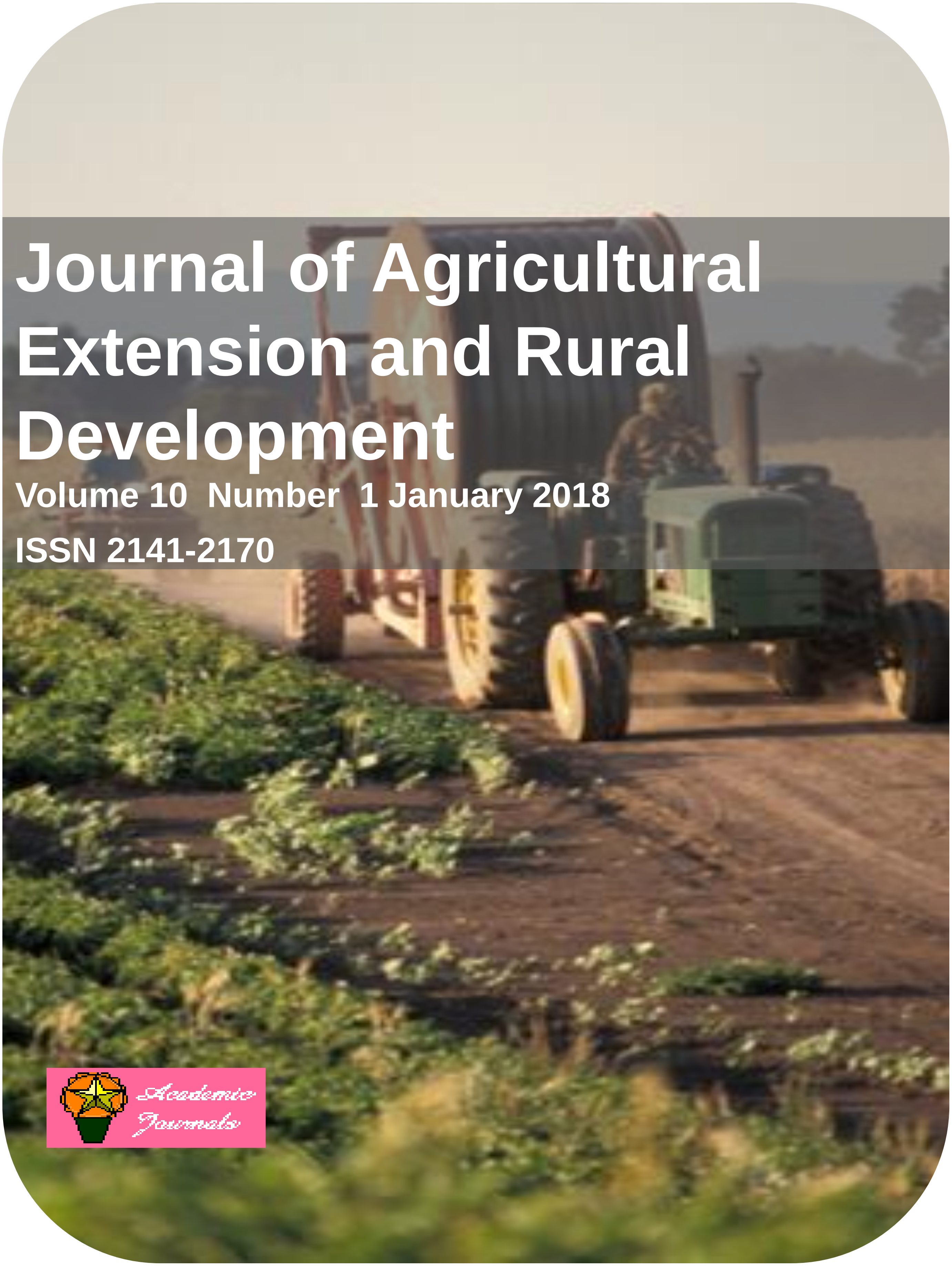

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Full Length Research Paper

Assessment of on-farm storage of Bambara groundnut (*Vigna subterranea*) and roselle grains (*Hibiscus sabdariffa*) in Niger

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The objective of this study was an assessment of on-farm storage practices for Bambara groundnut and roselle grains in Niger. It is based on a random sample of 164 farmers producing both crops in the Dosso and Maradi regions using a semi-structured questionnaire. Analysis of the data used Probit regression and budgeting. Fifty four percent of respondents use some type of potentially hermetic container for storage of Bambara groundnut and 46% use that type of container for roselle. Potentially, hermetic containers include metal drums, plastic jugs, and single, double and triple layer plastic bags. About 67% of the quantity of Bambara groundnut stored was in potentially hermetic containers and 58% of roselle. Triple layer Purdue Improved Crop Storage (PICS) bags were used mainly by Bambara groundnut farmers storing larger quantities. While only about 10% of the respondents reported storing Bambara groundnuts in PICS bags. The quantity stored by those respondents is quite large, so about 39% of the total quantity of Bambara groundnut stored by the respondents was stored in PICS bags. For roselle, PICS bags were used by 4% of respondents for only 3% of quantity stored. Profitability of using PICS bags for one or two years is comparable to that achieved with the common practice of storing in woven bags with insecticide. While PICS bags use does not increase profitability substantially compared to insecticide use, it does allow the producer to reduce pesticide exposure and the associated health risks.

Key words: Adoption, Bambara groundnut, hermetic storage, profitability, roselle.

INTRODUCTION

While agriculture in much of the world has focused on a few crops, African agriculture has a diversity of locally and regionally important crop species. Little research is done on those crops and the post-harvest aspects are especially neglected. This study focuses storage practices and storage economics for two of those

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regionally important crops, Bambara groundnut (*Vigna subterranea*) and roselle (*Hibiscus sabdariffa*). Bambara groundnut is mainly grown as a subsistence crop, mostly by women and generally on abandoned or fallow land.

Roselle is a versatile broadleaf plant that is often intercropped with cereals. Roselle leaves are used as a vegetable, the flowers are used for herbal tea and the seeds are used as a high protein ingredient in sauces. Bambara groundnut and roselle are important food security crops in West Africa and add resilency to the food system. In sub-Saharan Africa, Bambara groundnut ranks third among cultivated legumes after peanuts (*Arachis hypogaea*) and cowpea (*Vigna unguiculata*) (Hampson et al., 2000). Bambara groundnut cultivation has several advantages in that it can give acceptable yields on poor soils and with a low rainfall. Nutritionally, it is superior to other legumes and is a preferred food source by many individuals. In addition, the plant has the ability to capture and fix atmospheric nitrogen contributing thus increasing yields of subsequent crops.

Bambara groundnut has potential for industrial processing and increased use for derived products. However, dry seeds are very difficult to cook, requiring more time (45 min for fresh seeds; 1 to 3 h for dry seeds) and energy (Berchie et al., 2010) than other grain legumes. Grain yields are estimated between 650 and 850 kg ha^{-1} with significant variations between the different countries in sub-Saharan Africa (Ajayi and Lale, 2001).

In Niger, the Bambara groundnut is usually grown as a monocrop in small areas or in combination with cereals in family fields. It is in most cases harvested before the grains ripen and consumed fresh by the farmers after being boiled or sold directly at the weekly markets, while the remainder is dried and stored for later use as seed, for consumption or for sale. There is a renewed interest by farmers in Niger for Bambara groundnut production. In the year preceding this study (that is, 2012), the production was estimated at 32,228 tonnes against 22,447 tonnes, an average for the five previous years, that is to say an increase of 46% (DSA/MA, 2012). Area planted in 2012 was 70,342 ha.

Roselle is a multipurpose plant with the flowers, leaves and seed used for human consumption and animal feed. This study focuses on the seed. In Niger, the seeds are used to prepare the "Soumbala", an important condiment used to flavor sauces, especially in rural areas. The seeds have a high oil content (16.8%). In some countries, such as Uganda, the seeds are eaten roasted (FAO, 1990). In Niger, the roselle area in 2012 was estimated at 174,857 ha and production of roselle seeds at 32,056 tons. Boureima et al. (2015a, b) describe the cultivation, utilization and research base for both Bambara groundnut and roselle in more detail.

Both Bambara groundnut and roselle are damaged by storage pests. Bambara groundnut seeds are consumed fresh, but a large quantity are stored for later consumption during the year. Grain prices are relatively high in the post-harvest period because demand exceeds supply. However, the major constraint to an increased and sustainable consumption of Bambara groundnut remains high with losses due to pest infestations during storage (Ayamdoo et al., 2013). According to Golob et al. (1996), the destruction of the seed by insects starts in the fields, but takes place mostly during storage.

Weevils (Coleoptera: Bruchidae) are the most important destructive insects for stored grain legumes in the tropics (FAO, 2009). Various weevils also damage roselle grains in storage. These insects infest seeds in the field and continue to multiply during storage (White, 2001). Losses caused to stored grains by these insects are very important and can reach 100% in the case of a *Callosobruchus maculatus* F. infestation, the most common weevil in hot regions (FAO, 2009). Experimental studies under controlled conditions showed that female weevils can lay more than 100 eggs and a generation of only one month causes infestations to increase exponentially until the complete destruction of the stock in a few months (Dick and Credland, 1984). In an experimental study, Maina et al. (2011) reported that the severity of damage caused by *Callosobruchus subinnotatus* is higher starting from the third month of Bambara groundnut seeds storage and reports that the longer the storage term is, the more important the damage is because of the increase spawning and adult emergence of *C. subinnotatus*. Damage by bruchids in the field before harvest has rarely been reported. For Bambara groundnut, Amuti and Larbi (1981) recorded an average loss of 3.7% after 5 months of storage in Ghanaian local conditions, while Golob et al. (1998) reported Bambara groundnut seed losses exceeding 20%. Baoua et al. (2015) reported losses of 61.8% for Bambara groundnuts and 83.9% due to *C. maculatus* and *C. subinnotatus* in Niger after 7 months of storage without treatment. In Niger, farmers and traders traditionally use indigenous methods for the storage of Bambabra groundnut, often storing smaller quantities in pod form. Compared to large farmers and traders who use jute bags and granaries, small farmers use drums and jars for their stocks (Chougourou and Alavo, 2011).

During the harvest period, the supply of both Bambara groundnut and roselle is high compared to the demand, which leads to lower prices, but after the harvest season the supply of both grains is erratic and prices fluctuate. In general, the price fluctuations between periods of harvesting and consumption allow farmers and buyers to capture gains from storage investment (Jones et al., 2011a, b). However, many small farmers do not take advantage of price seasonality in marketing agricultural products because many are obliged to sell some or all of their crop immediately after harvest due to cashflow constraints or to repay debt or simply because they do not have adequate storage systems to protect their harvest until a more favorable sale period (Stephens and

Table 1. Villages sampled in the three regions of Niger.

Village	Longitude	Latitude	Region
Mourin Dan Dounia	7.57	13.60	Maradi
Milli (Madoua)	7.88	13.47	Maradi
Magami	7.54	13.42	Maradi
Kore	7.95	13.79	Maradi
Debi	8.20	13.78	Maradi
Zigaya	9.23	13.76	Zinder
Fotoro Bougaje	9.20	13.76	Zinder
Baoure	9.23	13.56	Zinder
Angoual Anne	8.94	12.92	Zinder
Ara	8.94	13.00	Zinder
Guesse Beri	3.14	13.23	Dosso
Saboudey	3.39	13.25	Dosso
Carre Roubouki	4.08	13.48	Dosso
Kiria	3.85	14.05	Dosso
Angoual Saoulo	3.96	13.67	Dosso
Darogi Dambo	3.93	13.49	Dosso

Barrett, 2009). Delaying sale of agricultural products to the post-harvest period when prices are rising forces farmers to cover current expenses from alternative sources of income (Jones et al., 2011a).

While traditional storage methods are often ineffective for Bambara groundnut and Roselle grain, and have loss rates up to 100% in some cases, improved storage techniques, especially hermetic methods, allow a significant reduction in storage losses. Purdue University's project for improved cowpea storage (PICS) has implemented the wide dissemination of the triple bagging method since 2007. This technique has proved to be very effective for the conservation of cowpea and economically profitable for small farmers. These farmers were ahead of researchers testing hermetic methods with products other than cowpea, particularly in this case with Bambara groundnut.

