Journal of Rural Studies 47 (2016) 220–230

Contents lists available at ScienceDirect

Journal of Rural Studies

journal homepage: www.elsevier.com/locate/jrurstud

Enhancing resilience of farmer seed system to climate-induced stresses: Insights from a case study in West Nile region, Uganda

Monica K. Kansiime [a, b, *], Astrid Mastenbroek [c]

[a] The Horn Economic and Social Policy Institute (HESPI), P. O. Box 2692 Code 1250, Addis Ababa, Ethiopia
[b] CAB International, P. O. Box 633-00621, Nairobi, Kenya
[c] Wageningen University and Research Centre, Centre for Development Innovation, P. O. Box 88, 6800AB Wageningen, The Netherlands

ARTICLE INFO

Article history:
Received 24 March 2016
Received in revised form
21 June 2016
Accepted 9 August 2016
Available online 17 August 2016

Keywords:
Adaptation
Drought
Farmer-saved seed
Local Seed Business
Socio-ecological factors

ABSTRACT

Given the challenges facing African agriculture resulting from climate-induced stresses, building resilience is a priority. Seed systems are important for enhancing such resilience as seed security has direct links to food security, and resilient livelihoods in general. Using data from a case study in West Nile region in Uganda, we studied practices in farmer seed systems and decisions, particularly in response to climate-induced stress. Results helped to generate recommendations for enhancing seed system resilience. We used social-ecological framework and multinomial logit model to analyze seed systems and factors influencing farmers' decisions about seed use respectively. Farmers ranked drought as the most important climate factor affecting crop production. With over 50% of farmer seed sourced on farm, the effect of climate factors on seed system functioning was perceived in relation to diminishing levels in quantity and quality of yield. Decline in yield affected farmer seed saving, increased grain prices due to high demand, affecting seed availability and affordability. The relative importance of seed sources varied during normal and stress periods, and by crop. Farmers tended to shift from farm-saved seed to social networks and local markets during stress periods. Local Seed Businesses emerged as an alternative source of planting material during stress periods. Formal seed enterprises were important in delivering improved seed, especially for maize, though their importance during stress periods diminished. Farmer characteristics and ecological factors played a role in defining the type of seed used, though their significance varied by crop. We recommend an approach that integrates farmer seed systems with the formal system in general, but specifically focusing on strengthening social networks, promoting farmer seed enterprises and crop adaptation practices at farm scale.

1. Introduction

Agriculture is the backbone of most African economies and livelihood of many people. However, agriculture is often characterized by high variability of production outcomes and production risks. Unlike most other entrepreneurs, agricultural producers cannot predict with certainty the amount of output their production process will yield, due to external factors such as weather, pests, and diseases (van de Steeg et al., 2009). The effects of climate change and variability add to the challenges facing agricultural producers in Africa in producing enough food for the growing population. Rapid and uncertain changes in temperature and rainfall patterns markedly affect food production, lead to food price shocks, increase the vulnerability of smallholder farmers and accentuate rural poverty (AGRA, 2014). Crop adaptation, including diversifying agriculture with crops and varieties that can perform better under various climatic stresses and substitution of plant types, is among the most cited strategies for adapting agriculture to climate variability and change (Cooper et al., 2008; Di Falco et al., 2006; Kurukulasuriya and Mendelsohn, 2006; Nzuma et al., 2010). This requires farmers to make decisions on which crops are suited to their environments. Seed systems play a crucial role in providing farmers with access to adaptable crops and varieties, and the flexibility of obtaining seed when required.

A seed system is the economic and social mechanism by which farmers' demands for seed and the various traits they provide are met by various possible sources of supply (Lipper et al., 2010). Two different types of seed systems (i.e. formal and informal) are widely

* Corresponding author. CAB International, P. O. Box 633-00621, Nairobi, Kenya.
E-mail address: monkansiime@yahoo.co.uk (M.K. Kansiime).

http://dx.doi.org/10.1016/j.jrurstud.2016.08.004

known (Almekinders and Louwaars, 1999). The formal seed system is characterized by a clear chain of activities, usually starting with plant breeding and promotion of materials for formal variety release and maintenance. Regulations exist in this system to maintain variety identity and purity as well as guarantee physical, physiological and sanitary quality. Seed marketing takes place through officially recognized seed outlets, and by way of national agricultural research systems (Louwaars, 1994; Subedi et al., 2013).

The informal seed system on the other hand embraces most other ways in which farmers access seed. The same functions of selection, multiplication, dissemination and storage take place in the informal system as in the formal, but they take place as integral parts of crop production rather than as discrete activities (Sperling et al., 2013). There is a growing recognition of a third type of seed system, the intermediate seed system (Subedi et al., 2013). This system is characterized by entrepreneurial farmers and farmer groups that produce and market crops that are not covered by the formal seed system. In Uganda these groups are called Local Seed Businesses (LSBs) that produce Quality Declared Seed (QDS), which is inspected by the Ministry of Agriculture, but sold within their communities.

In this paper we use the term farmer seed system to encompass both the informal and intermediate system, where farmers have direct control over seed selection, production, quality and distribution. We focus on farmer seed system because of its significance in providing seed to smallholder farmers in Africa. McGuire and Sperling (2016) estimate that farmers in Africa access 90.2% of their seed from informal systems with 50.9% of that derived from local markets. In Uganda, farmer seed systems provide more than 80% of seed required by farmers (Ferris and Laker-Ojok, 2006; Gareeba-Gaso and Gisselquist, 2012; ISSD Uganda, 2014), and play a key role in multiplying planting material for vegetatively-propagated crops and seed of self-pollinated crops, for which it is easy to maintain genetic purity through successive generations. In contrast, formal enterprises are constrained by narrow crop choice and affordability (Sperling and McGuire, 2010), and are considered particularly weak in high stress areas (Tripp, 2001). This puts farmer seed systems at the heart of strategies for coping with stress. However, being integral to farmers' crop production, farmer seed systems are affected by the same factors as crop production. There is therefore need to enhance resilience of farmer seed systems to continue to provide the required seed at the right time. Resilient seed systems have the capacity to absorb shocks, and reorganize to maintain seed security over time (Cabell and Oelofse, 2012; Walker et al., 2006), which has direct links to food security and resilient livelihoods in general (McGuire and Sperling, 2011).

This paper focuses on understanding practices and decisions in farmer seed systems, particularly in response to climate-induced stresses. Specifically the study analyses; i) farmers' perceptions of climate variability, and effects on crop production and seed systems; ii) the role of farmer seed systems in meeting farmers' needs for planting materials both in normal season and during unexpected stress; and iii) the influence of social-ecological factors on farmers' decisions to use specific seed types. Key result of the analysis provide strategic inputs for recommendations for enhancing resilience of farmer seed systems to common stress factors faced by farmers. Given the diversity in farming systems in Uganda, insights from Uganda are relevant to a number of Sub-Saharan farming systems.

2. Methodology

2.1. Study area and sampling design

We used a case study research design, in order to get in-depth insights of practices in farmer seed systems, particularly in response to unexpected stress. The case study was conducted in West Nile region in Uganda. Average rainfall in the region is 1259 mm with high variability, from about 800 mm within the Lake Albert basin to about 1500 mm over the western highlands (Zombo), with good to moderate rated soils. Most of the agricultural production occurs in a single rainy season of about 8 months, from late March to late November with the main peak from August to October and a secondary peak in April/May (MAAIF, 2010). Crop farming combines both annual and perennial crops often in intercrops. The main food crops are cassava, maize, beans, banana, simsim, sorghum and rice, while major cash crops are tobacco, coffee and cotton. The region comprises 8 districts distributed across three livelihood zones (FEWS NET, 2010). Livelihood zones group together people who share similar options for agricultural production, securing cash income, accessing markets, and exposure to production risks, which is related to geographical location. Table 1 shows the major livelihood zones in West Nile and biophysical characteristics.

In order to capture diversity of farming systems in the region, we sampled one district per livelihood zone for the study (see Table 1). We then purposively selected one sub-county per district, targeting areas with operational Local Seed Business (LSBs) supported by the Integrated Seed Sector Development (ISSD) Uganda program. In each of the LSB locations, we conducted Participatory Rural Appraisal (PRA) exercise. Four PRA tools were used - resource mapping, time line creation, seasonal calendar and matrix ranking. These helped to gain a deep understanding of key resources in the community, trends and variability in climate, community perceptions on occurrence of shocks, adjustment in farming practices in response to climate variability, and possible actions to respond to production stresses. PRAs had mixed gender and age categories which helped to understand perceptions of different social categories with regard to the research questions.

