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ORIGINAL PAPER

Assessing the value of diverse cropping systems under a new agricultural policy environment in Rwanda

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Abstract In Rwanda, farmers' traditional farming systems based on intercropping and varietal mixtures are designed to meet a variety of livelihood objectives and withstand risks associated with fluctuation in market and agro-climatic conditions. However, these mixed systems have been disappearing since 2008 when government mandated intensification strategies. In this paper we use a mixed methods approach to evaluate intercropping and sole cropping systems against farmers' criteria for success: yield, market value, contribution to nutritional quality, and land-use efficiency. We used qualitative interviews to understand the criteria by which farmers evaluate cropping systems, and data from crop trials to assess common bean ((*Phaseolus vulgaris* L.) and maize (*Zea mays* L.)) sole crops and intercrops against those criteria. We found that an improved intercropping system tends to outperform the government-mandated system of alternating sole-cropped bean and maize season-by-season, on all four of the criteria tested. Although Rwanda's agricultural intensification strategy aims to improve rural livelihoods through agricultural modernization, it fails to acknowledge the multiple and currently non-replaceable benefits that diverse cropping systems provide, particularly food security and risk management. Agricultural policies need to be based on a better understanding of smallholders' objectives and constraints. Efforts to improve farming systems require innovative and inclusive approaches that enable adaptation to the socio-ecological context.

Keywords Agriculture-nutrition · Agrobiodiversity · Intercrop · Resilience · Traditional knowledge

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Introduction

Smallholder farmers manage 80% of the world's farms and produce approximately 80% of the world food supply (HLPE 2013), often using diversification and risk minimization strategies to cope with complex agroecological environments. These smallholder farming systems have been developed to be flexible and adaptable under naturally fluctuating socio-ecological conditions, but this intentional resiliency has rarely been a source of innovations for new production systems (Darnhofer et al. 2010a, b) despite the potential for learning risk mitigation strategies for changing environments. Smallholder farmers are vulnerable to production risks, which will continue to be modified by climate change (HLPE 2013), uncertain markets, and institutional drivers such as national agricultural policies. Learning from existing farming systems to develop increasingly more resilient farming systems that maintain and balance the economic, nutritional, and social needs of rural communities in a constantly changing socio-ecological environment, is a pathway to reducing these risks and improving food security.

Traditional farming systems that have developed over generations of practice and observation of natural ecosystems (Altieri 2004) can be more resilient than conventional farming systems because they tend to rely more on biodiversity and associated ecological processes than the input-intensive regimes of conventional agriculture (Jackson et al. 2012; Tscharntke et al. 2012). These traditional systems are designed to elicit multiple provision services (food, fuel, fiber) (Power 2010; Lin 2011) and are reliant on integrated management of local natural resources (Malézieux 2012) because input markets are unreliable or inaccessible. Farmers who manage these systems have unique needs that are specific to their own agronomic and socio-economic situations (Ashby and Sperling 1995) and are embedded within culture and local knowledge systems. Understanding farmer expectations of their cropping systems and how they cope with stresses is one way to improve our ability to develop with farmers resilient and context-appropriate farming systems.

Smallholder farmers around the globe rely upon intercrops and diverse mixed cropping systems, many of which provide the basis for food security and diverse diets – but most studies on these systems are focused on the ecological contribution to ecosystem services such as nutrient cycling, mitigation of greenhouse gas fluxes, biological pest management, and other regulating services (Lin 2011). Numerous authors have conducted agronomic and ecological assessments of intercropping systems (Vandermeer 1992; Connolly et al. 2001; Seran and Brintha 2010; Lithourgidis et al. 2011) and the main advantages of intercropping include the potential for resource efficiency (Trenbath 1986; Francis 1989; Ghanbari et al. 2010) and the mitigation of risk associated with crop loss (Jodha 1980; Lithourgidis et al. 2011; Rusinamhodzi et al. 2012). Others have explored economic returns (Francis and Sanders 1978; Mucheru-Muna et al. 2010), pest control (Trenbath 1993; Boudreau 2013), and of course productivity (Fukai and Trenbath 1993). More recently, scientists have studied the biodiversity found in species-rich cropping systems and identified a multitude of ecosystem services provided by these systems (Altieri 1999; Hooper et al. 2005; Thrupp 2000; Tscharntke et al. 2005; Kremen and Miles 2012).