The overall objective of this study was an assessment of the on-farm storage methods used by farmers producing Bambara groundnuts and roselle in Niger. The specific objectives were to: (i) describe how these seeds are currently being stored and sold; (ii) identify seasonal price fluctuations of Bambara groundnut and roselle seeds and whether these changes are significant enough to justify storage; (iii) assess the added value of the use of Purdue Improved Crop Storage (PICS) bags compared to the common storage methods, and (iv) determine key factors influencing the PICS adoption decision.

METHODOLOGY

To achieve the objectives of this study, surveys were conducted in three regions of Niger, namely Dosso, Maradi and Zinder, during the month of July 2013. Over 80% of the production of Bambara groundnut and roselle in Niger occurs in these three regions. In the region of Dosso, 6 villages belonging to three different rural communities (Arewa, Dogondoutchi and Dosso) were targeted while in Maradi, 5 villages belonging to three rural communities (Gazaoua, Aguié and Tessaoua) were covered by the survey. In Zinder, 5 villages spread in two rural communities (Mirriah and Magaria) were selected. A total of 164 respondents were interviewed: Dosso, 65; Maradi, 50; and Zinder 49.

A 5 part questionnaire was developed. The first part concerns general information (region, town, site, etc.), the second is related to socio-economic characteristics of farmers (name, sex, age, status, experience, etc.), the third part deals with planted areas and production, the fourth part is concerned with the varieties used, and the fifth part focuses on storage methods.

In each region, villages were randomly selected based on the list of villages producing both Bambara groundnut and roselle (Table 1). An exhaustive list of all Bambara groundnut farmers was established in village and the survey sample was drawn randomly on the basis of this list. Ninety seven percent of the 169 farmers randomly selected responded to the survey. The data collection method was personal interviews conducted with the respondents based on a questionnaire written in French. Few Nigerien farmers are literate, so the interviewers asked the survey questions in Hausa and Djerma. Because these languages are primarily oral, the questionnaires were not written out in each language. Questions related to Bambara groundnut and roselle were asked of all respondents. The collected data was used to calculate the percentage of farmers using each storage method, shelf life and amount of Bambara groundnut seeds stored using each method. Microsoft Office Excel 2007 was used for the calculation of the descriptive statistics (that is, means, percentages).

To test the effect of quantity of Bambara groundnut and roselle produced, membership in a village association, gender and other factors on adoption of PICS bags binary probit analysis was used. Probit was used because the cumulative normal distribution curve is like the "S" shaped curve often used in analyzing adoption. Greene (2012) provides an overview of probability models including logit, probit, and tobit. Feder and Umali (1993) review the early uses of probability models. Mercer (2004) reviews the use of these models for forestry and agricultural. Factors such as age, gender, education, sources of information, participation in farmer's organizations, and farm area often are statistically significant in these models depending on the product produced, technology, ethnic group, gender roles, etc.

The dependent variable was 1 if PICS bags were used and zero if other storage techniques were employed. The independent variables included in the Probit equations were based on experience with adoption equations for hermetic storage of cowpea (Moussa et al., 2014; Ibro et al., 2014). The independent variables used were: region, Dosso = 1 and otherwise zero; sex, 1 if male and zero otherwise; experience, number of decades of experience producing the crop; village association, 1 if member of a village association and zero otherwise; production, the larger of quantity produced in 2011 or 2012 in 100 kg units.

All the independent variables are hypothesized to have positive effects on PICS bag adoption. Region is expected to be positive because Dosso region has an active PICS bag dealer. Sex is expected to be positive because male farmers in Niger often have been access to information about new technologies and to inputs need to use those technologies. Experience is expected to be positive because experienced farmers are more likely to have had problems with storing these grains in the past and consequently are more likely to seek alternatives. Village association is expected to be positive because village association members should have been information about new technologies. Production 2012 is also expected to be positive because farmers with more grain to store have more incentive to seek out improved storage methods.

Because the Bambara groundnut and the roselle grains are both high protein foods and the storage choices are being made by the same individuals, those decisions are probably subject to some common influences, but chosing a given storage method for one crop does not directly affect the choice for another crop. Consequently, seemingly unrelated regression (SUR) is chosen for the two Probit equations. SUR was first proposed by Zellner (1962) and assumes that the error terms of equations are correlated.

The Probit SUR was estimated using the Stata (StataCorp, 2015) command "biprobit" which uses maximum-likelihood. An introduction to bivariate Probit models is given by Greene (2012). The correlation between error terms in the two equations is measured by "ρ" which is not directly estimated in maximium likelihood process, but atanh ρ ((1/2)ln ((1+ ρ)/(1- ρ)) is. Atanh ρ is used to test whether there is a significant correlation between the two equations.

Interpretation of the estimated probability model focuses on the sign and significance of the coefficients. The magnitude of the coefficients cannot be directly linked to changes in probability. To explore the magnitude of effects, marginal values are estimated. The marginal value is defined as the change in probability that results from a small change in the independent variables holding continuous variables at their sample averages and discrete variables at modal values. Because the two equations in an SUR bivariate probit are correlated, the total marginal effects include a direct or univariate effect from each equation and an indirect effect from the other equation. To focus the discussion on results by crop, only the direct or univariate marginal effects will be discussed. More information on estimation and interpretation of binary models can be found in Greene (2012).

RESULTS AND DISCUSSION

The continuous variable demographic statistics for the sample are shown in Table 2. Discrete variables are explained in the text. The average age of respondents was 48 years (Table 2), 59% male, 89% currently married and 11% widowed. Eighty nine percent had no formal education and most of the rest only had some primary school. The respondents were primarily farmers, but 39% reported livestock production and 30% small scale commerce as secondary activities. With respect to sources of information, 47% reported belonging to a village association and 50% owned a radio. Consistent with the intensive PICS extension effort for cowpea storage in Niger, 73% came from villages which have had PICS cowpea storage demonstrations. About 40% of the Bambara groundnuts were marketed and about 50% of roselle grains.

Fifty four percent of respondents reported using some type of potentially hermetic container for storage of Bambara groundnut and 46% use that type of container for roselle (Table 3), sometimes with the addition of insecticide, sand or ash as a protectant. About 22% of respondents used some type of plastic bag for Bambara groundnut and 24% for roselle. Ten percent of respondents used the triple layer PICS bags for Bambara groundnut and 4% for roselle. Plastic jugs were the single most commonly reported hermetic container, with 27% of respondents using them for Bambara groundnut and 18% using plastic jugs for roselle. Woven sacks, sometimes with insecticide, sand or ash added at a protectant were in common use. About 28% respondents used woven sacks for Bambara groundnut storage and 44% for roselle storage. About 17% of all respondents used storage insecticide for Bambara groundnut and 13% for roselle.

Compared to previous studies in other parts of West Africa, this study finds a much higher proportion of Bambara groundnut farmers using hermetic storage. Bediako (2000) found that farmers in Ghana used mainly mud brick granaries, baskets and woven bags to store grain legumes. Berchie et al. (2010) found that most farmers surveyed in Ghana stored Bambara groundnut in woven bags: 90% in the Guinea savannah, and 67% in the forest transition area. Ayamdoo et al. (2013) found most farmers in the Upper East Region of Ghana storing Bambara groundnut in either clay pots or woven bags. Ayamdoo et al. (2013) study estimated that about 23% of the farmers stored in potentially hermetic containers (that is glass bottles, plastic containers or plastic bags). Tinkeu et al. (2016) found that most farmers in the Adamawa region of Cameroon stored Bambara groundnut in clay jars or bags. Tinkeu did not specify what type of bags was used. The percentage of farmers using hermetic storage for Bambara groundnut and roselle in Niger is similar to that of cowpea (Moussa et al., 2014; Ibro et al., 2014). The common use of hermetic grain storage in Niger can probably be linked to the extension efforts by non-governmental organizations (NGOs) and the PICS project to inform farmers about the use of this type of storage and facilitate access to plastic jugs, drums, and bags containers.

Use of storage insecticide for Bambara groundnut in Niger is in the range found by previous studies in other

Table 2. Continuous demographic variables in the sample of Bambara groundnut and roselle farmers in Niger in 2013.

Item	Mean	Max.	Min.
Age	48	95	20
Household size	12	43	1
Experience producing Bambara nuts	11	45	5
Experience producing roselle	10	45	0
Bambara groundnut production (kg)	243	3000	0
Roselle grains production (kg)	170	1300	1
Bambara groundnut stored (kg)	168	3000	0
Roselle grains stored (kg)	98	1283	0
Bambara groundnut stock later sold (kg)	101	1798	0

Table 3. Storage methods used for Bambara groundnut and roselle grains in Niger (% of respondents).

Item	Bambara groundnut	Roselle grains
Plastic jugs	21.5	14.1
Plastic jugs with insecticide	3.5	2.1
Plastic jugs with sand or ash	2.1	1.4
Metal barrel	0.7	2.1
Metal barrel with insecticide	1.4	0.0
Metal barrel with sand or ash	0.0	0.7
Jar or Canary	5.6	4.9
Jar with insecticide	0.0	0.0
Jar with sand or ash	1.4	3.5
Granary	7.6	0.7
Granary with insecticide	2.1	0.0
Granary with sand or ash	1.4	0.0
Woven bag	20.1	26.8
Woven bag with insecticide	6.9	7.7
Woven bag with sand or ash	1.4	9.9
Single layer plastic bag	0.0	7.0
Single layer plastic bag with insecticide	0.0	0.0
Single layer plastic bag with sand or ash	0.0	2.8
Double bag	8.3	6.3
Double bag with insecticide	2.8	2.8
Double bag with sand or ash	0.0	0.7
Triple bag	10.4	4.2
Triple bag with insecticide	0.0	0.0
Other	2.8	2.1
Total	100.0	100.0

West African countries and similar to that of cowpea in Niger. Bediako (2000) indicates that none of the farmers interviewed used storage insecticides for Bambara groundnut. Berchie et al. (2010) found that 37% of farmers were using storage insecticides for Bambara groundnut. Ayamdoo et al. (2013) indicate that 10% use storage insecticides. Golob et al. (1998) state that very few farmers use storage insecticides for Bambara groundnut.

In terms of percentage of overall quantity stored, most Bambara groundnuts and roselle grains are stored in potentially hermetic containers (Table 4). About 84% of Bambara groundnut is stored in such containers and 91% of roselle. While only about 10% of respondents reported storing Bambara groundnuts in PICS bags, the quantity stored by those respondents is quite large, so about 39%

Table 4. Percentage of Bambara groundnut and roselle grain quantity stored in Niger by storage method.

Item	Bambara groundnut	Roselle grains
Plastic jugs	7	5
Plastic jugs with insecticide	1	0.1
Plastic jugs with sand or ash	0.2	1
Metal barrel	1	1
Metal barrel with insecticide	3	0
Metal barrel with sand or ash	0	1
Jar or canary	1	0.4
Jar with insecticide	0	0
Jar with sand or ash	0.3	1
Granary	11	1
Granary with insecticide	2	0
Granary with sand or ash	2	0
Woven bag	0.04	1
Woven bag with insecticide	0	0
Single layer plastic bag	15	35
Single layer plastic bag with insecticide	7	19
Single layer plastic bag with sand or ash	0.4	15
Double bag	7	10
Double bag with insecticide	3	2
Double bag with sand or ash	0	0
Triple bag	39	3
Triple bag with insecticide	0	0
Other container with insecticide	0	0
Other container with sand or ash (plastic bag)	0	3
Other	1	0.3
Total	100	100

of the total quantity of Bambara groundnut stored by the respondents was stored in PICS bags. About 16% of the quantity of Bambara groundnut was stored with insecticide and about 21% of roselle.