Further to PRA, we randomly sampled 90 farm households (see Table 1) and conducted a household survey. The sampled households were not necessarily LSB members, nor those that had participated in the PRA exercise. We used a computerized system of data collection whereby enumerators directly captured information using mobile phones during data collection. The mobile phone application was loaded with a data entry application with in-built range and consistency checks to ensure good quality data. The Team Leader ran checks on data while still in the field thereafter electronically transmitting it to the online web console at ISSD (powered by Mobenzi Researcher). We collected information on household characteristics, cropping activities, farmers' perceptions of climate variability (occurrence of climate extremes, effect on crop production and coping measures), seed system functioning (sources of seed during normal or unexpected stress periods & perception of reliability of seed sources) and perceptions on varietal uniqueness. Fig. 1 shows the map of West Nile region and sample sub counties.

2.2. Theoretical framework

Several approaches for analyzing seed systems have been employed in research (for example, Hirpa et al., 2010; Jones, 2013; Remington et al., 2002; Weltzien and vom Brocke, 2001). These approaches generally suggest analyzing seed systems by focusing on their functions - seed quality, appropriateness of variety, timeliness of seed availability, conditions under which seed is available, and capacity to innovate. However, farmers in many developing countries are often unable to obtain healthy viable seed of preferred varieties at the time and under conditions that are best for them. McGuire (2001) describes this in terms of the health of

Table 1
Characteristics of areas selected for the study and sample size.

Livelihood zone	Biophysical characteristics	Sample district (sub-county)	Respondents
West Nile Arabica Coffee and Banana Zone	Bimodal rains 1400–1600, clay soil with medium organic matter. Highland ranges, with an elevation of 1478 m.a.s.l and population density of 244.9 persons per sq. km.	Zombo (Atyak)	30 household interveiws, one PRA (17 male and 12 female)
West Nile Tobacco, Cassava and Sorghum Zone	Moist savannah grasslands, with bimodal rains averaging 1229 mm, soils are sandy clay loam and clay loam with low organic matter. Elevation is 1059 m.a.s.l. with population density of 240 persons per sq. km.	Arua (Vuura)	30 household interveiws, one PRA (25 male and 7 female)
North Kitgum-Gulu-Amuru Simsim, Sorghum and Livestock Zone	Bimodal rains averaging 1259 mm, sandy clay loam and sandy loam with low organic matter. Para-savannahs and low land areas with an elevation of 948 m.a.s.l. and population density of 177.2 persons per sq.km.	Nebbi (Wadelai)	30 household interveiws, one PRA (14 male and 10 female)

Source: Adapted from FEWS NET, 2010.

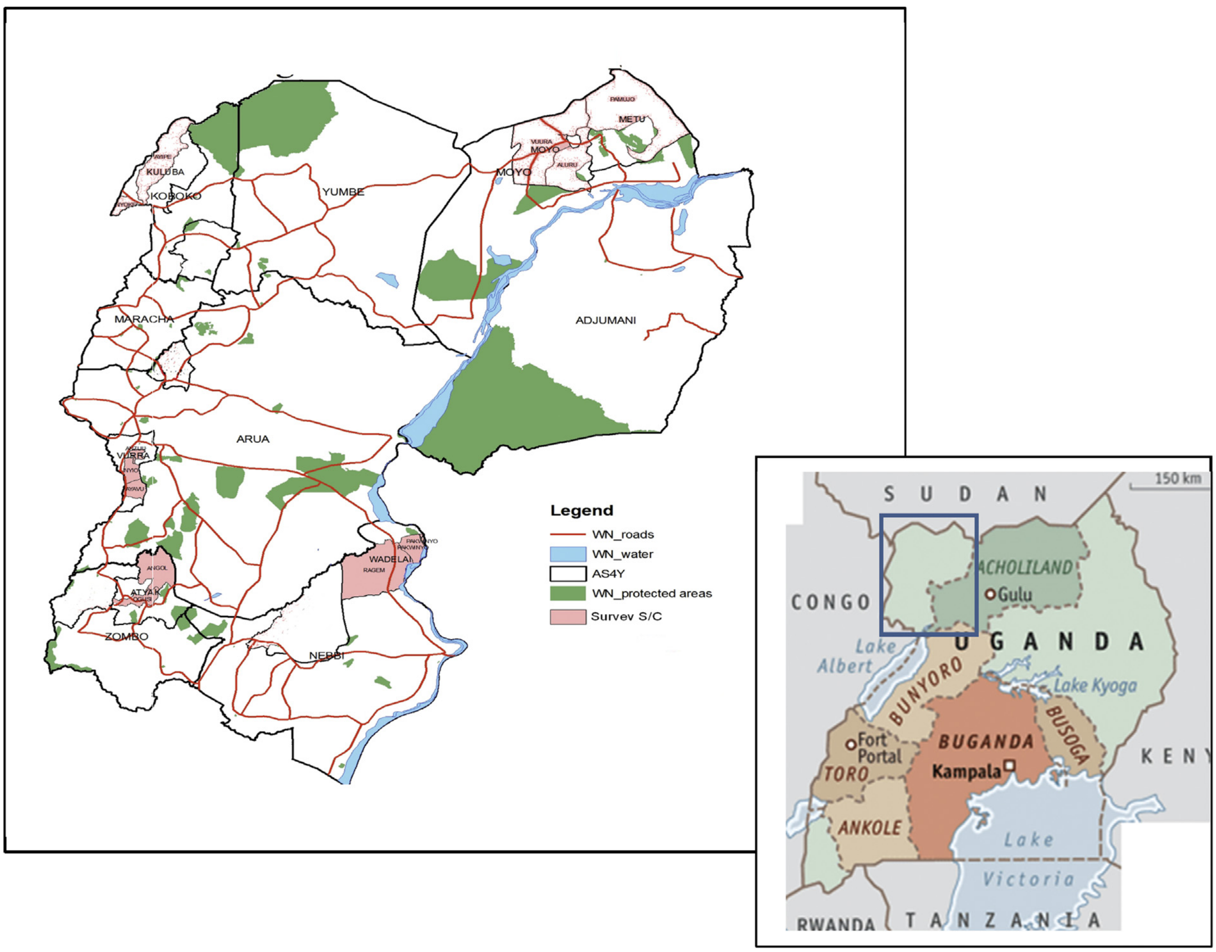

Fig. 1. Map of Uganda showing West Nile region and sample sub counties.
Source: Adapted from AS4Y project and online resources.

the seed system and whether particular systems are under stress. This implies that seed system resilience is also determined by socio-ecological systems.

This study therefore employed a framework that combines both social and ecological approaches to analyze seed systems resilience (McGuire and Sperling, 2013). Socio-ecological approaches focus on understanding the dynamic interrelations among various personal and environmental factors, paying attention to the social, institutional, and cultural contexts of people-environment relations. Resilience refers to the amount of disturbance a system can withhold before shifting to a different regime (Walker et al., 2006). Two aspects are integral to seed system resilience; adaptability of the seed system (i.e. how actors in the system manage resilience), and transformability (i.e. ability to create a complete new system if the old one is unattainable). We tested the hypothesis that farmers' social-ecological characteristics influence their decisions about the type of seed and exchange mechanisms they use.

2.3. Analytical methods

Seed system analysis involved assessment of seed access, availability and utilization. First, we classified different seed sources used by farmers as either formal or informal (Sperling, 2008). We assessed seed sources both in normal and stress periods, and farmers' reasons for using different sources. Then, we assessed how farmers acquired seed for various crops and varieties (whether purchased, exchanged or obtained for free). Lastly, we classified different crop varieties used by farmers as either local, improved or farmer-recycled (Westengen and Brysting, 2014), based on information provided by households. This helped to understand the traits farmers look for and how these relate to seed sources and climate perceptions. Improved seed/varieties were defined as something new, brought from outside. If farmers like the variety, they will recycle it and continue to use it. It becomes part of the community genetic resources and is described alongside local varieties. Most times, these recycled improved varieties receive local names, describing their main traits. Thus recycled varieties were defined as improved varieties re-used on farm for two or more seasons. Local varieties on the other hand, were classified as farmer varieties that have been around for a long time and have well defined characteristics. They included landraces and creolized improved varieties.

