Sironko and parts of Mbale), placing appropriate land management measures such as soil bunds, mulching and cover crops, could help minimise runoff, increase infiltration and reduce soil degradation. In low lying and low-rainfall areas (e.g. Pallisa), interventions such as soil bunds and compost manure may be appropriate in conserving the little rains received, and improving fertility, respectively. Second, the need to focus not only on the technical aspects of technologies, but also the social dimensions such as perceptions of smallholder farmers of technology effectiveness, if adoption and retention of adaptation technologies by farmers is to be enhanced.

RECOMMENDATION

Development and research organisations promoting adaptation options should involve farmers in technology evaluation so as to recommend the most feasible options given farmers' situations and local perceptions.

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