Overall, the average quantity of Bambara groundnut stored per respondent was 168 kg and for roselle it was 98 kg. Respondents with larger quantities of Bambara groundnut or roselle to store tended to use metal drums, woven sacks, granaries or multilayer plastic storage bags, while those with smaller quantities reported storing in plastic jugs, canary jars, or single layer plastic bags (that is, shopping bags) (Table 5). For Bambara groundnut, the storage method with the highest average quantity stored was the PICS bag at 500 kg per respondent. For roselle, the storage method with the highest average quantity stored was the woven bag with insecticide at 260 kg per respondent.

Profitability of alternative storage technologies

For the estimation of storage losses, the budget calculations used the Baoua et al. (2015) data showing Bambara groundnut grains losses at 61.8% and roselle losses at 83.9% after 7 months of storage using traditional methods. For the analysis of the sensitivity, gains on storage were calculated by considering ±5% of the storage loss rate. For PICS bags, losses were considered at 0.6% as recommended by Jones et al. (2011b). Estimation of returns to storage used the budget approach described by Jones et al. (2014). To calculate the gain on investment, the price of the PICS bag was estimated at 1000 FCFA and a negligible cost in terms of storage infrastructure used by the farmers.

Tables 6 and 7 show the return on storage estimates for Bambara groundnut after eight to nine months and roselle grains after seven months of storage with opportunity costs of 25 and 35%. The storage period for each crop corresponds to a strategy of marketing in the lean season when prices are typically in highest, in May for roselle and July for Bambara groundnut. Average harvest time and lean season prices are those reported in the survey. Roselle prices are reported by farmers to rise from an average of 81 FCFA/kg at harvest to an average of 213 FCFA/kg in the lean season, a seasonal price increase of 142 FCFA/kg. Bambara groundnut prices are

Table 5. Amount of Bambara groundnut and roselle grains stored per respondent by storage method (kg per respondent).

Item	Bambara groundnut	Roselle grains
Plastic jugs	43	41
Plastic jugs with insecticide	36	5
Plastic jugs with sand or ash	12.1	59
Metal barrel	100	54
Metal barrel with insecticide	303	0
Metal barrel with sand or ash	0	75
Jar or canary	35	8
Jar with insecticide	0	0
Jar with sand or ash	29	35
Granary	189	138
Granary with insecticide	126	0
Granary with sand or ash	206	0
Woven bag	100	144
Woven bag with insecticide	153	260
Woven bag with sand or ash	42.5	189
Single layer plastic bag	0	5
Single layer plastic bag with insecticide	0	0
Single layer plastic bag with sand or ash	0.0	9
Double bag	113	150
Double bag with insecticide	132	74
Double bag with sand or ash	0	88
Triple bag	501	87
Triple bag with insecticide	0	0
Other	67	13
Overall sample	135	105

Table 6. Profitability of Bambara groundnut post-harvest alternatives (harvest October and sold in July).

Parameter	Sell at harvest	Storage in woven sacks		PICS storage bags	
		Without insecticide	With phostoxin	1 year	2 years
Initial stock (kg)	100	100	100	100	100
Storage loss (%)	0	61.8	1	0.6	0.6
Commercial quantity (kg)	100	38.2	99	99.4	99.4
Selling price (CFA/kg)	165	449	449	449	449
Total revenue (FCFA)	16550	17164	44484	44663	44663
Bag cost	0	250	250	1000	500
Insecticide cost	0	0	450	0	0
Total cost of storage	0	250	700	1000	500
Net cashflow (FCFA)	16550	16914	43784	43663	44163
Return on storage (%) with 25% opportunity cost of capital	NA	-17%	139%	136%	143%
Return on storage (%) with 35% opportunity cost of capital	NA	- 24%	135%	134%	138%

NA: Not applicable.

reported by farmers to rise from an average of 165 FCFA/kg at harvest to an average of 449 FCFA/kg in the lean season, a season price increase to 284 FCFA/kg. Based on the literature review, average storage losses

Table 7. Profitability of roselle post-harvest alternatives (harvest in November).

Parameter	Sell at harvest	Storage in woven sacks		PICS bags storage	
		Without insecticide	With phostoxin	1 year	2 years
Initial Stock (kg)	100	100	100	100	100
Storage loss (%)	0	83.90	1	0.60	0.60
Commercial quantity (kg)	100	16.10	99	99.40	99.40
Selling price (FCFA/kg)	81	213	213	213	213
Total revenue (FCFA)	8100	3435	21120	21205	21205
Bag	0	250	250	1000	500
Insecticide cost	0	0	450	0	0
Total cost of storage	0	250	700	1000	500
Net cashflow	8100	3185	20420	20205	20705
Return on storage (%)	NA	-73%	125%	118%	123%
Return on storage (%)	NA	-79%	120%	113%	115%

NA: Not applicable.

were estimated for both crops at 1% after a phostoxin insecticide treatment (3 tablets per 100 kg of grain). Because seasonal price changes storage was very profitable for Bambara groundnut and roselle farmers. Estimated returns with PICS bags were comparable to storage with insecticide and substantial better than unprotected storage in woven sacks without insecticide.

With an opportunity cost of 25%, a Bambara groundnut farmer who chooses to store his or her production with PICS bags could have doubled annual revenue with a 136% return on resources invested in storage when the bag was used for a season and 143% if the PICS bag was reused for a second season (Table 6). With 35% opportunity costs, the returns were slightly lower. In both cases, the profitability of using the PICS bag was comparable to that obtained with an insecticide treatment (Phostoxin), while unprotected storage shows a loss. While use of PICS bags did not provide a large monetary gain compared to insecticide use, it did allow the farmer to reduce pesticide exposure and the associate health risks.

With an opportunity cost of 25%, a roselle farmer who chose to store his or her production with PICS bags would have more than double their money. With a 25% opportunity cost the returns to storage investment was 118% when the PICS bag was used for one year and it was 123% if it was used two years. With a 35% opportunity cost the returns to storage were slightly lower, but still close to those achieved with insecticide in woven bags.

Probit analysis of PICS bag adoption

The SUR Probit estimate identified factors that are important for the adoption of PICS bags by farmers who store Bambara groundnut and roselle (Table 8). The overall Wald Chi Square was statistically significant at the 5% level indicating the Probit model explains an important portion of the overall variability in adoption. The estimated correlation between errors in the two equations (that is, ρ) was 0.81. The atanh ρ was estimated at 1.1318 and was statistically different from zero at the 1% level indicating statistically significant correlation between the error terms in the equations and supporting the use of SUR.

The estimated coefficients indicate that for Bambara groundnut the most important factors predicting adoption of PICS bags were being in the Dosso region, experience in production and membership in a village association. Dosso region had a very active PICS vendor and consequently the positive coefficient for that region probably reflected greater availability of the bags. The sex of the respondent and whether or not PICS demonstrations had been done in the village for cowpea were not significant. Estimated univariate marginal values indicated that farmers in the Dosso region are about 13% more likely to adopt PICS bags than those in other regions. A decade of experience increased probability of PICS adoption by about 10% and membership in an association by about 11%.

For roselle, the most significant variable in the Probit estimation was the quantity produced. With a probability of 10.8%, the village association membership coefficient was almost significant at the 10% level. For roselle, sex of the respondent, PICS cowpea storage demonstrations in the village and experience producing roselle were not significant at any conventional level. For roselle marginal effects, none of the variables were significant at conventional levels. The univariate roselle production marginal effect had a P value of 0.11 and indicated that each 100 kg of roselle grain produced increases the probability of adoption of PICS bags by 9%.

Table 8. Seemingly unrelated probit regression estimates for PICS bag adoption for Bambara groundnut and roselle grain storage.

Parameter	Bambara groundnut		Roselle grains	
	Estimated coefficient	**Univariate marginal effects**	**Estimated coefficient**	**Univariate marginal effects**
Region	0.8313**	0.1285**	NA	NA
Site category	0.3378	0.0457	0.1965	0.0144
Sex	0.2879	0.0410	0.6406	0.0449
Experience	0.6648***	0.0961***	-0.5516	-0.0437
Village association	0.8039*	0.1105**	0.7929	0.0559
Production 2012	0.0353	0.0051	0.1156*	0.0092
Constant	-3.4478***	NA	-2.4398**	NA
Number of obs =157				
Wald $chi^2(11)$ = 22.65**				
Log likelihood = -60.205423				
Athrho = 1.1318**				
Rho = 0.8116				

'*', '**' and '***' indicate statistical significance at the 10, 5 and 1% levels. NA: Not applicable.

Conclusion

This study documents the on-farm storage practices for Bambara groundnut and roselle grains in Niger. It is based on a random sample of 164 farmers of both crops in the Dosso and Maradi regions in 2013. Over half of respondents used some type of potentially hermetic container for storage of Bambara groundnut and 44% used that type of container for roselle. About 22% of respondents used some type of plastic bag for Bambara groundnut and 24% for roselle. Ten percent of respondents used the triple layer PICS bags for Bambara groundnut and 4% for roselle. The use of hermetic storage for Bambara groundnut was found to be much higher than previous studies in other West African countries, probably due to the intense hermetic grain storage extension effort in recent years in Niger by NGOs and other organizations.

About 17% of respondents used storage insecticide for Bambara groundnut and 13% for roselle. The use of storage insecticide for Bambara groundnut was in the range found by previous studies in other West African countries.

While only about 10% of respondents reported storing Bambara groundnuts in PICS bags, the quantity stored by those respondents is quite large, so about 39% of the total quantity of Bambara groundnut stored by the respondents was stored in PICS bags. Respondents with larger quantities of Bambara groundnut or roselle to store tended to use metal drums, woven sacks, granaries or multilayer plastic storage bags, while those with smaller quantities reported storage in plastic jugs, canary jars, or single layer plastic bags.

From an economic perspective, storage of Bambara groundnut and roselle is quite profitable. Farmers could potentially double their revenue from either crop by storing. Profitability of using PICS bags for one or two years was comparable to that achieved with the common practice of storing in woven bags with insecticide.

The Probit analysis indicates that for Bambara groundnut in the Dosso region, with easier PICS sack availability, there was significant production and membership in a village association. For roselle, only production was significant with membership in a village association almost significant at the 10% level. The adoption decision did not seem to be affected by the sex of the respondent or whether a PICS cowpea storage demonstration had been done in the village. Marginal estimates indicate that farmers in the Dosso region are 11% more likely to adopt PICS bags for Bambara groundnut than those in the other regions, probably in part because of the active PICS distributor in that region.

Overall, the data suggest that while many Bambara groundnut and roselle farmers in Niger are using hermetic storage, but only a few have adopted the use of PICS bags. The relatively modest level of PICS bag used for Bambara groundnut and roselle can be linked to: (1) supply chain issues limiting local availability of the bags in villages, (2) lack of a PICS storage extension effort targeted at Bambara groundnut or roselle (PICS training was exclusively for cowpea storage), and (3) technology diffusion lags. It takes time for farmers to learn about, test and adopt any new technology. Those that use PICS bags seem to be among the larger farmers. Because of substantial and relatively predictable seasonal price increase, storage of Bambara groundnut and roselle is quite profitable. While PICS bags use does not increase profitability substantially compared to insecticide use, it does allow the farmer to reduce pesticide exposure and the associate health risks.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Perceptions and choices of adaptation measures for climate change among teff (*Eragrostis tef*) farmers of Southeast Tigray, Ethiopia

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This study was conducted in Southeast Tigray of Ethiopia using teff (*Eragrostis tef*) producing farmers. Teff production with regards to climate change has significant implications on food security and poverty in Ethiopia. The aim of this study was to analyze factors influencing choice of adaptation strategies among teff farmers in Ethiopia. A stratified simple random sampling technique was employed to select 210 farm households as respondents from the three agro-ecological zones of the highlands of Endamehoni, and midlands and lowlands of Raya Azebo. A multivariate model was used to analyze the data obtained from farm households. The study found that from the sixteen predictor variables fitted in the model, nine variables including age, education of household head, household size, distance to produce market, farm to farm extension services, access to credit facilities, average temperature, climate information on weather and climate and agro ecology have significant influence on adaptation strategies with model coefficients at p=0.05 or less. It is therefore, recommended that policies of government on adaptation to climate change should be given emphasis in order to enhance the adaptive capacity of teff farming community.