The literature indicates the breadth of agroecological and socio-ecological benefits associated with mixed cropping systems and agricultural diversity, and many of these services are increasingly understood to be positively associated with resilience in the face of climatic and other risk factors (Mijatović et al. 2013). New research is also emerging that links functional agrobiodiversity and ecological studies with human nutrition outcomes (DeClerck et al. 2011; Döring et al., 2014; Herforth et al. 2014; Jones et al. 2014). Despite this evidence, diversification and intercrop production in particular is often marginalized in favor of input-intensive sole cropping. Given the changing climatic conditions and uncertain market access faced by vulnerable farmers, there is a need to explore mixed cropping from the perspective of these farmers. This research contributes to the literature by assessing the value of diversification and intercropping systems through smallholder farmer-driven criteria, using a case study from Rwanda.

In this study we used mixed methods to apply farmer-driven criteria to assess the value of intercrop and sole crop systems in the rapidly transforming agricultural context of Rwanda. We hypothesized that combining farmers' perceptions of farming system services with agroecological evaluation of those services will provide unique insights into the impact of government agricultural policies that prioritize sole cropping over traditional mixed systems. The specific objectives were to 1) identify services farmers expect to obtain from crop systems, 2) apply this framework to assess four bean and maize systems within the agro-ecological and political context of northern Rwanda and 3) evaluate the contribution of sole versus mixed cropping systems to system resilience.

Traditional cropping systems in Rwanda

The traditional farming systems found in the Rwanda highlands are representative of highland agriculture in East Africa where over 65 million people cultivate mixed cropping systems (Garrity et al. 2012) and the diversity found within these systems is potentially more resilient to socio-ecological fluctuations (Lin 2011). In Rwanda food crops account for 92% of the total land cultivated while cash crops coffee and tea account for 6.3 and 1.6%, respectively (MINIAGRI 2009a; b). Farm households traditionally grow a diverse range of crops in both polycultures and sole crops, with bananas (genus *Musa*), common beans (*Phaseolus vulgaris* L.), sorghum (*Sorghum bicolor*), maize (*Zeas mays* L.), sweet potatoes (*Ipomea batatas*), and cassava (*Manihot esculenta*) dominating (Voss 1992). Varietal mixtures, or multiple varieties of a crop planted in the field together, are frequently used in Rwanda and provide resilience to environmental variation (Voss 1992).

Agricultural policy in Rwanda

Historical records indicate that crop diversification in Rwanda was pursued by government policy as early as the 1920s as a means to improve food security (Kangasniemi 1998), and current conditions are still challenging. As one of the most densely populated countries in Sub-Sahara Africa, Rwanda faces high population pressure with more than 60% of farm households cultivating less than 0.5 ha (MINIAGRI 2012). Approximately 82% of the population is engaged in small-scale food production (NIS 2010) and food insecurity is 21% (World Food Program 2012). To address these issues of high population density, land scarcity, and rural poverty, the Rwandan government began to implement the Strategic Plan for the Transformation of Agriculture (PSTA I&II) in 2004. This Strategy aimed to stimulate the intensification of agricultural production to support economic growth, and improve the livelihoods of rural Rwandans through the commoditization of agricultural production for regional and international export markets (MINIAGRI 2004–2012). Drawing on agricultural success stories in China and Brazil, the policy goals were to structurally transform and accelerate agricultural growth sustainably through intensification of production, support to professionalization of producers, promotion of commodity chains, and institutional development (MINIAGRI 2004–2012). Strategy documents indicate the plan was developed in a highly participatory manner with communities prior to implementation and specific strategy goals include participation, local ownership of activities, sensitivity to issues such as gender, and flexibility (MINIAGRI 2004–2012). The plan acknowledged that large paradigm shifts in agricultural production are not without risks, and require openness to revisions.

A major component of PSTA I&II in Rwanda is the Crop Intensification Program (CIP), which promotes a shift from the traditional fragmented landholdings that produce diverse crops to consolidation of parcels that produce single crops for markets (MINIAGRI 2004–2012). In Northern Province where this case study took place, implementation of this policy at the farm level began in 2008–09. Sole crops, land consolidation, and the use of subsidized inputs were highly encouraged, while traditional intercrop systems were banned (Huggins 2013). This policy was enforced at the household level by the local authority and non-compliance could have serious consequences, including fines (Huggins 2013). Farmers in this area were required to plant sole crops of beans and maize according to a schedule defined by the government. As such, farmers grew beans in one season and maize in the other season. In contrast to this government-directed prioritization of sole crops in Rwanda, there is increasing evidence in the literature that mixed cropping – whether traditional or intensified – is critical to providing multiple services at the farm and community levels (Snapp et al. 2010; Malézieux 2012; Jackson et al. 2012).

While the intensification policies associated with PSTA I&II aim to improve cultivation practice and develop sustainable, market-oriented production systems, the impact of the program on farmer livelihoods and farming systems is unknown. We explored how these agricultural policies affected the supply of provision services, how they might affect system resilience and if they expose farmers to higher risks associated with narrowly defined crop choice (Walker et al. 2010). Finally, we considered the impact of transitioning from a subsistence-based agricultural system to a market-based system in marginalized regions of Rwanda.