Using multinomial logit model, we analyzed factors influencing farmers' decisions about seed type to use. The dependent variable (seed/variety type) was defined as farmer utilization of each group of varieties - local, improved or farmer-recycled. This was coded as binary variable where presence of variety type was coded as one, and zero, otherwise. Given that the dependent variable has more than two alternatives among which the decision maker has to choose, the appropriate econometric model would either be multinomial logit or multinomial probit regression model. This study employed the multinomial logit model because of its documented superiority and ease of computation (Greene, 2003). The independent variables included; individual characteristics (sex, age, education and farming experience of the household head, farm size), institutional support services (extension, credit and market information), farmers' perception of variety characteristics (marketability, yield potential, climate adaptability), ecological factors (farmers' perceptions of climate factors), and the seed system where the particular variety was accessed (farmer or formal).

Probability of a farmer i's choice of variety type j, was estimated using multinomial logit model as in equation (1) (Greene, 2003).

$$P_{ij} = \frac{e^{X_i\beta_j}}{\sum_{j=1}^{j} e^{X_i\beta_j}}, \quad \text{for } j = 1\ldots3 \tag{1}$$

Where P_{ij} is the probability representing the ith farmer's chance of using seed type j, X_i represents a set of explanatory variables, e is the natural base of logarithms, and β_j are parameters to be estimated by maximum likelihood estimator (MLE). The estimated equations provide a set of probabilities for the $j + 1$ choice for a decision maker with X_i characteristics. For identification of the model, there is need to normalize by assuming $\beta_0 = 0$. Thus the probabilities are given by equations (2) and (3):

$$\text{Prob.}\left(Y_i = {}^{j}/_{X_i}\right) = P_{ij} = \frac{e^{X_i\beta_j}}{\sum_{j=2}^{j} e^{X_i\beta_j}}, \text{ for } j > 1 \tag{2}$$

$$\text{Prob.}\left(Y_i = {}^{1}/_{X_i}\right) = P_{1j} = \frac{1}{1 + \sum_{j=2}^{j} e^{X_i\beta_j}}, \text{ for } j > 1 \tag{3}$$

The marginal effects of explanatory variables on probabilities are specified as:

$$\Delta ij = \frac{\delta P_{ij}}{X_i} = P_{ij}\left[\beta_j - \sum_{j=0}^{j} P_{ij}\beta_j\right] = P_{ij}\left[\beta_j - \beta^-\right] \tag{4}$$

In these models the log odds type of variety used were modeled as a linear combination of the explanatory variables. Our analysis was structured along three key crops – cassava, maize and beans. These were identified during the study as the most commonly grown crops in the region, also with national/regional relevance. Focus on different crops helped unleash seed system issues that may pertain to a particular crop/variety. Our analysis largely used farmers' perspectives for identification of specific seed systems strengths and weaknesses.

3. Results

3.1. Farmer perceptions of climate variability and effects of crop production and seed systems

All the respondents (100%) from the household survey indicated that they had observed climate variability. The most commonly mentioned climate factors by farmers were; prolonged droughts, pests and diseases and too much/too little rainfall (Table 2). Drought, and pests and diseases were particularly more common in Arua, compared to the other study locations, while too much rainfall (heavy and erratic) was mostly reported by farmers in Nebbi and Zombo. The heavy and erratic rainfall also led to flash floods, particularly in Nebbi because it's low lying. Farmers reported experiencing prolonged droughts, which reduced the length of growing seasons, particularly the first season which had reduced to just two months – April and May. Moreover, rainfall in these months was perceived to have reduced compared to 15 or so years ago. Across sample districts, significant ($p < 0.1$) differences were observed in farmers' perceptions of occurrences of droughts, floods and delays in rainfall. The difference in farmer perceptions could be due to differences in cropping patterns and livelihood strategies in the respective locations.

We further established the importance of the various climate factors, according to farmers' perspectives. Survey respondents ranked the perceived climate factors based on frequency of occurrence and level of impact on crop production. Drought, too much rain and delayed rain were ranked as the most important climate factors (Fig. 2). Subjective ranking by PRA participants indicated similar results, where farmers ranked drought as the most important climate factor affecting their farming operations.

Farmers perceived the impact of climate variability on crop production and seed systems in relation to failed or successful crop yields. Changes in climatic conditions influenced the cropping cycle – field preparation, planting and field management practices, and subsequently the expected yield. Low or poor yields affected the amount and quality of seed farmers saved for subsequent planting seasons. Grain shortages also led to increased demand for food, as such grain prices tended to increase particularly at planting time. This affected farmers' access to seed from market sources.

3.2. Coping mechanisms

Farmers practiced a wide range of coping activities. Majority of the farmers mentioned early land preparation and planting, changing sowing dates, introducing drought resistant crop varieties, growing crops in swamps or near river banks, and growing early maturing crops/varieties (Table 3). Coping mechanisms differed slightly by study location, attributed to different farmer perceptions on climate variability and importance of climate

Table 2
Farmer perception of climate variability.

Climate factors	% of respondents reporting climate factor			Pearson χ^2 (2)	P value
	Arua (n = 30)	Nebbi (n = 30)	Zombo (n = 30)		
Too much rainfall	38	50	48	1.085	0.581
Little rainfall	34	43	33	0.725	0.696
Delayed rainfall	9	17	29	3.333	0.089
New pests and diseases	59	50	43	1.447	0.485
Flash floods	9	43	0	18.188	0.000
Drought	91	60	62	8.763	0.013
Shorter season	38	43	24	2.082	0.353
Longer season	13	20	14	0.700	0.705
Others	9	17	29	3.333	0.189

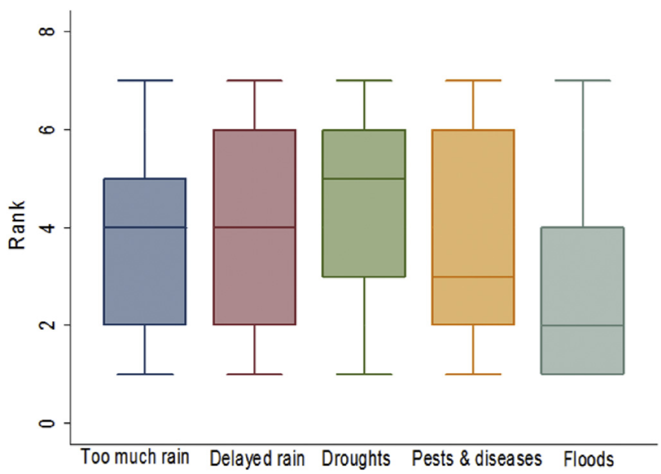

Fig. 2. Box plot with mean (middle line), quartiles (boxes) and variability outside the upper and lower quartiles (whiskers). Climate factors ranked from 7 (worst) to 1 by households in West Nile region (n = 90).

factors. In Arua, majority of farmers mentioned changing sowing dates, early planting and drought tolerant crops as the key coping measures, in response to prolonged droughts and increased pest incidences. Growing crops in swamps and along river banks was more common in Zombo, mainly in response to prolonged droughts, but also because Zombo is characterized by large swamps and water streams that farmers easily capitalized on to access water for production. We also noted a number of farmers, (over 30%) who indicated that they did not do anything to cope with climate variability. These farmers indicated that in cases of extreme weather events, they would not plant anything but rather wait for the following season.

Responses from PRA participants indicated similar coping measures. Farmers gave examples of crops with known tolerance to droughts such as sorghum, millet, cassava (particularly NASE 14 and TME 14), sweet potatoes and bananas. They also included early maturing crops like cowpeas (*Boo*) and jute mallow (*Otigo*). Use of improved varieties of seed and tubers was supported in many cases by the government in collaboration with other agencies (AGRA and DANIDA were mentioned by farmers). Seed related strategies employed by farmers (only mentioned by PRA participants) included, increasing seed density (seed rate), changing crop varieties and changing crop association (crop mix in an intercrop). Increasing crop density was linked to continuous planting, mixed cropping and re-planting practices which were common, aimed at increasing chances of getting harvest even under climatic stresses. Farmers also deliberately sowed more seed per area with hope that at least some seed would germinate even if the onset of rains was not timely.