Key words: Teff, climate change, adaptation, Southeast Tigray, Ethiopia.

INTRODUCTION

Climate change is a real global challenge and its impacts are increasingly felt presently, all over the world (Yumbya et al., 2014). There is an increasing agreement in the scientific texts that in the forthcoming years, higher temperatures and reduced rainfall levels triggered by climate change will reduce crop yields in many countries (Yesuf et al., 2008; Di Falco et al., 2011). The impact of climate change is critical in low-income countries, where

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capacity to adapt is alleged to be low (Intergovernmental Panel on Climate Change- IPCC, 2007). With a population of more than 85 million inhabitants, Ethiopia comes second as the most populated country in sub-Sahara Africa (SSA), whose economy is largely built on weather-sensitive agricultural production (Mendelsohn, 2000; IPCC, 2007).

Grains such as teff, wheat and barley are the most essential field crops in Ethiopia, covering 86% of the agricultural fields (CSA, 2015). Teff forms the staple diet of many Ethiopians as the flour is made into *injera* (unleavened bread). Approximately, one million hectare of land is under teff cultivation annually and it occupies about 25 to 32% of the total land under cultivation with cereal crops (CSA, 2015). Teff is adaptive to different agro-ecological zones and grows on diverse soil types, under relatively wide ranging climatic conditions. Teff is a top value crop, which is consumed, and mainly sold to earn income to purchase other cheaper cereals. Given its staple nature, teff production by smallholder farmer in the face of climate change has significant implications for food security and poverty in Ethiopia. Hence, assessing factors that influence choice of adaptation on teff production by smallholder farmers is essential.

The United Nations Framework Convention on Climate Change (UNFCCC) assigned high priority to climate change adaptation for protecting the most vulnerable population. Adaptation is required to reduce the impact of climate change now and in the future. However, resource availability is yet to be transformed into improved adaptation capacity in the farming sector. This failure has been attributed to several factors, one of them being delayed decision-making processes, hence the requirement to understand appropriate and cost effective adaptation strategies. Effective adaptation strategies in the agricultural sector are vital for protection of livelihoods of the poor rural communities and ensuring food security (Bryan et al., 2009). Approaches to investigate the climate change adaptation are therefore essential in to come up with information that is exhaustive enough for effective and informed decisions making.

Several studies carried out in Nicaragua, Zimbabwe and Ethiopia have indicated that farmers do perceive that climate is changing and have developed coping strategies to reduce the negative impacts of climate change on their farming activities (Bayecha, 2013; Zivanomoyo and Mukarati, 2013; Zuluaga et al., 2015). Evidently, attempts have been made by some writers to analyze factors that influence choice of adaptation to impacts of climate change in Africa (Di Falco et al., 2011; Deressa et al., 2009; Nhemachena et al., 2014). Studies have used the Ricardian methodology to estimate the impact of climate change on agriculture (Polsky, 2004; Deressa et al., 2014; Ndambiri et al., 2016). Though the applied approach included adaptation, they did not fully address the influencing factors for choice of adaptation measures in agriculture. Others that attempted to analyze the factors affecting the choice of adaptation methods did not implicitly show how farmers perceived changes to climate and adapt to the changes (Phiri, 2011; Komba and Muchapondwa, 2015).

Furthermore, past studies have argued that climate change adaptation is a two-fold which requires first, the perception that climate change exists and secondly, adaption to existing changes to climate (Wang et al., 2009; Apata, 2011). The IPCC (2007) argues that emphasis should focus on adaptation because anthropogenic activities have already influenced fluctuations in the climate and even the most stringent efforts cannot avoid further impacts in the coming decades. This work has benefited from studies of Maddison (2006) and Deressa et al. (2009) that used a two-fold process on climate change adaptation at regional levels designed for African countries. The methodologies used assisted to advance the model adopted for this research. The main objective of this study therefore, was to examine factors that influence choice of adaptation measures to perceived changes in climate for teff growing farmers in Southeast Tigray, Ethiopia.

The conceptual framework of the study is that agricultural adaptation models involve two decisions, whether to adopt or not. The decisions require the perception on how severe the impacts of climate change are (Deressa et al., 2009). Therefore, adaptation to climate change is two-fold, it starts with the perception first, then the decision to adopt. The basis of the theory is that only those farmers who perceive the risk will respond to the risk provided that the benefits of adaptation compensate for the presumed costs.

Probit and logit models are the most commonly used models in climate change adaptation in agriculture (Hausman and Wise, 1978; Wu and Babcock, 1998). Binary probit or binomial logit models are employed when the choices available are only two (adopt or not). Multivariate probit is employed when choices available are more than two. It has some advantages over binary probit and binomial logit in two facets. They explore both factors, that is, according to specific choices or a combination of them but also self-selection and interactions between alternative choices. To this effect, a multivariate probit model was employed to determine farmers' decisions to adapt to impacts of climate change. It is hypothesized therefore, that household characteristics, socio-economic, climate factors, access to institutional support, production factors (land size, seed, fertilizer) and agro-ecological settings influence farmers' decisions to adapt to impacts of climate change.

These models have also been employed in climate change studies because of the conceptual similarities with agricultural adaptation studies. For example, Nhemachena et al. (2014) employed a multivariate

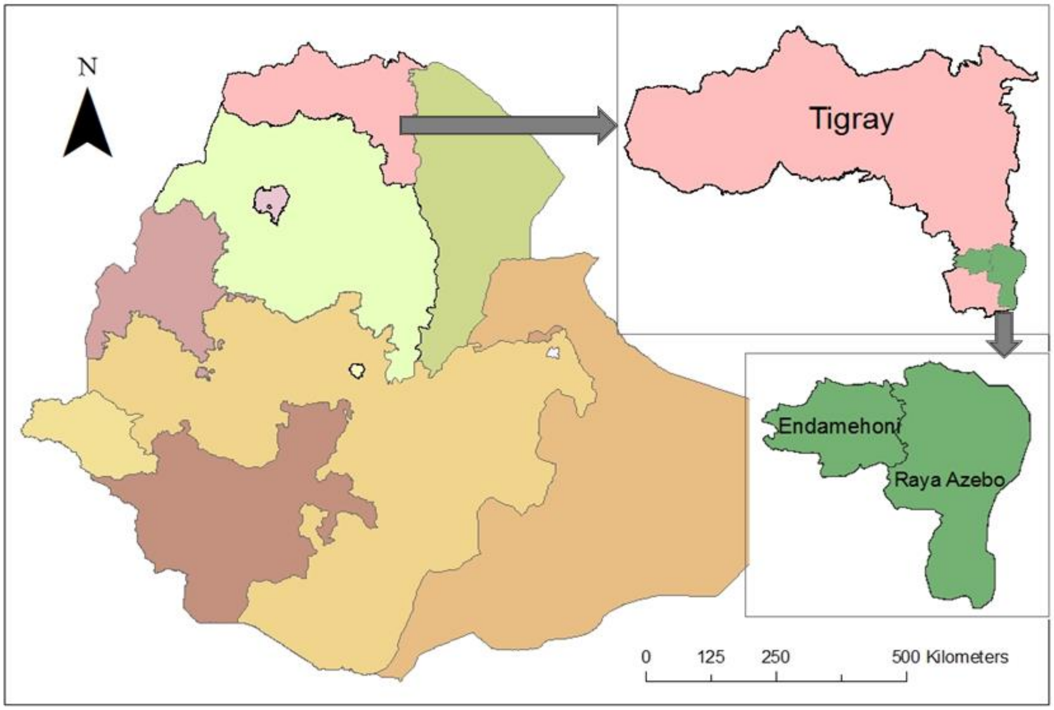

Figure 1. Map of Ethiopia showing the location of Tigray and the study site.

discrete choice model to analyze determinants of farm household adaptation strategies. Similarly, Deressa et al. (2009) adopted the multinomial logit model to analyze factors that affect the choice of adaptation methods in the Nile basin of Ethiopia. Additionally, Deressa et al. (2014) used multivariate model to investigate climate change adaptations of smallholder farmers in South Eastern Ethiopia to see if farmers perceived climate change and how they adapted. The study therefore used multivariate probit regression to analyze factors influencing choice of adaptation measures for climate change impacts among teff farmers in Southeast Tigray.

METHODOLOGY

Study area

Tigray is located in the northern part of Ethiopia with an altitude ranging between 400 to almost 4,000 m above mean sea level. It is located between 12° 15' N and 14° 57' N, and 36° 27' E and 39° 59' E. It covers an area of about 53,000 km² (CSA, 2015). Administratively, Raya Azebo is subdivided into 18 *kebeles* at an altitude ranging from 930 to 2,300 m above mean sea level (Tesfay et al., 2014). The climate is predominantly semi-arid with irregular rainfall accompanied by frequent drought periods. Average annual rainfall ranges from 800 to 1,000 mm per year reducing to 400 mm (Edwards et al., 2006). In most parts, it averages between 600 and 400 mm per year. The study was conducted in Endamehoni and Raya Azebo *weredas* of the Southeastern part of Tigray (Figure 1).

Data sources and sampling techniques

Both quantitative and qualitative data were used. The data used in the study was mainly obtained from a survey conducted at the three villages using a structured questionnaire. In designing the survey, a stratified sampling with purposive random technique was employed. At first, two out of 35 *weredas* were selected from the three agro-ecological zones of highlands, midlands and lowlands. The two *weredas* were Endamehoni and Raya Azebo. Secondly, three villages were purposively selected from the two *weredas* because of their vulnerability to climate change but also teff growing areas. Thirdly, purposive random sampling technique was used to select only teff growing farmers in the study area. Respondents were randomly selected from across the three villages. Finally, a questionnaire was administered to the 210 sampled households selected from the study area. This was proportionally allocated to the three agro-ecological zones as follows: 70 farm households from the Endamehoni highlands, 70 from the midlands and 70 from the lowlands of Raya Azebo. The survey included perceptions of farm households on climate change and adaptation methods. Farmers were specifically asked questions on changes in rainfall pattern and temperature over the past 30 years.

Econometric model

The study used multivariate probit regression model to analyze factors affecting choice of adaptation methods. This model is normally used to analyze the determinants of adaptation measures (relationship between adaptation measures and explanatory variables). The multivariate probit analysis models the influence of a set of explanatory variables on every different adaptation measure while allowing the unobserved or unmeasured factors (error terms)

Table 1. Description of the explanatory variables included in the econometric models.

Variable	Code	Variable typ	Expected sign
Gender of household (HH) head (1=male, 0=female)	sex	Dummy	+/-
Education of HH head (years of schooling)	sch	Continuous	+
Age of HH head (years)	age	Continuous	+
Household size (number of individuals in a HH)	hh_size	Continuous	+
Access to climate information (1=yes, 0=no)	ac_info	Dummy	+/-
Access to formal extension (1=yes, 0=no)	form_ext	Dummy	+/-
Farm-to-farm extension (1=yes, 0=no)	fam_fam	Dummy	+/-
Access to credit (1=yes, 0=no)	acc_credit	Dummy	+/-
Livestock (number of animals)	animl	Continuous	+
Land size in hectares (ha)	land_s	Continuous	+
Seeds (Kg/ha)	seed	Continuous	+
Fertilizer (Kg/ha)	fertliz	Continuous	+
Labour(no. of individuals engaged in farming)	labour	Continuous	+
Distance to market (Km)	mkt_dist	Continuous	+
Temperature (°C)	avg_temp	Continuous	-
Rainfall (mm)	ann_rain	Continuous	+

to be freely correlated (Greene, 2003). The presence of unobservable farm specific factors that affect choice of adaptation option that is not easily measurable (indigenous knowledge) could be a source of error. The correlations are taken care of in the multivariate probit model.