Methods

Overview

This study takes an interdisciplinary, participatory approach to explore the effects of an agricultural policy on the livelihoods and farming systems of smallholder farmers in Northern Province, Rwanda. The data were collected as part of a larger study focused on participatory variety selection of bean genotypes for intercrop systems (Isaacs 2014). The work represents a collaborative and participatory approach (Greenwood and Levin 2007; Reason and Bradbury 2001) in which scientists work with farmers and develop a knowledge system that combines farmers' and researchers' ways of knowing (Hoffmann et al. 2007; Weltzien and Christinck 2011). Researchers, therefore, form a strong, collegial relationship with participating farmers and farmer associations, with the lead author residing in Musanze, Rwanda over the entire period of study (February 2011–April 2012) and interacting with the farmer associations bi-monthly.

As a mixed methods study, this paper combines economic and agro-ecological measures derived from field trial data conducted at two research stations with the strength of ethnographic methods. Two main sources of data were used: 1) yield measurements taken from agronomic field trials and 2) in-depth interviews with farmers who participated in the evaluation of field trials conducted by Isaacs (2014) that explored farmer cropping system preferences (Fig. 1). Informed consent and Institutional Review Board approval were obtained and locations of the farmers associations remain confidential to protect the participants.

Study sites and sampling

Northern Province is located in the sub-humid tropics of northern Rwanda and is characterized by multiple soil types and heterogeneous microclimates. The region has a bimodal rain distribution with cropping and rainy seasons spanning from September to early January in season 'A' and from late February to early June in season 'B′. Total rainfall ranges from 1300 to 1600 mm with approximately a third of annual rainfall in each of these periods and the growing seasons extending on either side.

Field trials were carried out at two research stations in Northern Province, Rwanda and on-farm in seven community sites (on-farm agronomic data not reported here) during the growing seasons 2011B and 2012A. Musanze Station is a mid-altitude site at 1850 m.a.s.l. and Rwerere Station is a high-altitude station at 2100 m.a.s.l. The soil classification for Musanze is an umbric slandic Andosol characterized as a nutrient rich volcanic loam while Rwerere is a dystric Regosol (Entisol) characterized as a well-drained clay soil. Rwerere soils were higher in Organic C (2.46–2.70%) than Musanze (1.29–2.19%), and Rwerere soils were also higher in total N (0.27–0.29%) than Musanze (0.21–0.13). Conditions at the two research stations were representative of the diverse environments in the region in that soil types, elevation, and microclimatic features were distinct.

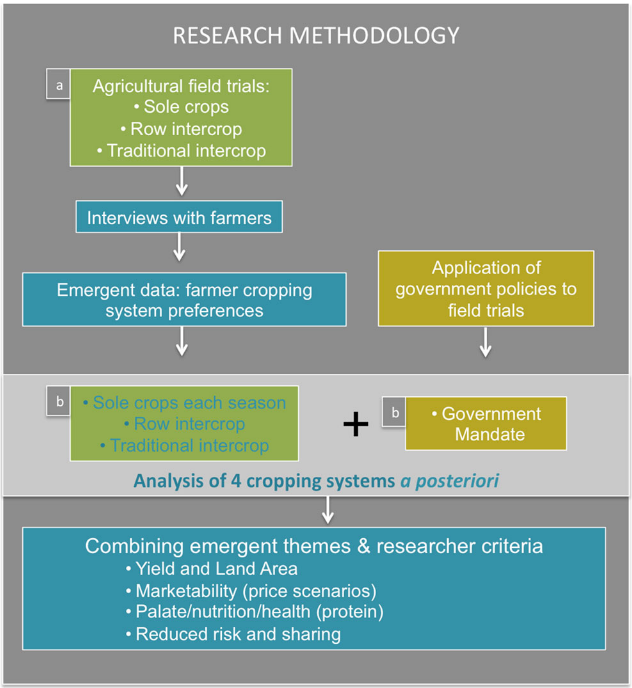

Fig 1 Research methodology for analysis of field trials using emergent data from farmer interviews

Qualitative interviews were conducted with farmers associations that were participating in the on-farm field trials. Seven farmer associations were identified with the assistance of a local organization that works extensively in the area. The associations were purposively identified based on three different agroecological environments (in terms of elevation and edaphic features) and their willingness to participate in a bean-maize cropping system trial. Many farmers associations in this area are composed of a majority of women and those that are included in this study were created specifically for women farmers. Field trials were carried out with these associations (on community plots) and interviews were conducted with the participating member farmers. All participants were invited to participate and participation was voluntary.