3.3. Seed system performance

3.3.1. Seed access

We asked farmers their most common sources of seed for cassava, maize and beans, and proportion of seed they obtained from each source. While farmers obtained seed from multiple sources, farm saved seed dominated, providing between 49% and 69% of farmers' seed (Table 4). Local market played a key role in providing seed for beans and maize, supplying on average 43% and 20% respectively. Local markets sell grain that farmers plant as seed. Though it was noted from PRA exercise that at planting time, local markets tend to distinguish grain suitable for planting from that for consumption, and usually the price will differ with the former priced higher. Asking seed from neighbors as gifts, was a fairly important channel for cassava besides farm-saved, while agro-dealers played a fair role as source of maize seed. Other seed

Table 3
Coping mechanisms employed by farmers in the study areas.

Coping mechanisms	% of farmers mentioning coping mechanism[a]			
	Arua (n = 30)	Nebbi (n = 30)	Zombo (n = 30)	Overall sample
Grow drought tolerant crops (e.g. cassava, millet, sorghum)	34	30	10	27
Grow crops in swamps and along river banks	19	17	43	24
Grow water tolerant crops (e.g. rice, bananas, yams)	3	23	5	11
Early land preparation and planting	44	30	19	33
Grow pest resistant crop varieties	6	3	5	5
Introducing other crop varieties	3	10	–	5
Use of water ways to divert excess water	6	13	–	7
Grow crops in upland areas in case of flash floods	–	7	–	2
Grow early maturing crops (e.g. vegetables)	22	3	10	12
Changing sowing dates	41	27	29	33

[a] Multiple responses possible.

Table 4
Farmers' source of seed during normal season and periods of stress (n = 90).

Farmers source of seed[a]	During normal season (%)			During stress or unexpected shock (%)		
	Cassava	Maize	Beans	Cassava	Maize	Beans
Farm saved	69	55	49	10	19	3
Local market	8	20	43	22	41	69
Neighbors as gifts	14	6	2	51	24	18
Agro-dealer	0	14	3	0	8	5
Local Seed Business (LSB)	3	0	1	7	0	2
Government/research	6	4	1	8	6	3
NGO project	0	1	0	2	2	0
Barter/exchange	0	0	0	2	2	3
% formal	6	18	5	8	14	8
% informal	93	82	95	92	86	92

[a] Seed source is given as percentage of total seeds reported for the crop. Seeds from agro-dealer and government provision were classified as formal channels, and the rest as informal.

sources included Non-Governmental Organisation (NGO) project, government, local seed businesses and barter with neighbors. Taken together, informal system supplied more than 80% of seed for cassava, maize and beans.

During stress periods, the informal seed system still supplied most of the seed used by farmers. However, quantities obtained from farmer-saved seed reduced substantially, increasing the role of local market and gift seed from neighbors. At least 10% and 19% of seed for cassava and maize respectively was still obtained from own sources, even during stress periods further confirming the importance of farm-saved seed. Government played an increasing role in supplying seed/planting material for all crops, though proportions still remained less than 10% of farmers' seed requirement. Local seed businesses also played an increasing role in supplying cassava planting materials.

3.3.2. *Seed availability*

Farmers were asked if they had access to sufficient quantities of planting material, obtainable within reasonable proximity and in time for critical sowing periods. At least 39% of farmers indicated that seed was easily available and enough, while 47% indicated that seed was moderately available and just sufficient (Fig. 3). A small proportion (14%) indicated that seed was less available and not enough. Seed availability also varied by crop with much more less availability for maize compared to for example cassava and beans. The commonly cited reasons for lack of seed were; droughts, lack of money, and pests and diseases (Fig. 4). Drought affected crop growth and subsequently the quantity and quality of grain and seed available. Lack of money or disposable income hindered access to seed especially for crops where market sources played a role in providing seed e.g. maize and beans. High demand for food was also mentioned by farmers as an important factor affecting seed availability, as food takes precedence over seed saving. Farmers indicated that produce was normally sold away immediately after harvest due to high demand for food and need for immediate cash to cater for other household needs. A small proportion of farmers indicated that maize seed was not available because of agro-dealers being located far away, yet improved (hybrid) maize varieties could not easily be recycled.

3.3.3. *Seed utilization*

We assessed the type of seed used by farmers for cassava, maize and beans. Use of local varieties dominated for cassava (49%) and beans (52%), while for maize use of recycled varieties (43%) dominated (Fig. 5). Interestingly, use of improved seed was higher for beans (24%) compared to either maize or cassava (21% and 13% respectively), despite the fact that farmers sourced most of their bean seed from local market. Farmers indicated that some of the improved bean seed varieties were initially distributed by government programs (especially the National Agricultural Advisory Services – NAADS). Much as farmers have recycled these varieties over time, they are distinctly different in size, color and shape and have desired attributes that make them more preferred than local varieties. Farmers therefore reported use of improved bean varieties in relation to their local varieties/landraces, but are technically farmer recycled varieties.

Farmers' reasons for cultivating different genetic resources and their perceptions of variety attributes showed that most commonly grown crop varieties combined attributes of high marketability, climate adaptability and better yield (see Fig. 5). Farmers perceived local cassava varieties to be highly marketable, while improved and recycled varieties presented better attributes with regard to yield and adaptability to climate related stresses. For maize, improved varieties were considered to be higher yielding and more adaptable than the other seed types, though farmers ranked then slightly lower in terms of marketability. While majority of bean growers used local varieties, they rated them low in terms of the studied varietal attributes, compared to improved or recycled varieties. Recycled bean varieties on the other hand, were rated as more yielding, adaptable and marketable compared to local varieties.

3.4. *Social and ecological factors affecting farmer's choice of type of seed*

Multinomial regression of reported variables by farmers showed that individual, institutional and ecological factors to a great extent

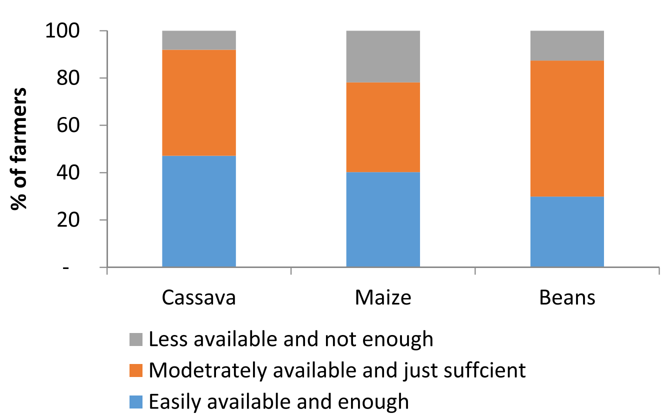

Fig. 3. Farmers' perception of seed availability for cassava, beans, and maize (n = 90).

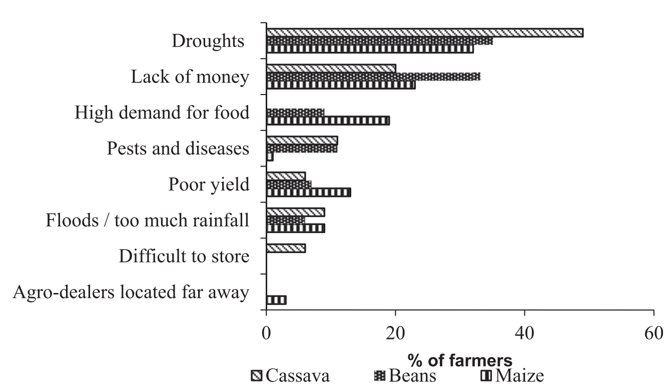

Fig. 4. Farmers' reasons for low seed availability (n = 90).