This study uses multivariate probit technique to overcome the shortfall of using other models like binary probit and multinomial probit models. Following Lin et al. (2005), the multivariate probit approach is characterized by a set of *n* binary dependable variables Y_i such that:

$$Y_i = 1 \; if \; X'\beta_i + \varepsilon_i > 0, = 0 \; if \; X'\beta_i + \varepsilon i \; \leq 0, i = 1, 2, \dots, n, \qquad (1)$$

Where X is a vector of explanatory variables, β_1, β_2,…. B_n are random error terms, ε_1, ε_2, …, ε_n are distributed as multivariate normal distribution with zero means, unitary variance and n x n correlation matrix R = [ρ_{ij}], with density $\Phi(\varepsilon_1, \varepsilon_2, \dots, \varepsilon_n; R)$. The likelihood contribution for an observation is the *n* – variance normal likelihood:

$$P_r\left(Y_{1,\dots,}Y_n \middle| X = \int^{(2y1-1)x'\beta 1} \int^{(2y2-1)x'\beta 2} .. X \int^{(2y2-1)x'\beta 1} \Phi\left(\varepsilon_1, \varepsilon_2, .., \varepsilon_n; Z'RZ\right) d\varepsilon_n, .., d\varepsilon_2 d\varepsilon_1\right) \qquad (2)$$

Where, Z = diag [$2y_1$-1,…$2y_n$-1]. The maximum likelihood estimate maximizes the sample likelihood function, a product of probabilities (equation 2) across sample observations. Calculation of maximum likelihood function using multivariate normal distribution involves multi-dimensional integration. The indicator (direction) effect of the explanatory variables on the susceptibility to adopt each of the different adaptation strategies are estimated as:

$$\frac{\delta L_i}{\delta X_i} = \Phi(X'\beta)\beta_{i,} \;_i = 1,2, \dots .. n \qquad (3)$$

Where L_i is the likelihood (probability) of event $_i$ (increased use of each adaptation strategy), Φ(X'β) is the standard univariate normal distribution function, *X* is the regression vector and *β* is the model parameter (Hassan, 1996).

Definition of the model variables

The multivariate probit analyzed whether a farmer adopted a specified adaptation strategies or not. The dependent variables therefore, are the adaptation strategies adopted by farm households. The adaptation strategies include: soil and water conservation, improved crop variety, planting trees, selling livestock, changing farming type from crop to livestock, early and late planting, etc. The independent variables are household characteristics, climatic factors, formal and non-formal institutional support, production inputs and outputs and agro-ecological settings. These explanatory variables indicated were chosen from literature based on impact of climate change on agriculture and adaptation strategies (Apata, 2011; Di Falco et al., 2011; Deressa et al., 2014), available data and previous knowledge on the area.

Based on the theoretical and empirical literature and considering household head characteristics, climatic factors, socio-economic, production factors and agro-ecological settings, households' choice of adaptation strategies to climate change with their expected signs are summarized in Table 1.

RESULTS AND DISCUSSION

Farmers' perceptions of climate change

Figure 2 presents the results of farmers' perception of long-term temperature and rainfall in the study area. The results indicate that 92% of respondents perceived decreasing annual rainfall over the past thirty years; 2.5% perceived increasing rainfall and 5.5%, no change (same). Similarly, 90% of respondents perceived increasing mean temperatures over the same period; 4% perceived decreasing temperatures and 6%, no change (same). Increasing temperatures and declining rainfall

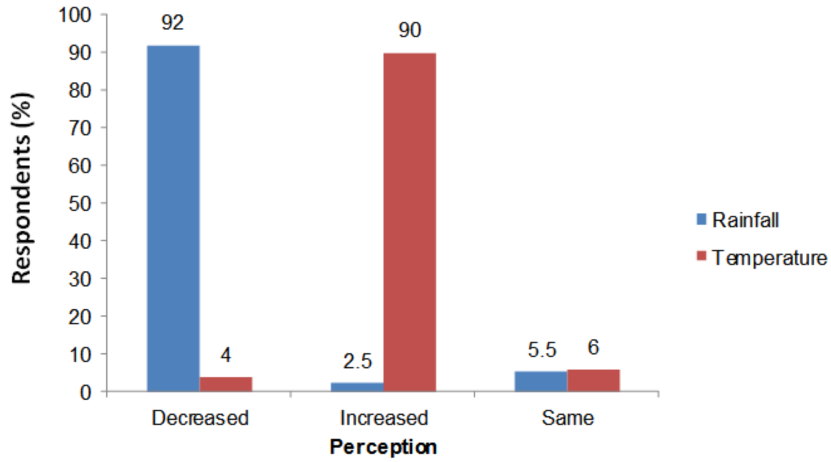

Figure 2. Farm households' perceptions of rainfall and temperature.

Table 2. Households' noticed indicators of climate change variability.

Variables	Minimum	Maximum	Mean	Std. Dev.
Increased uncertainty	0	1	0.875	0.331
Decreased rainfall	0	1	0.995	0.071
Reduction in teff yield	0	1	0.955	0.208
Decreased water availability	0	1	0.920	0.272
Frequent droughts	0	1	0.740	0.439
Famine	0	1	0.020	0.140
Shortage of rangeland	0	1	0.985	0.122
Poverty	0	1	0.885	0.319

are the leading perceptions among farm households in the study area.

Farmers' perceptions of noticed indicators of climate change variability

About 90% of farmers noticed the indicators of climate change over the past three decades as summarized in Table 2. Increased uncertainty in climate change (87%), frequent droughts (74%), decreasing rainfall (99%), reduction in teff yields (95%) and poverty (85%) were key indicators of climate change variability among the perceptions of teff farming households. Perception of indicators of climate change variability was very strong (>70%) among teff farmers.

Variability in temperature trend

Average temperatures indicate an increasing trend of 0.1°C as shown by the trend line from 1980 to 2010 (Figure 3). The increasing temperatures have a negative impact on teff growth. Yumbya et al. (2014) found ideal climatic limit for teff growth to be 13°C minimum and 25°C maximum annual temperatures. Currently, temperature conditions for the study area are ideal for teff growth. But if the increasing trend in temperature (0.1°C) continues, it will reach a critical limit for teff growth before 2050. The increasing average temperatures bring much stress on teff growth, hence reducing the yields.

Variability in rainfall trend

Figure 4 indicates a decreasing trend in amount of annual rainfall by 0.029 mm from 1980 to 2010. The ideal annual rainfall for teff growth ranges between 600 mm and 1,900 mm (Yumbya et al., 2014). Currently, the rainfall conditions are ideal for teff growth but already affected by frequent droughts (e.g. 1990; 1991; 1999; 2000; 2011; 2014). If the current decreasing trend in annual rainfall

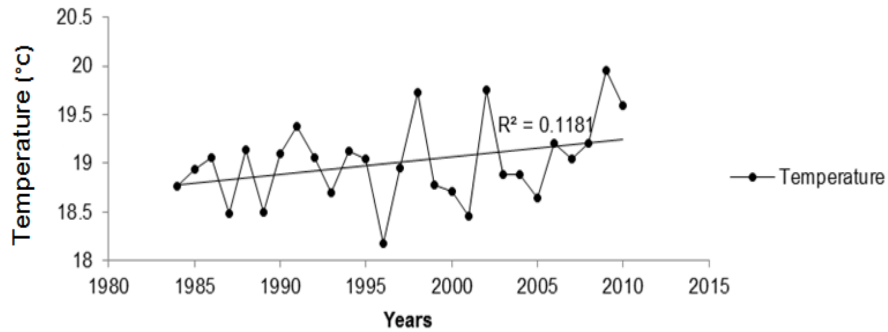

Figure 3. Increasing trend in average temperature of Maichew Meteorological Station. Data Source: Government of Ethiopia (2016).

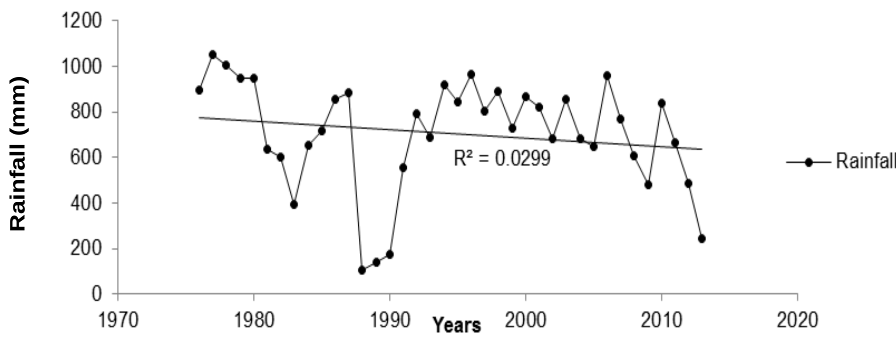

Figure 4. Decreasing trend in annual rainfall of Maichew Meteorological Station. Data Source: Government of Ethiopia (2016).

continues, it will reach a critical limit for teff growth before 2050. The declining trend in annual rainfall exposes farm households to poor teff production.

Multivariate probit regression analysis

For the multivariate probit model, it was first run and tested for its appropriateness over the standard model. The outcome of this operation show that most of the explanatory variables and their marginal values are statistically significant at 5% or less and the signs are as expected on most variables except for a few as indicated in Table 3. The regressed marginal effects measure the expected changes in the probability of climate change adaptation option with respect to changes in the independent variables.

The results from the multivariate probit model indicates that age of farm household head is statistically significant and has a positive influence on early and late planting (p=0.017), and improved crop variety (p=0.010). The results suggest that age of household head increases farmers' use of early and late planting techniques and use of improved crop variety, keeping other factors constant. This is an indication that the likelihood of changing planting dates and use of improved crop variety was higher among older farm households. As the age of the household head increases, it is assumed that the farmer is expected to acquire more experience in changing planting dates and use of improved crop varieties which influences the likelihood in older farmers practicing adaptation strategies. A study by Deressa et al. (2014) found that one unit increase in age of household head results in 9% increase in growing improved crop variety.

Household size is statistically significant with positive influence on soil and water conservation (p=0.034), planting trees (p=0.041), off-farm activities (p=0.046), and early and late planting (p=0.034). The results suggest that a large farm household increases farmers' use of soil and water conservation, off-farm activities, planting trees and early and late planting, keeping other factors constant. A bigger household size therefore is an important factor in the study area because it provides increased work-force on soil and water conservation, tree planting, off-farm activities and the probability of shifting

Table 3. Estimates of probit adaptation regression.