Data collection

Agronomic field trials Four climbing bean and maize cropping systems were planted at Musanze and Rwerere Research Stations for two consecutive growing seasons, seasons 2011B and 2012A. These included 1) a sole crop of maize; 2) a sole crop of beans; 3) a bean and maize row intercrop; and 4) a bean and maize traditional intercrop. In-depth details of the environments and the field trials, including experimental design, management practices, and varieties used, are given in Isaacs (2014).

The four cropping systems were planted in a randomized complete block design. Blocks were replicated four times at each station, for two seasons with a new field site each season; hence the experiment was replicated over time and space four times. Individual plots within the block were 3 m × 4 m. There was uniform spacing between plots (0.75 m) and 1.0 m between blocks. According to farmer practice, the maize was planted first and the beans were planted 29–31 days later in every treatment.

All of the maize and climbing bean varieties were adapted to the region and both improved bean varieties and farmer bean mixtures (varietal mixtures) were used in the crop trials (Isaacs 2014). All climbing bean genotypes were large seeded Andean Type IV cultivars. The maize variety was Pool9A and open-pollinated (Highland Late White Dent) (Friesen and Palmer 2004).

The sole crop bean and sole crop maize system plant densities were designed based on regional recommendations. In the maize sole crop, there was 0.75 m between the row spacing and 0.25 m between each plant within the row. Two seeds were planted per hole for a total plant population of 106,700/ha. In the bean sole crop, between row spacing was 0.50 m and the distance between each plant within the row was 0.20 m. Two seeds were planted per hole for a total plant population of 200,000/ha.

The intercrop system plant densities were researcher designed for the Row Intercrop (RI) and farmer designed for the Traditional Intercrop (TI). For the RI, maize (0.3 m spacing between plants) and beans (0.1 m spacing) were in the same row (0.75 m between rows), thus two bean plants grew up a single maize plant. The maize and bean populations in the RI were 44,400 and 106,700 plants/ha respectively, for a total plant population 151,100/ha. In the TI 2 maize seeds were planted per hole and 2–3 bean seeds were planted in different holes in a scattered pattern throughout the plot. The maize and bean populations in the TI were 75,000 and 458,300 plants/ha respectively, for a total plant population of 533,300/ha.

All trials were fertilized following recommended practices, and weeded at bean planting and at least once more as needed during the season. Beans were staked in the sole crop and the RI. Yields of maize and beans were collected at physiological maturity. For yield, the entire plot was harvested (3 m × 4 m) and moisture contents were corrected to 15.5% and 12% for maize and beans, respectively.

Statistical analysis of cropping systems The yield and nutritional comparisons of cropping systems were analyzed using PROC MIXED in the program SAS with a model including fixed effects of cropping system. Random effects were season, location, and replicate. To address the different number of treatments (varieties) in each cropping system in the experimental design, treatment was dropped from the model and contrasts were used to further splice the data when an interaction occurred. There were season by location by cropping system interactions for all variables except maize yield. Subsequently, all comparisons were conducted separately for each site. Planned contrasts between cropping systems were used to identify differences in yield and protein content.

Qualitative interviews The main purpose of the interviews used in this study was to understand farmer expectations about cropping systems. The collaborative relationships with farmers and their associations were critical to providing a trusting environment in which interviews and observations could be conducted with farmers. In-depth, open-ended interviews were carried out once at the end of the second growing season in 2012 with 44 farmers who participated in the field trials. All interviews were conducted by the lead author with a trained interviewer-translator and were part of a larger survey that lasted approximately 45 min. This portion of the interview followed an ethnographic style, using an interview guide and conversation-specific follow-ups to gain depth and detail (Rubin and Rubin 2012). Farmers used their own terms and spoke in the manner that was logical for them about the crops they grow, the reasons for growing them, the importance of the crops to their livelihood strategy, and the reasons for ceasing to grow specific crops. A sample of interviews was recorded electronically, and the lead author took translated verbatim handwritten notes during each interview.

Basic demographic information was collected from each farmer, including age, education, landholdings, and poverty category. Poverty categories were based on the official classification of poverty developed by the Rwandan government (Howe and McKay 2007).

To analyze the interviews, data were coded around the question, "What do farmers expect from their cropping systems?" Emergent themes were then used to develop a framework for analyzing the cropping systems (Fig. 1). The first five interviews were coded based on emerging themes. These themes were expanded and tested with additional interviews and definitions were modified and adjusted where necessary. Final coded text was extracted for each theme and summaries of the coded text were written. Percentages reported are the percent of interview respondents that discussed the theme. Descriptive statistics were used to analyze the responses by demographic group.