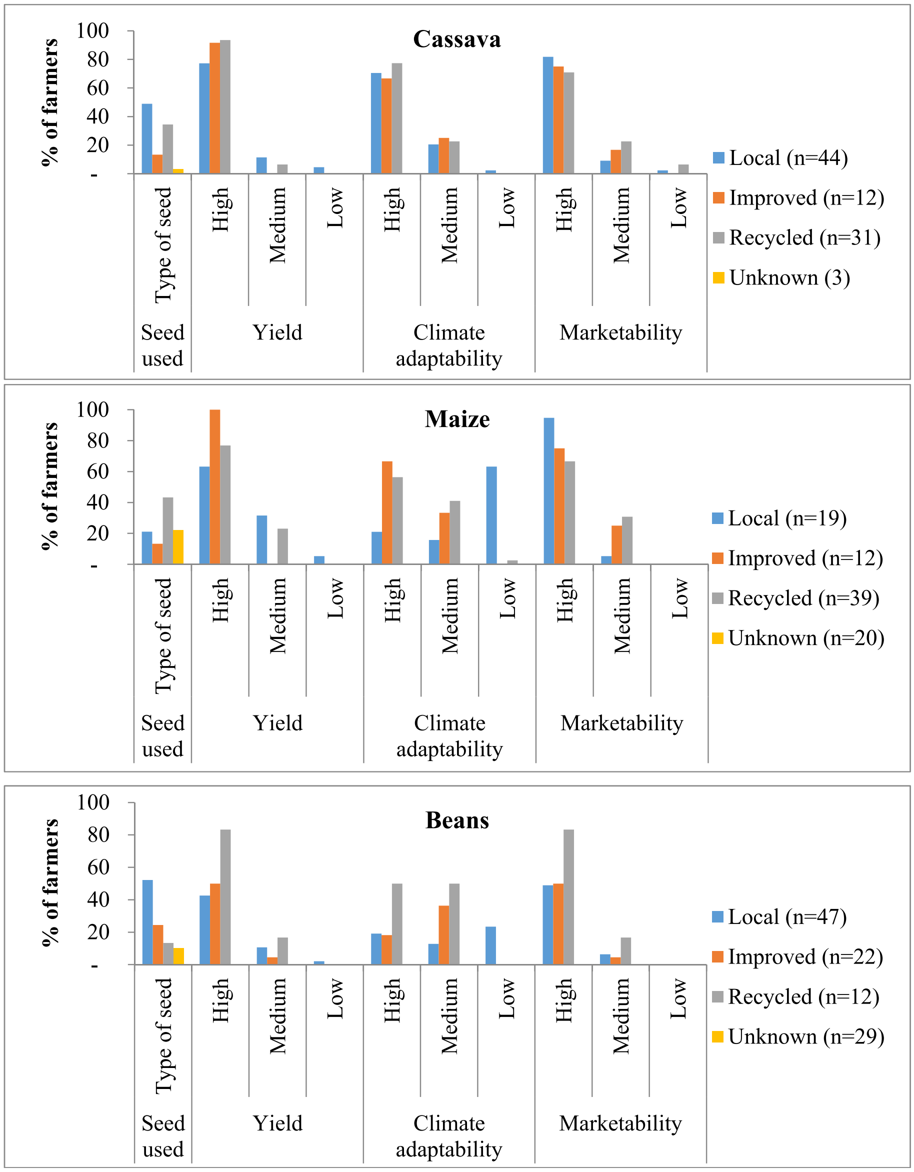

Fig. 5. Variety uniqueness by type of seed (as a proportion of farmers using a particular seed type) (n = 90).

explain the type of cassava, maize and bean varieties used by farmers (Table 5). Individual characteristics – education and age of household head were associated with increase in the relative odds of using improved and recycled cassava varieties compared to local varieties. This implies that increase in education and age would be associated with higher probability of a farmer using either improved or recycled varieties of cassava. Farming experience was more likely to increase the probability of using improved or recycled bean varieties compared to local varieties.

Farmers' access to different sources of seed played an important role in the type of variety they used. Use of farmer-saved seed was negatively related to farmers' use of improved varieties of cassava, beans and maize, compared to local varieties. This is rather obvious since farmer-based systems generally supplied local varieties or improved recycled varieties. This then means that if farmers were able to access other seed sources, they would likely use improved varieties. Access to extension services and market information were more likely to result in positive impact on use of improved cassava varieties, but less likely to influence utilization of improved maize or beans varieties in comparison to local varieties.

Perception of cassava marketability reduced chances that farmers would use recycled varieties and showed negative but not significant effect on use of improved varieties compared to local varieties. This implies that farmers' perception of cassava marketability was associated with local varieties. Local varieties were also assumed to have better taste than improved varieties, though they were considered highly susceptible to pests and diseases. For maize, on the other hand, farmers' perception of marketability, yield and adaptability increased the chance of using recycled varieties compared to local varieties. Variety characteristics had no significant influence on the probability of farmers using any type of variety for beans.

Farmers' perception of more drought incidences reduced the chance of growing improved or recycled cassava varieties compared to local varieties, while perception of higher incidence of crop pests and diseases significantly reduced the chance of using improved or recycled bean varieties compared to local varieties. Under drought conditions, farmers were more likely to use local

Table 5
Factors affecting farmers' choice of seed type, reported by households in West Nile (N = 90).

Variety type[a]	Cassava		Beans		Maize	
	Improved	Recycled	Improved	Recycled	Improved	Recycled
Individual characteristics						
Gender (Male = 1, Female = 0)	−0.853	−1.941**	−1.206	−1.573	−44.232	−11.897
Farming experience (Number of years)	−1.123	−0.451	2.879**	1.648*	13.958	4.989
Education (Categorical)[b]	1.118*	0.805*	0.211	1.733*	37.670	5.471
Age (Chronological age)	1.391*	1.155*	−2.552**	0.123	−33.880	−7.093
Farm size (Acres)	−0.072*	−0.032	0.238	0.035	2.003	0.381
Institutional factors						
Credit (Yes = 1, No = 0)	1.181	0.132	0.075	−0.189	−37.912	−3.115**
Extension (Yes = 1, No = 0)	17.152	1.873**	−0.240	2.286	−4.766	2.723**
Market information (Yes = 1, No = 0)	16.567	0.359	−0.339	−2.003	7.353	0.042
Seed system (Farmer-saved = 1, other = 0)	−1.121*	0.836*	−2.930*	1.577	−74.535	−4.268*
Variety characteristics						
Marketability (High = 1, Otherwise = 0)	−2.669	−2.203*	22.365	0.834	−36.617	2.925*
Yield (High = 1, Otherwise = 0)	16.803	3.522**	19.373	−0.023	95.732	2.820**
Adaptability (High = 1, Otherwise = 0)	1.182	−0.866	−0.599	0.764	12.043	7.607*
Ecological factors (farmers' perceptions of)						
Prolonged droughts (Yes = 1, No = 0)	−3.215**	−2.008**	−0.261	−1.109	−45.644	3.065
Too much rainfall (Yes = 1, No = 0)	−2.639	0.223	−0.900	−1.485*	7.771	−0.517
Increased pests and diseases (Yes = 1, No = 0)	−1.370	−1.033	−1.727**	−1.662**	16.913	−2.522
More frequent floods (Yes = 1, No = 0)	−17.466	1.841*	−14.117	−13.941	33.209	−19.117
Shorter seasons (Yes = 1, No = 0)	−2.927	−0.884	−0.566	−1.207	−3.755	−11.974
Constant	−62.326	−3.391*	−44.154	−11.594**	−45.786	−4.648
Observations	90		90		90	
LR Chi^2	78.21		158.59		215.60	
Prob > Chi^2	0.000		0.000		0.000	
Log likelihood	−44.635		−28.417		−6.402	
Pseudo R2	0.467		0.736		0.944	

Reported figures are coefficients from the MNL model.
Significance: ***<0.001, **$p < 0.05$, *$p < 0.1$.
[a] Varieties were categories into Local = 1, Improved = 2 and Recycled = 3. The multinomial logistic regression set the base outcome as Local varieties.
[b] None = 1, Primary = 2, Secondary = 3, Tertiary = 4, Adult learning = 5.

varieties for beans and cassava, compared to improved varieties. A possible explanation would be that farmers considered their local cassava and bean varieties to be more adaptable to drought and pests respectively, based on their experience with these varieties and the confidence they have gained over time using them. Similarly, farmers were able to retain and recycle improved varieties that showed preferred characteristics, particularly tolerance to both biotic and abiotic stresses. On the other hand, perception of climate factors showed no significant influence on the type of maize variety farmers used.