Variable	Soil conservation		Improved crop variety		Early /Late plant		Planting trees	
	Coef.	P>|z|	Coef.	P>|z|	Coef.	P>|z|	Coef.	P>|z|
Gender of hh head	0.547	0.204	-0.172	0.716	-0.166	0.706	-3.675	0.986
Age of hh head	-0.002	0.907	0.002	0.010*	0.027	0.017*	-0.030	0.046*
Marital status	0.417	0.469	-0.264	0.684	0.057	0.919	-3.366	0.979
Education hh head	0.104	0.042*	0.106	0.015*	0.122	0.632	-0.136	0.637
Household size	0.146	0.034*	0.102	0.332	0.146	0.034*	0.205	0.041*
Distance to market	0.055	0.679	0.095	0.025*	0.007	0.851	-0.038	0.536
Labour	0.013	0.500	0.012	0.454	-0.022	0.006*	0.013	0.253
Livestock	0.079	0.313	-0.014	0.596	0.000	0.963	0.001	0.964
Formal ext	-0.126	0.529	-3.821	0.984	0.162	0.658	-5.149	0.999
Farm-to-farm ext	-0.088	0.651	0.506	0.000*	0.161	0.374	0.352	0.216
Access to credit	-0.147	0.507	-0.486	0.391	1.336	0.024*	-0.674	0.138
Climate info	0.560	0.423	0.075	0.001*	1.005	0.001*	0.149	0.700
Average temperature	-3.492	0.716	1.676	0.031*	1.729	0.003*	1.729	0.004*
Rainfall	0.236	0.679	0.147	0.798	0.063	0.861	-0.206	0.703
Highland	-1.235	0.278	0.830	0.278	1.547	0.011*	0.857	0.158
Midland	0.709	0.360	0.362	0.508	-0.262	0.394	0.144	0.728
	Sell livestock		**Off-farm act**		**Changing farm type**		**New technology**	
	Coef.	**P>|z|**	**Coef.**	**P>|z|**	**Coef.**	**P>|z|**	**Coef.**	**P>|z|**
Gender of hh head	-0.294	0.531	-0.574	0.216	3.659	0.990	0.651	0.257
Age of hh head	-0.140	0.296	-0.005	0.542	-0.034	0.046*	-0.002	0.002*
Marital Status	-0.290	0.639	0.547	0.353	-0.897	0.171	1.015	0.125
Education hh head	3.732	0.967	-0.095	0.652	0.728	0.025*	0.341	0.446
Household size	0.155	0.164	0.102	0.046*	0.068	0.440	0.062	0.535
Distance to market	-0.079	0.423	-0.054	0.182	-0.079	0.377	0.063	0.507
Labour	0.016	0.468	0.007	0.320	0.005	0.712	0.089	0.030
Livestock	0.112	0.103	0.059	0.007*	0.024	0.236	0.028	0.459
Formal extension	0.171	0.401	-0.065	0.743	-0.069	0.845	0.092	0.850
Farm-to-farm ext	0.318	0.110	-0.075	0.681	-1.634	0.039*	0.025	0.941
Access to credit	0.234	0.304	0.286	0.316	0.303	0.397	1.278	0.021*
Climate infor	0.358	0.081	0.272	0.179	0.298	0.443	0.664	0.064
Average temperature	-3.850	0.999	0.040	0.874	0.349	0.472	0.072	0.090
Rainfall	0.153	0.771	-0.102	0.743	0.041	0.933	0.442	0.292
Highland	2.305	0.999	0.795	0.035*	-0.339	0.492	-0.474	0.759
Midland	0.663	0.282	-0.862	0.000*	-0.433	0.283	0.761	0.319

Likelihood ratio test of rho21 = rho31 = rho32 = 0: chi^2 (3) = 20.1099 Prob > chi^2 = 0.0002; hh: household; *significance at 5%.

planting dates due to changes in climate. The findings are in line with the argument which assumes that larger farm household provides extra earnings through creation of additional labour gained from other activities outside farming.

Education of farm household head is statistically significant with positive influence on soil and water conservation (p=0.042) and improved crop variety (p=0.015). The results suggest that farm households with better education have increased chances of practicing soil and water conservation measures and growing improved crop variety, keeping other factors constant. The argument could be that higher education is likely to expose farm households to better information on soil and water conservation and improved crop variety. Higher levels of education in farm households are more likely to increase information access and assumed to improve farmers' capacity to perceive, understand and translate information necessary to make innovative decisions in practicing soil and water conservation and using improved crop variety.

Distance to produce market is statistically significant with positive influence on improved crop variety (p=0.025). The results suggest that shorter distance to produce market increases farmers' use of improved crop variety, keeping other factors constant. If farm households are located far away from produce markets, the possibility of obtaining latest information on improved crop variety is reduced, experience sharing among farmers is reduced and it is difficult for farm households to acquire new technology on improved crop variety. A produce market is therefore, an important factor because it serves as a place where farmers obtain information on newly introduced improved crop varieties on the market.

Access to information on weather and climate is statistically significant and positively influence improved crop variety (p=0.001) and early and late planting (p=0.001). The results suggest that access to weather and climate information increases the probability of using improved crop variety and adjustments of planting time (early and late planting), keeping other factors constant. Access to information on weather and climate in the study area equips farm households with knowledge on use of improved crop variety and shifting planting dates to better cope with impacts of climate change.

Farm-to-farm extension services were found to be statistically significant and positively influence improved crop variety (p=0.000) and negatively influence changing farming type (p=0.039). The results suggest that farm households with better access to farm-to-farm extension services have an increased probability of using improved crop variety and a decreased probability of changing farming type from crop production to livestock, keeping other factors constant. Sharing information among farm households is very essential as different farmers have different skills, different experiences on crop varieties and farming habits. It is an important factor because farm households enhance their knowledge by sharing experiences on improved crop varieties.

The results of the study showed that access to formal credit services is statistically significant and influence new farming technologies (p=0.010) positively. The results suggest that farm households with better access to formal credit services have the probability of increasing new farming technologies in response to impacts of climate change, keeping other factors constant. Access to formal credit services is an important factor in the area because it increases the likelihood of farm households to have sufficient money to purchase the most needed farm inputs to increase teff produce. Hence, access to formal credit influences decisions on use of farming technologies that would improve teff yields to enable food security among farm households.

Average temperature was found to be statistically significant with positive influence on planting trees (p=0.004), improved crop variety (p=0.031) and changing (early and late) planting dates (p=0.003). The results suggest that increasing average temperature leads to the probability of planting more trees, increased use of improved crop variety, and changing planting dates (early and late planting), keeping other factors constant. This is evident in the highlands of Endamehoni where farm households are reported to be used to red teff plating, but due to increasing temperatures, farmers have changed to growing white teff (improved variety) which is tolerant to higher temperatures. Average temperature is an important factor in the area because it influences farmers' use of improved crop variety, growing of more trees, and changing planting dates to cope with changes in temperature.

Agro-ecology

The study found variation in the use of adaptation strategies among households living in different agro-ecological zones. The results found that highlands were statistically significant with positive influence on shifting planting dates (early and late) (p=0.011) and off-farm activities (p=0.055), while midlands were found to be statistically significant with negative influence on off-farm activities (p=0.000). The results suggest that farm households in highlands (as compared to lowlands) have an increased probability of shifting planting dates (early and late planting) and off-farm activities, while farm households in the midlands have decreased probability of off-farm activities, keeping other factors constant. Agro-ecological setting is an important factor because it influences shifting of planting dates and practicing off-farm activities due to changes in climate.

Conclusion

The descriptive analysis found that most farm households were aware of the long term change in rainfall and temperature. Increasing temperatures and declining rainfall are the leading perceptions among farm households in the study area. Farm households also noticed the indicators of climate change variability of frequent droughts, reduction in teff yield, poverty and shortage of rangeland. Meteorological data shows increasing average temperatures for about 0.1°C and decreasing annual rainfall by 0.029 mm between 1980 and 2010. Sixteen explanatory variables were hypothesized to affect decision on choice of adaptation strategies. Results concluded that education, age of household head, access to weather and climate information, access to formal extension services, access to credit, average temperature, distance to produce market and livestock were statistically positive and significantly influenced the likelihood of practicing adaptation measures. However, negative influence was noticed with the adoption of off-farm activities in the midlands, suggesting a decreased probability of the adaptation measure in the midlands. Older farmers have better opportunity to practice crop diversification (improved crop variety) and adjustment of planting time (early and late) measures than younger farmers. Better access to climate information was found to increase the probability of early/late planting in response to adverse effects of climate change. Similarly, education of household head, household size and access to credit facilities appeared to be strong determinants of adaptation strategies for impacts of climate change. It was therefore recommended that policies of government on adaptation to climate change should be given priority in the study area in order to enhance the adaptive capacity of the rural farming community. Government should invest on improved teff varieties (temperature stress tolerant) and improved production technologies to reduce adverse impacts of climate change. Further research is recommended to analyze cost of adaptation to assist in making sound decisions effecting only those adaptation strategies that are economically cost effective.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Evaluation of frontline demonstration of herbicide (Pyroxsulam) for weed control in bread wheat in Tigray, Northern Ethiopia

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Frontline demonstration of herbicide was conducted in four districts of Tigray Region with objective of improving productivity of unit area and enhancing the income of farming community. Technology demonstration followed by perception assessment survey was conducted on the direct beneficiaries of the technology. A total of 40 farmers were selected purposively. The herbicide and improved bread wheat was offered. Yield, production cost and perception data were collected. To measure the attitude of farmers towards the improved technology, a five-point Likert scale were used. The data was analyzed using t-test and statistical analytical techniques such as descriptive, frequency, percentage and partial budget analysis. The result of this activity shows that in the four districts, an average of 2236, 2050, 3025 and 2712 kg ha^{-1} of grain yield were harvested from Pyroxsulam application, whereas, an average of 1689, 1356, 2127 and 1832 kg ha^{-1} grain yield were harvested from hand weeding, respectively. This can show us that farmers from the districts had an increment of yield by 32.39, 51.18, 42.22 and 48.03% in Hintalo-Wajirat, Enderta, Saesie Tsaeda-Emba and Glomahda districts, respectively. The t-test result also showed that there is statistically significant mean difference between the two groups at less than 5%. The average marginal rate of return of the four districts was 259% and shows greater than the minimum acceptable rate of return (100%). Hence, further scale up need to be made concerning rural institutions.

Key words: Demonstration, hand weeding, herbicide, improved wheat, profitability, pyroxsulam.

INTRODUCTION

Ethiopia is the largest wheat producer in sub-Saharan Africa. In Ethiopia, wheat is the most important cereal crop in terms of the area of land allocated, volume produced, and the number of farmers engaged in its production. About 4.7 million farmer households are involved in the production of about 3.9 million tons of

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wheat across 1.6 million hectares of land, with an average productivity of 2.4 t ha^{-1} (Central Statistics Authority - CSA, 2012).

Although efforts are being made by the government and other development partners, such as United States Agency for International Development (USAID), the wheat supply does not meet the national demand; the estimated annual deficit is about 25 to 30%, which is filled by imported grain from other countries (United States Agency for International Development - USAID, 2014). One of the most limiting factors in the production of wheat in Ethiopia in general, and Tigray region in particular is grassy and broad-leaved weeds.

Wheat is among the major cereal crops grown in Tigray region which accounts for 30% of the total production (CSA, 2012). Wheat production in the region is highly threatened by numerous production constraints, among which weeds are frequently occurring production constraints in which its effect is aggravated by traditional cultural methods that the farmers are practiced. Crop-weed competition trials conducted on various farmers field indicated that uncontrolled weed growth resulted to a regional yield reduction of 31% (Agronomy Progress Report, 2012). Though both grasses and broad leaved weeds are responsible for the reduction of yields, the wheat production areas showed similarities in that the grassy weeds particularly wild oat, had become a serious problem.

This is attributed to cereal-based cropping system, insufficient or late weeding and use of local seed which is not clean. The traditional method of sowing makes weed virtually impossible to distinguish and manually removed sufficiently early to reduce yield losses; consequently, weeding remains a neglected problem. Though the farmers practiced fertilizer use in wheat, experiments elsewhere indicated that in uncontrolled weed growth, wild oat utilized nitrogen better than wheat. Therefore, insufficient weeding, which is the common phenomenon of the region, resulted to low fertilizer use efficiency. Thus, the full benefits from increased usage of fertilizer may not be realized without the application of improved weed control technology, increasing crop yield as well as improved product quality by suppressing weed growth (Ferdous et al., 2017). Based on this, herbicide chemical (Pyroxsulam) was tested in different mandate areas giving promising result in reduction and removing of wild oat and broad-leaved weeds. Pyroxsulam was more effective on controlling broadleaved weeds which reduced the weed population as compared to other herbicides and can also control serious grassy weeds on wheat (Muhammad et al., 2013).

However, demonstration, social and economic importance of this herbicide on farmers' field is not done widely in order to popularize and promote the technology in the area. Hence, addressing this knowledge and development gap is of paramount importance in order to enhance their production and improve their income which is capable of bringing about significant development impacts.

MATERIALS AND METHODS

Description of the study area

The Tigray National Regional State is situated between 12° 15' and 14° 57' N latitude and 36° 27' and 39° 59' E longitude. It is bordered to the North by Eritrea; to the West by the Sudan, to the South by Amhara and to the East by Afar Regional States. It covers a total of 53,638 km^2 surface area and belongs to the African dry lands, which are often called the Sudano-Sahelian Region (Emiru et al., 2011). The region is divided into six administrative zones which has 54 districts and nearly 800 peasant associations (CSA, 2010). The study was done on two zones of Tigray region by selecting four districts in regard to their weed coverage. The districts are named Gulomahda and Saeisi Tsaedaemba (Eastern zone) and Enderta and Hintalo Wajirat (South-eastern zone).