Combining the agronomic field trials with emergent interview data Two pieces of emergent data from the interviews were used to analyze the field trials a posteriori. These included 1) the types of cropping systems preferred by the farmers, and 2) farmer expectations of these cropping systems. In terms of cropping systems, farmers indicated they preferred 1) a sole crop of beans and a sole crop of maize grown each season (SC); 2) a bean-maize Row Intercrop grown each season (RI); or 3) a bean-maize Traditional Intercrop grown each season (TI) (Fig 1). Hence the field trial yields were calculated to reflect these "new" systems in comparison with the Government Mandate (GM) system, over 1 year (2 growing seasons) on a land area basis (Fig 1). The yield data from the original agronomic field trials was used to generate the data for the farmer preferred Sole Crops and the GM. The Row Intercrop and the Traditional Intercrop data remained the same with beans and maize planted each season. The Sole Crop system was ½ ha of sole crop beans and ½ ha of sole crop maize each season. The Government Mandate cropping system was a sole crop of beans in Season B and a sole crop of maize in Season A.

In addition, from these interviews, it emerged that diverse crops were important to farmer well-being because they provided services such as marketability, dietary quality, and cultural services. Thus, the performance of the four new cropping systems was analyzed using three indicators developed to represent concepts of interest to both farmers and researchers involved in the field trial study. These indicators for cropping system performance were: 1) yield and land-use efficiency; 2) contribution to dietary quality; and 3) economic value to the household. The three performance indicators relied upon yield data collected from the field trials conducted at research stations as well as existing secondary sources on prices and nutrient conversion tables (USDA 2013). All indicators were calculated on an annual basis to accommodate the annual design of the cropping system. In other words, Season B was added to Season A.

Land use efficiency is a common method used to compare sole crop systems with intercrop systems on a land area basis. The land-equivalent ratio (LER) was calculated as LER = $y_i/y_{ii} + y_j/y_{jj}$ according to Trenbath (1999) where y_i and y_j are the yield ha^{-1} of the bean and maize intercrop components i and j, and y_{ii} and y_{jj} are the corresponding yield ha^{-1} of the sole crops planted at optimum density and in the same conditions of soil and crop management as the intercrop. For the sole crop data (the denominator), data from each environment was averaged.

Yield data were converted to protein as a means to gauge the potential contribution of the different bean and maize cropping systems to one facet of household nutritional quality. Conversion of intercrop data to a standard unit such as protein is also a common way to compare cropping systems that have different components (Mead et al. 1986). The protein content was calculated based on USDA standards for mature, raw, uncooked maize and beans (USDA 2013). Maize had 9.42 g of protein per 100 g of grain and beans had 23.58 g per 100 g of seed. Total protein content was then calculated from the yield for each cropping system on an area basis (1 ha).

The four systems were analyzed in terms of the economic value of the total crop yield produced per hectare. Prices of maize and beans in Africa are highly variable inter annually as supply and demand fluctuates and there are significant differences in price between regional markets in Rwanda. There are multiple sources of bean and maize price data for Rwanda but there are discrepancies between the data and no reliable source of region-specific price data exist. It is hard to predict how relative prices will change over time so the value of the cropping systems were evaluated using six different relative price scenarios. These price scenarios give insight into how the economic value of intercropping versus sole cropping would respond to relative price changes rather than price changes over time. This focuses the analysis on the key economic indicator for evaluating the cropping systems, which is the relative price ratio of beans to maize.

The base scenario assumed that the price of both maize and beans per kilogram is constant over the year at 200 Rwandan Francs (RWF) per kilogram (Table 3). The remaining five scenarios were used to illustrate how fluctuating market prices might affect the value of various cropping systems on an annual basis. We simulated higher or lower relative bean prices within a range of 100 RWF in each of the alternate scenarios (Table 3).

At the time of research, farm gate prices of traditional bean varieties were between 280 and 320 RWF/kg and the farm gate price of maize varied between 120 and 180 RWF/kg. We looked at all possible combinations of this price difference between crop and season and calculated the economic value of one hectare of production for each cropping system, and then summed the two growing seasons. The total value of each of the three preferred cropping systems was subtracted from that produced by the government mandated (GM) system. If the value Y = Cropping System (x) – GM was negative, then the GM produced more economic value for the household. The total value per hectare was converted to dollars at an exchange rate of 600 RWF for $1, which was the approximate exchange rate at the time of research.

Results

Farmer demographics

The average land holding size of the 44 farmers interviewed was 0.6 ha and it ranged between 0.0 and 2.9 ha per household. Only three households owned more than 1.2 ha and six had less than 0.01 ha. The average age of farmers was 48 years and ranged from 22 to 70. The average years of education was 4.7 and ranged between 0 and 11. The average economic class category was 3.3 (“the poor” or *umukene*) and varied between 2 (“the very poor” or *umutindi*) and 4 (“the resourceful poor” or *umukene wifashije*) (Howe and McKay 2007). The associations selected to participate in this study were primarily women’s group, as a result only two of the participants in the interviews were men – and one was accompanied by his wife. Hence these results were all from the perspective of women.