4. Discussion

4.1. Climate variability and seed systems perspective

Farmers in West Nile region indicated that local climate had altered, with drought, too much and delayed rainfall ranked the most important climate factors affecting crop production and seed systems. Problems of availability and access to water for production and seasonal variability were considered worse than biotic stresses caused by crop pests and diseases. Moisture availability affects crop growth cycle, crop yield and quality. Halweil (2005) also reports that old patterns of rainfall and temperature are shifting, due to more erratic weather and shifts in the length of the growing season. Several studies in Africa have reported the direct effect of changes in precipitation and temperatures on food production, where yield decreases of up to 50% have been predicted (for example Agrawala et al., 2003; Brown and Crawford, 2007). Ferris (1999) reports a 15–35% global yield variation in wheat, oilseeds, and coarse grains, as a result of El Nino's Southern Oscillation phenomenon, with its associated cycles of droughts and flooding events. Similarly, studies conducted in Uganda indicate that increasingly unpredictable weather has led to poor yields and food insecurity, leading to poverty (Osbahr et al., 2011; Oxfam, 2008).

Variability in climate factors directly affects seed quality and availability. For example, heat stress increases the percentage of shriveled seed and decreases seed size (Prasad et al., 2003). Increased levels of pests and diseases, intense and frequent rains, and changing seasons compromise the level of viability of seed and crop performance, all leading to poor yields. This affects seed saving or seed gifting since farmers may not have adequate grain to satisfy their immediate consumption requirements. Low crop production also affects grain prices, making farmers' seed access from local markets unaffordable at the time of planting due to high demand. As such, households may lack sufficient seed to (re)sow, may only have poorly-adapted or unhealthy seed, or need to sacrifice other productive assets to obtain off-farm seed (McGuire, 2007).

Farmers employed several coping measures aimed at enhancing their crop production. Early land preparation and planting and changed sowing dates were the most commonly mentioned coping measures. These measures ensure more effective use of precipitation available during the season such that yields are optimised. Changing the timing of farm operations has potential to maximise farm productivity during the growing season and avoid heat stress during times of increased climate perturbations (Smit and Skinner, 2002). Kansiime et al. (2014) also report that changing sowing dates reduces risk of crop production, though does not necessarily affect mean crop yield.

Seed related strategies most commonly used by farmers were, increasing seed density/seed rate, changing crop varieties and changing crop association. Increasing seed density has implications on the quantities of seed used by farmers, as this tends to increase farmers' seed requirements. This also implies that seed should not only be available at planting time, but even during the growing season because farmers may need to re-sow if their seed failed to germinate. Much as farmers mentioned changing crop varieties, there was no deliberate introduction of new crops and varieties, but rather farmers exploited crops with known tolerance to droughts e.g. cassava, millet, sorghum and bananas. Cassava is a major food and cash crop in West Nile and substantial research has been done to develop varieties that are suited to the climate conditions and also tolerant to pests and diseases. Notable is the work of the National Agricultural Research Organisation (NARO) and the East Africa Agricultural Productivity Programme (EAAPP) to develop a center of excellence for cassava in Uganda targeting mainly West Nile and Northern agro-ecologies. Sorghum and millets are drought tolerant and have proved to be important crops especially in the semi-arid areas of Africa (Wambugu and Mburu, 2014). Similarly, bananas have ability to withstand dry spells. According to Jassogne et al. (2013) the permanent canopy, root systems, and mulch from the banana plants prevent soil erosion and degradation, thus making the crop more adaptable to climate variations.

4.2. Social-ecological factors and seed systems performance

Farmers obtained seed from multiple sources, often dominated by farm-saved seed. Multiple sources provide options which allow farmers to shift crop or variety portfolios in response to changing conditions (McGuire and Sperling, 2013). The relative importance of seed sources varied markedly during normal and stress periods, and by crop. This can be explained by social-ecological factors, which show how multiple levels of influence condition farmers' behaviors and decisions about seed types to use, and thus the functioning of the entire seed system. The levels of influence include intra- and interpersonal, varietal, institutional, and environmental, which directly affect seed availability, access and utilization, and farmers' decisions on seed type to use.

For example, for cassava, farmers' own stock and social networks dominated as sources of planting materials. This is partly due to social beliefs that planting material for vegetatively-propagated crops (VPCs) should be shared freely, but also due to limited market options for planting materials for VPCs (McGuire and Sperling, 2016). Farmers' perception that local cassava varieties has more desirable attributes in terms of yield, market and adaptation to climate factors could also explain their reliance on local seed networks for cassava planting materials. On the other hand, the formal seed system for cassava in Uganda is entirely public. National Research Systems have invested heavily in breeding varieties that are drought and disease resistant (in particular brown streak and mosaic virus), which are disseminated through government and NGO distribution programmes. If these varieties are appreciated, they are maintained by farming communities or taken up by local seed businesses for further multiplication. This justifies the increasing role of local seed businesses and farmers' use of recycled and improved cassava varieties.

For beans on the other hand, farmers mainly relied on farm saved and local markets, though the latter was more pronounced during stress periods. Bean seed from home-saved seed dropped to less than 5% during stress periods, and the gap filled by local markets. Given the fact that beans are important food in the region, sharing beans for purposes of planting gradually reduces during stress periods in preference for food. Seed exchange and gift-giving among farmers has also been noted to decline, as commercial transactions rise in importance (Rubyogo et al., 2010). In such situations, farmers may opt to use market sources to fill an immediate gap in seed supply (McGuire, 2007). The bean seed gap seems not yet filled by intermediate and formal seed systems. The formal system has not found bean seed to be lucrative because of its low multiplication rate. Also the low rate of bean out-crossing (generally <5%) means that farmers are able to recycle bean seed over time without losing varietal quality (Rubyogo et al., 2010).

Lastly, for maize seed, the formal system provided at least 20% of the seed; 14% through the private sector and 6% through public sector. Seed access from formal sources was higher for maize compared to other crops. This is related to the difficulty of maintaining genetic vigor for maize on farm, especially when farmers grow hybrid varieties. In stressed seasons, seed access from private sector reduced almost by half to 8%, and the gap filled by local markets and free handouts. Farmers' perception that improved varieties (provided by the formal sector) are higher yielding and more adaptable to climate variability, implies that formal seed enterprises could play a larger role in meeting farmers' maize seed requirement.

During stress periods, farmers tended to shift from farm-saved seed to using social networks (gifts from neighbors) and local markets. This justifies the importance of farmer seed networks in ensuring access to seed for seasonal planting, even during stress periods. However, the functioning of farmer seed networks may be weakened because everyone has seed shortfalls particularly after droughts (McGuire, 2007) or due to increasing commercialization, labour migration and livelihood diversification (Bellon, 2004), all of which might affect seed access from networks. This study also reveals that farmers' lack of access to seed was largely attributed to low incomes. The low purchasing power may affect affordability of seed, particularly certified seed from market sources, a situation that may be worsened during stress periods due to reduced household incomes/assets to finance seed purchases. As such, efforts to build resilience of farmer seed systems need to integrate approaches that can address the fragility of farmer seed networks during stress periods, while addressing seed affordability.

4.3. Building resilient farmer seed systems — recommendations

This study has shown that the informal seed system generally provides sufficient planting materials both during normal season and unexpected stress. The shift between good and bad seasons shows longer term resilience of informal seed systems and how farmers shift between multiple seed sources within the informal system. In the short term, the system absorbs shocks by drawing on social stocks, or resorting to market sources. Even for crops where farmers preferred improved varieties, normally supplied by the formal system, there was a strong tendency of shifting to informal seed sources during stress periods. The system renews itself periodically by recycling improved varieties that are perceived to have resilient characteristics. Further enhancing farmer seed systems will ensure that farmers have access to desired varieties at all times. We identified 4 key areas for action to make farmer seed systems more resilient:

Securing access to diverse seed at farm level: In this study, we observe an increasing role of local seed businesses in producing and supplying planting materials especially of cassava at local level. This provides an opportunity to strengthen the intermediate system (farmer seed entrepreneurship) as an alternative source of affordable quality seed of desired varieties by farmers, which could also potentially reduce stress on the neighbors as source of seed during stress periods. Farmer seed enterprises being commercially oriented appear to be sustainable (Anderson and Singh, 1990; David, 2004). Seed entrepreneurship achieves dual objectives; establishment of a regular source of clean seed of both local or modern varieties, and sustainable distribution and promotion of improved crop varieties (David, 2004). Some experiences have been documented in Ethiopia, Ghana, Tanzania and Uganda on farmer seed entrepreneurship with promising results in terms of quantities and quality of seed produced and supplied to farmers (Subedi et al., 2013). Secondly, the Quality Declared Seed (QDS) system could also be allowed for open pollinated maize varieties as the formal seed system is unable to reach the farmers with affordable varieties.