Enderta and Hintalo Wajirat are found in South Eastern Tigray Zone. Enderta is one of the four districts in the Southeastern administrative zone of Tigray. It is located at 13° 15`0" N and 39° 30`30" E with an altitude ranging from 1500 to 2000 m above sea level and shares borders with Kilte`Awlaelo district in the north, Hintalo Wajirat in the south, Afar Regional State in the east and the district of Degu'a Tembien in the west. The district covers a total area of 89,812 km^2 of which 30,062 ha is cultivable land. The total population size is 114,277 according to the 2010 population census of the CSA (2010). The agro-climatic state of the district is mainly (96%) warm mild climate, with remaining 3 and 1% hot low land climate and temperate climate respectively. Annual average rainfall ranges from 450 to 550 mm. In concurrence to the agro-climatic state of the district, smallholder mixed farming remains the single largest tributary to the livelihoods of the population. Major crops grown in the district include teff, wheat, barley, sorghum, millet, oil seeds, pulse seeds, horticultural crops and vegetables. Hintalo-Wajirat district is found in the south eastern zone of the Tigray Regional State. The district covering a total land mass of 193,309 km^2 is bordered by the Afar Regional State in the east, Raya Azebo district in the south east, Alaje district in the south, Saharti-Samre district in the west and Enderta district in the North. The district is found at an elevation which ranges from the lowest 1825 m to the highest 2625 masl. Climate classifications of the area comprise 22.5% kola, 63.75% weina-dega and 13.75% dega. Teff, wheat, barley, sorghum and vegetables are the most common types of crops growing in many places of the district. The district receives an average rainfall that ranges from the lowest 336 mm to the highest 933.75 mm per annum. The total population of the district is 180739 of which 88,950 are males and 91,789 are females (Hintalo-wajerat district Plan and Finance Development office - HWPFD, 2013).

The two districts of the study area, Saesi-Tsaeda-Imba and Gulomahda, are found in Eastern Tigray Zone. Saesie-Tsaeda-Imba is located in the eastern zone of Tigray region on which the capital Firewoyni is located 60 km far from Mekelle, on the way from Mekelle to Adigrat. It has a total area of about 933.12 km^2 and is divided into 24 administrative PAs of which 22 are rural and two Kebeles are town administration. Gulomahda district is found at 915 km north of Addis Ababa (Gebrehiwot and Fekadu, 2012). It is located at 14° 30' to 14° 50' N and 39° 20' to 39° 35' E and has an altitude of 1500 to 3200 ma.s.l. It is bordered on the south by Ganta-Afeshum district, on the west by the Central Zone, on the north by Eritrea and on the east by Erob district (Agricultural and Rural Development Office of Erob District - ARDOED, 2013).

According to the CSA estimation as of July 2010, the total population was estimated to be 139,191 and 84,236 for Saesie-Tsaeda-Imba and Gulomahda (CSA, 2010). The climate of the study districts is generally sub-tropical with an extended dry period of nine to ten months and a maximum effective rainy season of 50 to 60 days. The rainfall pattern is predominantly uni-modal (June to early September) (Belete et al., 2002).

Sampling and experimental design

The activity was conducted in the above mentioned four districts (Enderta, Hintalo-Wajirat, Saesie Tsaeda-Emba and Gulomahda) in two demonstration plots (Pyroxsulam and hand weeding) side by side. One kebelle from each of the four districts which were invaded by weeds were selected purposively. Besides, from the respective kebelles 10 farmers who were willing and able to participate in the new technology were purposively selected. The activity was carried out in collaboration with District Office of Agricultural and Rural Development staffs and development agents of the respective kebelle. Plot size of 10 m × 10 m for each Pyroxsulam (45 OD) and hand weeding treatment were applied. The herbicide was mostly used and effective for controlling grass and broad leaf weeds in wheat and teff. Herbicide treatment (Pyroxsulam 45 OD) was applied at 0.5 L/ha for wheat. Besides, the amount of water required 200 L/ha for both wheat. The herbicide was applied at early stage (25 to 30 days after emergence) and T-jet\Flat fan type of spray nozzle was used during the application. The wheat variety 'Picaflor' was used uniformly for all treatment and participating farmers. The seed rate of 125 kg\ha was used and sowing date was first week of July.

Data collection

Qualitative and quantitative data were collected from the demonstration trial. Qualitative data was collected through focus group discussion and informal discussion with farmers and development agents (DAs). Qualitative data was used to fill the gap in quantitative data which was then collected through personal interview using interview schedule. Sample yield data were also collected from demonstration plots and plots where farmers use his conventional practices. Production cost and benefits were collected to see the profitability difference of the treatments. Farmers' point of view on the attributes of the variety based on the composite indicators of yield and yield components were also collected using Likert scale method, a format that this is preferred by Derrick and White (2017).

Data analysis

The data were analyzed using t-test and statistical analytical techniques such as descriptive, frequency, percentage and graphs in line with Ferdous et al. (2016). Economic analysis was made using partial budget analysis which was done to determine the economic feasibility of the weed control methods. It was calculated by taking into account the additional input costs (variable costs) involved and the gross returns obtained from weed control treatments. The variable cost also included the labor cost involved in harvesting, threshing and winnowing as their cost varied according to the yield obtained in a particular treatment (CIMMYT, 1988). Besides, different parameters as suggested by Yadav et al. (2004) were used for calculating gap analysis. Technology gap, extension gap and technology index were calculated using the following formulas

Technology gap = Potential Yield – Demonstration Yield (1)

Extension gap = Demonstration Yield – Yield under farmers practice (2)

Technology index (%) = [(Potential Yield – Demonstration Yield) / Potential Yield] × 100 (3)

RESULTS AND DISSCUSION

The grain yield of the Pyroxsulam treatment was higher than the hand weeding treatment in all districts which could be due to the effectiveness of the herbicide in reducing weed competition at all stage of the crop. The herbicide was applied at early stage (25 to 30 days after emergence) which was effective in weed reduction than the hand weeding which started lately and even not weeded as required. Similarly, the straw yield of the Pyroxsulam (45 OD) treatment was better than the hand weeding in all participated districts.

As can be seen from Figure 1, in Hintalo-Wajirat, an average grain and biomass yield of 2236 and 4095 kg ha^{-1} were harvested from Pyroxsulam (45 OD) applied; whereas, an average of 1689 and 3212 kg ha^{-1} grain and biomass yield were harvested from hand weeding respectively. In Enderta district, an average of 2050 and 3765 kg ha^{-1} of grain and biomass yield were harvested from the improved practice (Pyroxsulam 45 OD), whereas 1356 and 3085 kg ha^{-1} of grain and biomass yield were harvested from hand weeding, respectively. Besides, in Saesie Tsaeda Emba and Gulomahda district the average yield obtained from the Pyroxsulam (45 OD) was 3025 and 2712 kg ha^{-1}; whereas, in the districts the average yield that farmer obtained from the local in the same production season was 2127 and 1832 kg ha^{-1}, respectively. Similar results were also observed by Sharma and Choudhary (2014).

In addition, the result reveals that the improved practice gave a percentage yield increment of 32.39, 51.18, 42.22 and 48.03 in Hintalo-Wajirat, Enderta, Saesie Tsaeda Emba and Gulomahda districts, respectively. This would imply that the improved practice (herbicide) can play significant roles in enhancing the productivity of wheat as well as improving the food security status of small holder farmers.

Yield of the demonstration trials and potential yield of the crop due to the herbicide was compared to estimate the yield gaps which were further categorized into technology index. The technology gap shows the gap in the demonstration yield over potential yield, and in all districts technology gap were 1564, 175, 777 and 1088 kg ha^{-1}, respectively. The observed technology gap may be attributed to dissimilarities in soil fertility, salinity and erratic rainfall and other vagaries of weather conditions in the area. Hence, to narrow down the gap between the yields of different varieties, location specific recommendation appears to be necessary. Technology index shows the feasibility of the technology at the

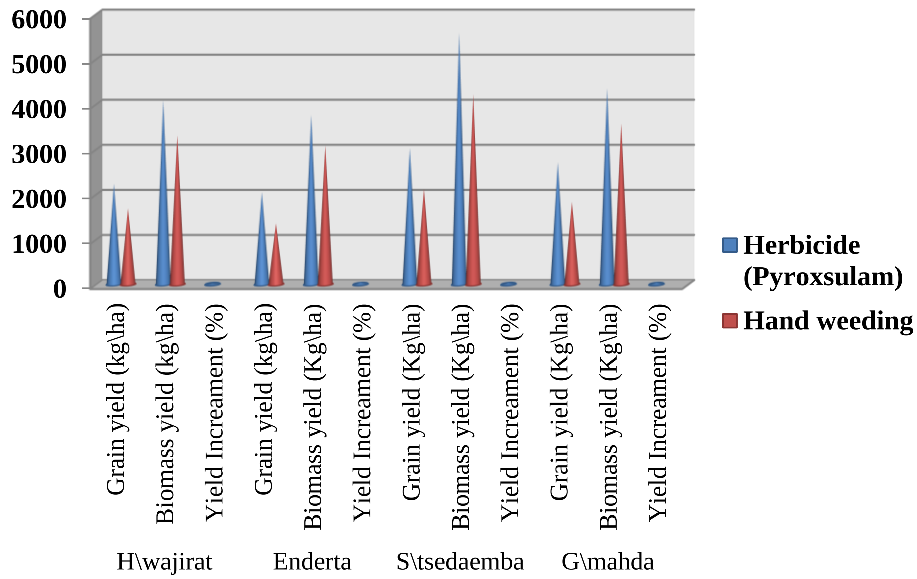

Figure 1. Grain and biomass yield of the demonstration of herbicide and hand weeding.

Table 1. Yield, technology gap and technology index of demonstration.

Districts	Practices	Yield (kg ha^{-1})	Yield increment (%)	Technology gap (kg ha^{-1})	Technology index (%)
H\wajirat	Pyroxsulam Hand Weeding	2236 1689	32.39	1564	41
Enderta	Pyroxsulam Hand Weeding	2050 1356	51.18	1750	46
Saesie Tsaeda Emba	Pyroxsulam Hand Weeding	3025 2127	42.22	777	20.44
Gulomahda	Pyroxsulam Hand Weeding	2712 1832	48.03	1088	28.6

Table 2. Main effect of herbicides on weeds and crop growth.

Attribute	Weeding	N	Mean	t	SEM*	df	P-value
Grain yield	Hand Weeding Pyroxsulam	20 20	1751 2506	-2.053	261.19 259.33	38	0.04

*SEM- Standard error difference.

farmer's field. The lower the value of technology index, the more is the feasibility. Table 1 revealed that the technology index values were 41, 46, 20.44 and 28.6%, respectively. The findings of the study are in line with the findings of Sawardekar et al. (2003), and Hiremath and Nagaraju (2009).

Moreover, the analysis of data concerning grain yield revealed significant differences among the hand weeding and pallas 45 OD (Pyroxsulam) as presented in Table 2. Chemical weed control in wheat was best in producing higher grain yield than hand weeding. Akhtar et al. (1991) found that application of grassy and broad leaf herbicides

Table 3. Partial budget analysis.