Interviews

We asked 44 farmers in northern Rwanda what type of farming system they preferred and what was important to them about these systems. From the data it emerged that the vast majority of farmers wanted to grow multiple crops, but the cropping system in which they wanted to grow them varied. Some farmers wanted to grow intercrops or mixed systems the same as they previously planted them (similar to the Traditional Intercrop), while others wanted to increase the spacing (more similar to the Row Intercrop): “the agronomist told us it is better production in the sole crop… I think when I grow maize, beans, and sweet potatoes there is competition (for nutrients), so if I grow one [crop] it is comfortable by itself. Now I would grow intercrops but increase the spacing.” Other farmers wanted to grow different crops as sole crops in the same season (similar to the Sole Crop), “Now we like sole cropping. For example, if we have 3 fields we could plant one maize, one beans, and one sweet potato.” The four “new” cropping systems, Sole Crop, Government Mandate, Row Intercrop, and the Traditional Intercrop, reflect these different farmer preferences.

From the data four major themes emerged that described farmer expectations of their farming systems. The recurring themes in the data referred to marketability, dietary quality, sharing, and well-being. Often these themes overlapped. For example, one woman remarked:

> *…[multiple crops] are important to have production. When one crop dies I can harvest something else in high quantity so there’s no hunger. Before, when I had all of these crops I ate well – fresh bananas and fresh beans, oil as fat, and I gave it to the children and they are happy. When we didn’t have one crop we could take one to the market and buy another.*

Thus, crop diversity provides farmers insurance against crop failure, ensures the family has a diversity of foods to eat, and the option to exchange crops on the market. All of these factors contribute to improved family well-being by minimizing production risk and diversifying income and diet sources. Underlying all of the themes were references to yield potential. While some farmers believed a sole crop was more productive, many also said that they could harvest more, or at least have more options, from the intercrop.

The most frequently discussed themes were marketability (98% of farmers interviewed) and issues related to having diverse foods (95%); they were often mentioned together. A typical response of farmers, “[All these crops] are important so we can change the daily food. It is good to have food for energy and immunity. The crops increase family income so you can buy what you need. If I have all of that production then I have money.” When farmers talked about marketability, they expected to be able to take a crop to the market to sell in order to cover school and health fees, purchase crops they did not have, pay for labor, and invest in livestock or additional fields. Farmers were concerned about the value of their crops on the market and most communities had different crops they considered cash crops:

> *With all of these crops the people were very rich. We sold fresh bananas or sorghum and bought other fields. Sorghum gave money for school fees. There was no hunger in the family – we had production. The most important economic crops were sorghum and banana but even if we still grow these crops the amount is less… When there is high production of maize there's no value on the market. Even if we harvest more, we still eat it everyday. So even if the production is high, we don't have money.*

Farmers also said having different crops meant they could take the more valuable crop, such as sorghum or sweet potatoes, to the market. It was clear from farmers that maize was not always considered a lucrative crop and did not necessarily fulfill food security needs.

In the theme dietary quality, farmers said they liked to grow diverse crops because they wanted to eat different foods, that eating the same food caused health problems, and diverse foods are important for nutrition. One farmer alluded to several important aspects of having diverse diets: "If you have production from all of these [crops] there's no hunger. And to change the food – today if we eat squash and beans the next day we can eat something else…Life is strong – there's no disease in the body and children don't get sick because they change the food every day." Some farmers also associated certain crops with fighting malnutrition, for example, "Beans and bananas help fight malnutrition." In addition to maintaining good health and nutrition, farmers said growing different crops mitigated hunger because diverse crops allowed the household to have a staggered harvest and a more steady food supply: "When we were waiting for one [crop], we could eat another. Different crops have different harvest periods, some are long, some are short, and some are medium in length. So we did not have hunger because we were not waiting for just one crop at one time."

Farmers utilized both time and space to vary crop production. Multiple crops were planted to take advantage of different harvest periods, different field types across the landscape, and to maintain seed over the seasons. Before the government mandated system, this farmer used the seasons and mosaic fields to maintain sweet potato slips ("seeds"), "We used to grow [sweet potato] in the valley which would give seeds for on the mountain. During the sunny season we planted sweet potatoes in the valley and during the rainy season we planted them on the hill." A few interviewees were concerned about crop failure. For example, farmers stated different crops "are important to have production. When one crop dies I can harvest something else in high quantity so there's no hunger."