Building stronger social networks: Seed exchange between households depends on the social ties between them, which in some cases may be compromised due to a number of factors. It is therefore important to strengthen leadership and social networks to strengthen adaptability. At the same time, these networks are under pressure when a covenant shock hits the entire community. A communal seed bank where key genetic material is stored in sufficient quantities is one way to strengthen the responsiveness of the system. Another aspect of social capital is trust. To capture new opportunities for intermediate seed systems, social certification could also be allowed in the QDS. Rather than engaging with the formal certification system and all monetary costs associated with it, socially certified seed producers can invest time and resources in their seed production and sell or exchange the seed at a premium with farmers who trust their reputation and shared history as assurance of quality of seed (Sperling and McGuire, 2010).

Enhance formal sector support to provide affordable seed: Farmers' reliance on multiple sources of seed highlights the need for existence of multiple channels from which farmers can make choices based on their preferences. There was evidence of feedback loops where recycling of improved varieties in farmer seed systems was common. The formal seed system (government and private sector) was important in providing the elite materials to farmers and supporting seed replacement on farm. Linking formal and informal seed systems is therefore suggested, presumed to give a degree of stability along with production gains. Louwaars and de Boef (2012), McGuire and Sperling (2013) and Sperling et al. (2013) detail the architecture of how this integration of multiple channels can be achieved in practice. Proposed actions that are relevant to this study include; expanding distribution outlets to more vulnerable locations, changing package size to suit small-scale farmers, and provision of information regarding new and improved varieties. While formal distribution channels are limited by high distribution costs, experience has shown that outlets can be scaled up by building on existing non-seed networks and locations where farmers have access to products, services and information. For example, in Malawi (Sperling et al., 2013) and Kenya (pers. observation), seed sale routinely takes place in supermarkets.

Promotion of drought resistant crop varieties: As with many recommendations on climate change adaptation, crop adaptation is suggested by this study. Researchers need to identify germplasm suited for different climate zones, or different possible conditions that might occur, which can be promoted among farmers. Participatory variety selection with farmers and availing appropriate information about alternative crop varieties will facilitate promotion of such crops amongst farmers. Significant agro-ecological and social variations work against a single crop and variety, requiring building up of physical stocks of seed as a way of building resilience. The selected germplasm must have the necessary traits to make it competitive for specific uses in various environments, such as consumption preferences and suitability for niche markets for landraces that are important to farmers' livelihood security (Bellon et al., 2011; Sperling et al., 2001). Such crops can be incorporated in local seed production processes, or with formal enterprises. In addition, packaging and promotion of improved production practices and technologies, in particular in response to droughts is recommended. Such practices may include; crop diversification in order to maintain a broad crop genetic base, use of drought tolerant cultivars or varieties, shift in sowing/planting dates (informed by appropriate climate information and advisories), soil and water conservation, and integrated soil fertility management. It should be noted that some of these are already being implemented at farm level either as routine farming practices or coping measures by farmers. There is need to climate-proof these practices at local level and deliberately include them in extension messages.

5. Conclusion

This study has documented farmers' perceptions of climate change and how their awareness conditions functioning of their seed systems. Drought was considered the most important climate factor affecting crop production and seed availability. Effect of drought on seed system was perceived in terms of failed or successful crop yields. While seed systems in the study area consist of both formal and informal elements, the informal elements were the most important supply channels for farmers' seed. In stress situations, farmers tended to shift between seed sources, with social networks and local markets playing significant roles in providing seed. However, during stress periods, access to farmer seed may be deteriorated by farmer's weakened functioning of social networks as everyone has seed shortfalls. Similarly, market sources may be weakened by farmers' low purchasing power. The emergence of LSBs seemed to play a key role in availing planting materials especially for cassava and beans, while the formal system played a role in delivering mainly improved and hybrid seed, especially for maize. This study therefore suggests an approach that integrates the existing seed systems in general, but more specifically focus on strengthening social networks and promotion of farmer seed entrepreneurship. Promotion of crop varieties suited for various climates/environments, along with climate-smart technological packages is recommended. This will promote increased productivity and seed saving.

Acknowledgement

Data analysis and manuscript preparation was done with assistance of the Africa Capacity Building Foundation (ACBF) funding to the Horn Economic and Social Policy Institute (HESPI). The study used data collected by the Integrated Seed Sector Development (ISSD) Uganda program with funding from the Kingdom of the Netherlands. We acknowledge funding from CAB International and ISSD Uganda for manuscript finalization and publication. Lastly, the comments of the anonymous reviewers helped to sharpen the article considerably. Their input is greatly acknowledged.

References

AGRA, 2014. Africa Agriculture Status Report: Climate Change and Smallholder Agriculture in Sub-saharan Africa. Alliance for a Green Revolution in Africa, Nairobi, Kenya.

Agrawala, S., Moehner, A., Hemp, A., van Aalst, M., Hitz, S., Smith, J., Meena, H., Mwakifwamba, S.M., Hyera, T., Mwaipopo, O.U., 2003. Development and Climate Change in Tanzania: Focus on Mount Kilimanjaro. OECD, Paris.

Almekinders, C.J.M., Louwaars, N.P., 1999. Farmers' Seed Production: New Approaches and Practices. Intermediate Technology, London, UK.

Anderson, P., Singh, R., 1990. NGO-government Links in Seed Production: Case Studies from the Gambia and Ethiopia. ODI Agricultural Administration (Research and Extension) Network, London: ODI. Network paper 14.

Bellon, M.R., 2004. Conceptualizing interventions to support on-farm genetic resource conservation. World Dev. 32, 159–172.

Bellon, M.R., Hodson, D., Hellin, J., 2011. Assessing the vulnerability of traditional maize systems in Mexico to climate change. Proc. Natl. Acad. Sci. U. S. A. 108 (33), 13432–13437. Accessed online at: http://www.jstor.org/stable/27979216. on 23rd September 2015.

Brown, O., Crawford, A., 2007. Climate change: a new threat to stability in West Africa? evidence from Ghana and Burkina Faso. International Institute for sustainable development (IISD). Afr. Sec Rev. 17 (3), 39–57.

Cabell, J.F., Oelofse, M., 2012. An indicator framework for assessing agro-ecosystem resilience. Ecol. Soc. 17 (1), 18.

Cooper, P.J.M., Dimes, J., Rao, K.P.C., Shapiro, B., Shiferaw, B., Twomlow, S., 2008. Coping better with current climatic variability in the rain-fed farming systems