Attribute	H/Wajrat		Enderta		S/T/Emba		G/Mahda		Average	
	Hand weeding	Herbicide	Hand weeding	Herbicide	Hand weeding	Herbicide	Hand weeding	Herbicide	Hand weeding	Herbicide
Yield (kg ha^{-1})	1689	2236	1356	2050	2127	3025	1832	2710	1751	2505
Straw yield (kg ha^{-1})	2270	2800	3085	3933	4233	5500	3570	4350	3289	4146
Gross field benefit (grain)	16045.5	21242	12882	19475	20206.5	28737.5	17404	25745	16634.5	23799.875
Gross field benefit (straw)	2837.5	3500	3856.25	4916.25	5291.25	6875	4462.5	5437.5	4355.625	5182.1875
Total gross benefit (Birr ha^{-1})	18883	24742	16738.25	24391.25	25497.75	35612.5	21866.5	31182.5	20746.375	28982.0625
Cost of weeding (Birr ha^{-1})	4500		5800		6700		6250		58125	
Cost of food for weeding (Birr ha^{-1})	0		700		1100		500		766.67	
Cost of pallas chemical (Birr ha^{-1})	0	1000		1000		1000		1000		1000
Cost of spraying (Birr ha^{-1})	0	150		150		150		150		150
Total variable costs (Birr ha^{-1})	4500	1150	6500	1150	7800	1150	6750	1150	6387.5	1150
Net benefit (Birr ha^{-1})	14383	23592	10238.25	23241.25	17697.75	34462.5	15116.5	30032.5	14358.88	27,832
Change in variable cost (Birr ha^{-1})		3350		5350		6650		5600		5,238
Change in net benefit (Birr ha^{-1})		9209		13003		16764.75		14916		13,473
MRR		2.75 ($64.1 USD)		2.43 (56.64 US USD)		2.52 ($58.74 USD)		2.66 ($62 USD)		**2.59** ($60.37 USD)

increased grain yield and yield components. An independent sample t-test was conducted to compare the mean difference between hand weeding and herbicide with respect to grain yield. The t-test result also showed that there is statistically significant mean difference between the two groups at less than 5% probability level (t=-2.05).

Partial budget analysis of the Pyroxsulam herbicide and hand weeding

The partial budget analysis which was expressed in hectare is shown in Table 3. The variable cost in hand weeding among the target farmers of the kebelle occurred mostly due to the frequency of weeding they practiced. The farmers of Saesie Tsaeda Emba demonstration area invested more of their time on weeding to the extent of eliminating the oats. On the contrary, farmers from H/Wajirat did not invest their time on weeding the oats.

In all, target farmers of the districts application of Pyroxsulam herbicide was profitable than hand weeding. In both Kebelles, wheat yield of the Pyroxsulam treatment were better than the hand weeding and more cost were incurred in hand weeding. The marginal rate of return (MRR) of 275, 243, 252 and 266% at H/Wajirat, Enderta, S/T/Emba and G/mahda, respectively shows that the application of Pyroxsulam herbicide was beneficial. The average MRR of the four districts (259%) shows greater than the minimum acceptable rate of return (100%). For every one Birr[1] investment in Pyroxsulam herbicide for wheat production there would be 2.59 Birr ($ 60.37 USD) return based on the demonstration conducted. This indicates that using improved technology can bring additional benefit to the farming community.

[1] Birr in this text is an Ethiopian currency and the current exchange rate of $1 USD is 23.31 Ethiopian Birr.

Major weed flora observed in the farmers' field

In the study area, different weeds were observed on farmers' field. Moreover the demonstration plot was infested with several broad leaf and grass weed species. The flora in the experimental fields indicated that the weeds belonged to 17 families which are eliminated by the herbicide (Table 4).

Plots treated by herbicide were free from most problematic weed species mentioned in the table and others. Besides, as the farmers said and from our observation, most of the weeds were eliminated by the Pyroxsulam. However, to some

Table 4. The major infesting weeds species observed through the demonstration season at study area.

Botanical name of weed species
Grass weeds
Avena fatua
Lolium temulentum L.
Snowdenia polystachya
Phalaris paradoxa L.
Bromus pectinatus
Setaria pumila
Cyperus rotundus L.
Broad leave weeds
Plantago lanceolata
Polygonum nepalense
Scorpirus muscata
Guizotia scabra
Galinsoga parviflora
Gallium spurium
Rumex abyssinica
Datura stromonium
Chenopodium album L.
Raphanusraphanixtrum L.

extent *Cynodon dactylon* and Convolvulus escaped and lately emerged since these weeds are hard and possess perennial characteristics, so it needs further study for these individual species.

Farmers' perception

In order to get essential information and insight into farmers' perception of the technology, looking at their perception on each attributes to which they are employing is quite important. Hence, knowledge of farmers' evaluative perception on technology attributes in the study area is an appropriate issue to be answered. Here under, the percentage scores of farmers' response to the perception statements of each attributes that relate to perceived technological characteristics are given in Table 5.

As presented in Table-5 the perception level of the farmers towards the pre and post-harvest attributes were putted as good and very good. Besides, most of the sample beneficiaries appreciated the herbicide. However, some farmers (38%) have negative\poor perception on straw yield. In general on the rest of the pre and post-harvest attributes of the variety due to Pyroxsulam majority of the host communities had positive perception.

As observed from Table 6, all of the respondent farmers from Enderta and Saesie Tsaeda Emba districts were highly satisfied on training (100%) followed by farmers from Gulomahda (80%); whereas 80% of farmers from Hintalo-Wajirat district had medium level of satisfaction. An average of 75% of respondent farmers was highly satisfied on supply of input, whereas a very few (25%) of respondents expressed medium level of satisfaction on supply of inputs. Moreover, most of the respondent farmers (80%) were highly satisfied on timeliness of input followed by medium level of satisfaction (20%). The level of satisfaction with respect to services rendered, linkage with farmers, and technologies demonstrated etc. indicate stronger conviction, physical and mental involvement in the demonstration, which in turn would lead to higher adoption. This finding meant that farmers were satisfied both with Pyroxsulam and existing extension approaches that has been deployed to disseminate the herbicide and innovations.

CONCLUSION AND RECOMMENDATIONS

Demonstration conducted under the close supervision of scientists is one of the most important tools of extension to demonstrate crop management practices at farmers' field under different agro-climatic regions and farming situations. As a result the activity was conducted in the moisture stressed areas of the eastern and south eastern zones of the Tigray Regional State. From the yield analysis and farmers evaluation, the grain yield of the Pyroxsulam treatment was higher than the hand weeding treatment in all districts, which is an indication that the above mentioned weeds competition reduces using the Pyroxsulam herbicide having the existing weed practice of the farming community. In all districts, wheat yield of the Pyroxsulam treatment were better than the hand weeding and more cost were incurred in hand weeding. The farmers also expressed medium to high level of satisfaction for extension services under demonstrations. The average MRR of the four districts (259%) shows greater than the minimum acceptable rate of return (100%). For every one birr investment in Pyroxsulam chemical for wheat production, there would be 2.59 Birr ($ 60.37 USD) return based on the experiments. Based on the findings, the following recommendations are forwarded so as to improve the wheat production and productivity:

i) The herbicide Pyroxsulam should be popularized in more target farmers and larger area to help farmers on its practicality at large.
ii) The herbicide Pyroxsulam utilization should be supported by practical training, technical backstopping and safety considerations to be sustainable.

Table 5. Perception of farmers on pre and post-harvest attributes.

Characteristics	Perception level (%)				
	V. poor	Poor	Neutral	Good	Very good
Effect of Pyroxsulam on vegetative period	-	-	-	13	87
Effect of Pyroxsulam on growth of the crop	-	-	-		100
Tiller number	-	-	-	76.2	23.8
Vegetative performance	-	-	-	90	10
Head size	-	4.8	-	85.7	9.5
Threshability	-	5		90	5
Seed weight	-	4.8	-	95.2	-
Seed uniformity	-	4.8	-	90.5	4.8
Seed size	-	4.8	-	90.5	4.8
Seed color	-	4.8	-	90.5	4.8
Purity	-	-	-	90.5	9.5
Yield	-	4.8	-	90.5	4.8
Straw yield	-	38.1	-	61.9	-
Straw palatability	-	20	-	80	-

Table 6. Satisfaction of the sample respondents on the Pyroxsulam demonstrating trail.

Service	Satisfaction level	District				Average
		Enderta	H/Wajirat	Saesie Tsaeda Emba	Gulomahda	
Training	High	100	20	100	80	75
	Medium	-	80	-	20	25
	Low	-	-	-	-	
Supply of inputs	High	70	50	80	100	75
	Medium	30	50	20	-	25
	Low	-	-	-	-	
Timeliness	High	60	80	100	80	80
	Medium	40	20	-	20	20
	Low	-	-	-	-	

iii) Office of Agriculture and Rural Development of the respective districts should jointly work in the popularization and own the work for further scaling up of the pallas herbicide.
iv) The reasons that could have hindered the sustainable use of the pallas herbicide like cost, technical knowhow and safety issues should be addressed in the popularization.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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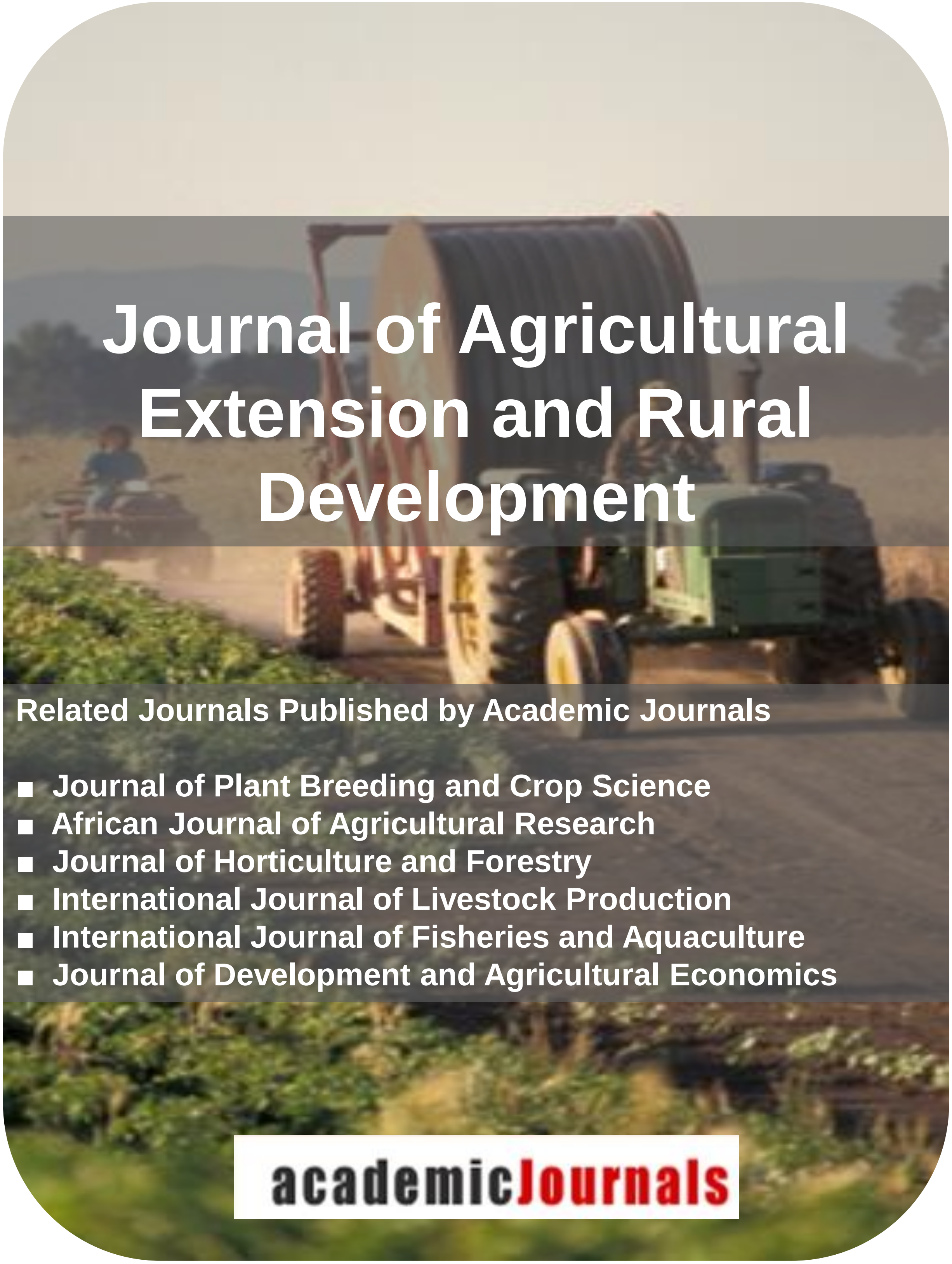

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