Fourteen percent of respondents talked about sharing and having preferred foods. When farmers have many crops they can share seeds or food with neighbors, or family members would gather. One farmer said of banana beer, "When we had it in the house the family would come, like the grandmother and all, and it made people come together and talk about how to make the family better" and another said, "It's important to have these crops to help people and share." The respondents also talked about how certain foods, such as sorghum, were preferred at different times of the year but many of them no longer had access to it. Multiple women farmers said, "If I have a small child it is better to feed them the boiled sorghum …the child doesn't like maize boil because we can't afford sugar," "boil of sorghum helped sick children," and "if we wanted to drink sorghum beer we got sorghum from the field but now everything is in the market and we don't have the money to buy those things in the market."

All of these themes contribute to improved family well-being through minimizing production and consumption risk. Farmers referred to having many crops as a marker of wealth, as happiness in the household, or as "a good life." A farmer in one site said, "With these crops we have more production to bring to market to buy clothes, school fees, to give friends, to give to those that have hunger. With all of these crops you are a rich woman" and another said, "With these crops we don't have hunger. There's no one that is poor because they have money and the children are happy because they eat everything."

Yields

The environments proved to be important, as there were location and seasonal effects on bean and maize yields. Bean yields as sole crop were higher at Rwerere than Musanze, with approximately 1 mt/ha more beans at Rwerere than Musanze over the year (Table 1). In contrast, total maize yields as sole crop at Musanze for both seasons were more than double maize yields at Rwerere. A seasonal effect was also observed, whereby beans performed the best in Season B and maize performed the best in Season A. These patterns are consistent with known seasonal factors for the region and are the basis for the government mandated cropping system: beans grow better in the longer rainy Season B and maize grows better in the short rains Season A.

Bean yields were affected by the cropping system but maize yields were not, except in the bean-dense Traditional Intercrop (Table 1). Average bean yields in the Traditional and Row Intercrops were 1.5 and 1.9 mt/ha respectively whereas average bean yield in the sole bean system was 3.4 mt/ha (Table 1). Maize yields in the Traditional and Row

Table 1 Total grain yield for each system and crop at Musanze Station and Rwerere Station for Seasons B and A, 2011–12

Cropping System	Row Intercrop	Traditional Intercrop	Bean Sole Crop	Row Intercrop	Traditional Intercrop	Maize Sole Crop
Location and Season	BEAN yield mt/ha			MAIZE yield mt/ha		
Musanze Season B	1.7^{B} (0.10)	1.8^{B} (0.18)	3.7^{A} (0.10)	5.8^{a} (0.26)	4.8^{a} (1.00)	6.4^{a} (0.42)
Musanze Season A	1.0^{B} (0.10)	2.3^{A} (0.23)	2.6^{A} (0.18)	7.4^{a} (0.31)	4.5^{b} (0.51)	8.8^{a} (1.25)
Rwerere Season B	1.9^{B} (0.10)	2.4^{B} (0.25)	4.4^{A} (0.20)	1.8^{a} (0.08)	1.4^{b} (0.18)	2.0^{a} (0.30)
Rwerere Season A	1.2^{B} (0.08)	1.4^{B} (0.21)	3.0^{A} (0.18)	3.9^{a} (0.17)	1.9^{b} (0.83)	4.0^{a} (0.61)
System Mean	1.5 (0.06)	1.9 (0.15)	3.4 (0.11)	4.8 (0.24)	3.1 (0.54)	5.1 (0.72)

The system mean is the average yield across seasons and locations for each crop in three different cropping systems: A row intercrop, a traditional intercrop, a bean sole crop, and a maize sole crop. For each season and location (across rows), bean yields with different upper-case letters and maize yields with different lower-case letters were statistically different (<0.01 - <0.0001). Standard errors are in parenthesis

Intercrops were 3.1 and 4.8 mt/ha, respectively, and average maize yield in the sole maize system was 5.1 mt/ha (Table 1). There were no differences in maize yield between the Row Intercrop and the Sole Crop.

Yield response from the crop trials were converted on a hectare basis to the four bean-maize cropping systems described in the methods. There were significant environment by system interaction for yield (0.003) so environments Musanze and Rwerere were considered separately. At Musanze, the RI was the most productive cropping system whereas at Rwerere both the RI and the GM were the most productive (Fig. 2). At Musanze, the RI had the highest combined yield of beans and maize over the year (16.0 mt/ha) (0.0008–0.05). The TI (13.6 mt/ha) and the GM (12.5 mt/ha) were not significantly different, nor the GM and the SC (10.9 mt/ha) (Fig. 2). At Rwerere the total yields were lower, and there was a difference at 0.1 between the top two yielding cropping systems, the RI (8.9 mt/ha) and the GM (8.3 mt/ha). The TI (6.9 mt/ha) and the SC (6.7 mt/ha) had similar yields and were lower than the other systems (<0.0001–0.002).