of the Sub-Sahara Africa: an essential first step in adapting to future climate change. Agric. Ecosyst. Environ. 126, 24–35.
David, S., 2004. Farmer seed entrepreneurship: a sustainable approach to seed delivery? Agri. Hum. Val. 21, 387–397.
Di Falco, S., Chavas, J.P., Smale, M., 2006. Farmer Management of Production Risk on Degraded Lands: the Role of Wheat Genetic Diversity in Tigray Region, Ethiopia. Environmental and Production Technology Division, Washington DC, USA. Discussion Paper 153 IFPRI.
Ferris, J., 1999. An analysis of the impact of ENSO (El Nino/Southern Oscillation) on global crop yields. In: Paper Presented at 1999 Annual Meeting of American Agricultural Economics Association, August 8-11, Nashville, TN, vol. 81, p. 1309. Am J Agric Econ.
Ferris, S., Laker-Ojok, R., 2006. Growth Prospects for Services within Selected Agricultural Sectors in Uganda. International Center for Tropical Agriculture.
FEWS NET, 2010. Livelihood Mapping and Zoning Exercise: Uganda. A special report ty the Famine Early Warning System Network (FEWS NET). January, 2010.
Gareeba-Gaso, E., Gisselquist, D., 2012. Operationalization of the non-ATAAS Component of the Development Strategy and Investment Plan. Final analytical report on seeds and planting materials. Ministry of Agriculture, Animal Industry and Fisheries, Kampala, Uganda.
Greene, W.H., 2003. Econometric Analysis. Prentice Hall International, Inc, New York University, New York, USA.
Halweil, B., 2005. The Irony of Climate. World Watch Institute: Vision for a Sustainable World. Accessed on 20th June, 2016 at: http://www.worldwatch.org/node/572.
Hirpa, A., Meuwissen, M.P.M., Tesfaye, A., Lommen, W.J.M., Lansink, A.O., Tsegaye, A., Struik, P.C., 2010. Analysis of seed potato system in Ethiopia. Am. J. Potato Res. 87, 537–552.
ISSD Uganda, 2014. Farmers' Access to Seed and Other Planting Materials in Uganda (Baseline report, Kampala Uganda).
Jassogne, L., Läderach, P., van Asten, P., 2013. The Impact of Climate Change on Coffee in Uganda: Lessons from a Case Study in the Rwenzori Mountains. Oxfam research reports, April 2013.
Jones, K., 2013. The Political Ecology of Market-oriented Seed System Development and Emergent Alternatives. Conference paper #54. Proceedings of Food Sovereignty: A Critical Dialogue. International Conference, Yale University, New Haven, CT (Sept. 14–15).
Kansiime, K.M., Shisanya, C.A., Wambugu, S.K., 2014. Effectiveness of technological options for minimizing agricultural production risks under variable climatic conditions in eastern Uganda. Afr. Crop Sci. J. 22 (s4), 859–874.
Kurukulasuriya, P., Mendelsohn, R., 2006. Crop Selection: Adapting to Climate Change in Africa. Centre for Environmental Economics and Policy in Africa (CEEPA) Discussion Paper No. 26. University of Pretoria, South Africa.
Lipper, L., Anderson, C.L., Dalton, T.J. (Eds.), 2010. Seed Trade in Rural Markets. Implications for Crop Diversity and Agricultural Development. Earthscan, London, UK.
Louwaars, N.P., 1994. Connecting formal and local seed systems in development: integrated seed supply systems. In: Stolp, P. (Ed.), Organisation and Management of National Seed Programmes, ICARDA, Aleppo, Syria. DSE Feldafing, Germany, pp. 10–17.
Louwaars, N.P., de Boef, W.S., 2012. Integrated seed sector development in Africa: a conceptual framework for creating coherence between practices, programs, and policies. J. Crop Improv 26, 39–59.
MAAIF, 2010. Agriculture for Food and Income Security: Agriculture Sector Development Strategy and Investment Plan, 2010/11–2014/15. Ministry of Agriculture, Animal Industry & Fisheries, Government of Uganda.
McGuire, S.J., 2001. Seed system health indicators: a note. In: Sperling, L. (Ed.), Targeting Seed Aid and Seed System Interventions: Strengthening Small Farmer Seed Systems in East and Central Africa. Proceedings of a Workshop Held in Kampala. CIAT, Kampala, Uganda. Uganda, 21-24 June, 2000.
McGuire, S.J., 2007. Vulnerability in farmer seed systems: farmer practices for coping with seed insecurity for sorghum in eastern Ethiopia. Econ. Bot. 61 (3), 211–222.
McGuire, S.J., Sperling, L., 2011. The links between food security and seed security: facts and fiction that guide response. Dev Pract. 21, 679–688.
McGuire, S.J., Sperling, L., 2013. Making seed systems more resilient to stress. Glob. Environ. Chang. 23, 644–653.
McGuire, S.J., Sperling, L., 2016. Seed systems smallholder farmers use. Food Secur. http://dx.doi.org/10.1007/s12571-015-0528-8.
Nzuma, J.M., Waithaka, M., Mulwa, R.M., Kyotalimye, M., Nelson, G., 2010. Strategies for Adapting to Climate Change in Rural Sub-Saharan Africa a Review of Data Sources, Poverty Reduction Strategy Programs (PRSPs) and National Adaptation Plans for Agriculture (NAPAs) in ASARECA Member Countries. IFPRI Discussion Paper 01013, July 2010.
Osbahr, H., Dorward, P., Stern, R., Cooper, S., 2011. Supporting agricultural innovations in Uganda to respond to climate risk: linking climate change and variability with farmer perceptions. Expl Agric. 47 (2), 293–316.
Oxfam, 2008. Turning up the Heat: Climate Change and Poverty in Uganda, July 2008, Oxfam GB.
Prasad, P.V.V., Boote, K.J., Allen Jr., L.H., Thomas, J.M.G., 2003. Supra-optimal temperatures are detrimental to peanut (*Arachis hypogaea* L) reproductive processes and yield at ambient and elevated carbon dioxide. Glob. Change Biol. 9, 1775–1787.
Remington, T., Maroko, S., Omanga, P., Charles, E., 2002. Getting off the seeds-and-tools treadmill with CRS seed vouchers and fairs. Disasters 26, 316–328.
Rubyogo, J.-C., Sperling, L., Muthoni, R., Buruchara, R., 2010. Bean seed delivery for small farmers in Sub-Saharan Africa: the power of partnerships. Soc. Natur. Resour. 23 (4), 285–302.
Smit, B., Skinner, M., 2002. Adaptation options in agriculture to climate change: a typology. Mitig. Mitig. Adapt Strategy Global Change 7, 85–114.
Sperling, L., 2008. When Disaster Strikes: a Guide to Assessing Seed System Security. International Centre for Tropical Agriculture, Cali, Colombia.
Sperling, L., McGuire, S.J., 2010. Understanding and strengthening informal seed markets. Expl Agric. 46, 119–136.
Sperling, L., Ashby, J.A., Smith, M., Weltzien, E., McGuire, S.J., 2001. A framework for analyzing participatory plant breeding approaches and results. Euphytica 122, 439–450.
Sperling, L., Boettiger, S., Barker, I., 2013. Integrated Seed Systems. Planning for Scale Brief #3, AgPartnerXChange. Retrieved on 26th August 2015 from. http://researchgate.net/publications/259459604.
Subedi, A., de Boef, W.S., Audet-Bélanger, G., Gildemacher, P., Heemskerk, W., 2013. Seed Systems Analysis. ISSD Technical Notes Issue no 2. Centre for Development Innovation, Wageningen UR & Royal Tropical Institute, Amsterdam.
Tripp, R., 2001. Seed Provision and Agricultural Development. Overseas Development Institute, London.
van de Steeg, J.A., Herrero, M., Kinyangi, J., Thornton, P.K., Rao, K.P.C., Stern, R., Cooper, P., 2009. The Influence of Current and Future Climate-induced Risk on the Agricultural Sector in East and Central Africa: Sensitizing the ASARECA Strategic Plan to Climate Change. Nairobi, Kenya, and ASARECA (Association for Strengthening Agricultural Research in Eastern and Central Africa), Entebbe, Uganda. Research report 22. ILRI (International Livestock Research Institute), Nairobi, Kenya, ICRISAT (International Crop Research Institute for the Semi-Arid Tropics).
Walker, B., Gunderson, L., Kinzig, A., Folke, C., Carpenter, S., Schultz, L., 2006. A handful of heuristics and some propositions for understanding resilience in social-ecological systems. Ecol. Soc. 11 (1), 13.
Wambugu, F., Mburu, N., 2014. Potential for Sorghum in Food Security and Economic Development Among Communities in Arid and Semi-arid Lands in Africa. Research report. Technical Centre for Agricultural and Rural Cooperation ACP-EU (CTA). Accessed at: http://knowledge.cta.int. on October 21, 2014.
Weltzien, E., vom Brocke, K., 2001. Seed systems and their potential for innovation: conceptual framework for analysis. In: Sperling, L. (Ed.), Targeted Seed Aid and Seed System Interventions: Strengthening Small Farmer Seed Systems in East and Central Africa. Proceedings of a Workshop Held in Kampala, Uganda, 21–24 June 2000. Kampala, pp. 9–13.
Westengen, O.T., Brysting, A.K., 2014. Crop adaptation to climate change in the semi-arid zone of Tanzania: the role of genetic resources and seed systems. Agric. Food Secur. 3 (3), 1–12.