Land-use efficiency

For the LER, values greater than 1.00 indicate the intercrop yields more on the same area as growing respective sole crops. Measures of land-use efficiency are particularly valuable in land-limited situations like Rwanda. At Musanze the RI (1.65) was the most efficient system in terms of land use and at Rwerere the GM (1.02) and the RI (1.01) were the most efficient (Table 2). The SC was the least efficient system at both locations.

The Alternative LER (Fig. 2) focuses on the RI system performance in comparison to the SC. In the SC, beans and maize were grown in a sole crop both seasons on one hectare of land (Fig. 2). In both locations, it was significantly more efficient to grow as RI than it was to grow the same crops as SC (Fig. 2). In fact, growing the sole crops both seasons was the least efficient system in terms of land-use. Only at Rwerere, where maize performs poorly both seasons, was the sole crop system GM as efficient as the RI (Fig. 2).

Protein

Converting the yields to grams of protein content per hectare is a way to compare all components of the cropping systems in a single unit (Fig. 3) and partially captures farmer interest in dietary quality. At Rwerere beans provided more of the total protein per cropping system and at Musanze maize generally provided more protein because maize yielded so high in this environment. Despite the lower overall maize and bean yields at Rwerere, the bean yield advantage at that location increased protein content substantially. At Musanze, all systems had similar protein content (1477–1901 g/ha) except the SC was significantly lower (1477 g/ha) (0.003–0.05) (Fig. 3a). However, the GM was significantly less than the RI at

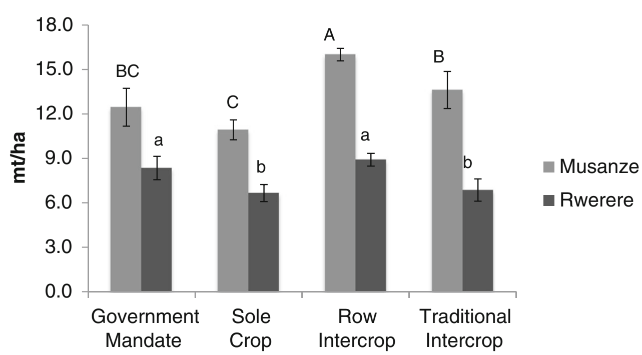

Fig 2 Yield and Alternative Land Equivalent Ratio on an annual basis demonstrating the combined maize and bean yields of four cropping systems over two seasons at Musanze and Rwerere stations for Seasons B and A, 2011–12. The government mandate cropping system is a sole crop of beans in Season 1 and a sole crop of maize in Season 2. The sole crop system is ½ ha of sole crop beans and ½ ha of sole crop maize each season. The row intercrop and traditional intercrop are beans and maize planted each season. Cropping systems with different upper-case letters were statistically different at Musanze and cropping systems with different lower-case letters were statistically different at Rwerere (<0.01 - <0.0001). Error bars are the standard errors

Table 2 Land Equivalent Ratio on an annual basis of four cropping systems over two seasons at Musanze and Rwerere stations for Seasons B and A, 2011–12

Location	CROPPING SYSTEM			
	Government Mandate Land Equivalent Ratio	Sole Crops	Row Intercrop	Traditional Intercrop
Musanze	1.38	1.20	1.65	1.51
Rwerere	1.02	0.83	1.01	0.85

Values larger than 1.0 indicate a greater land use efficiency

<0.10. In contrast, at Rwerere the GM had more protein (1406 g/ha) than either intercrop system (1175–1286 g/ha) (0.002–0.03). Similar to Musanze, the SC at Rwerere had the least total protein (1148 g/ha) and was significantly less than the RI and the GM (<0.05–0.001) (Fig. 3b).

Price scenarios

The price scenarios illustrate the value of each cropping system at various simulated market prices relative to the GM cropping system. Overall, at either location, the SC was the least profitable cropping system in any price scenario and the RI was the most profitable (Table 3). Only in Scenarios 4 and 5 at Rwerere was the GM more profitable than the RI.

Differences emerged between the two locations and were related to the season and location crop interactions. Conditions favor maize production in Musanze and bean production in Rwerere and favor maize production in season A and bean production in season B. At Musanze, the RI was between approximately $1170–$2310 more valuable per year than the GM. Scenario 1 was most similar to market prices at the time the research took place. In this scenario, the RI and the TI were more valuable than the GM ($330 and $1020, respectively) and the GM was $670 more valuable than the SC. Scenario 5 illustrates the collinear movement of prices which is likely to occur under the GM since all farmers are required to grow the same crops at the same time so supply would be high and demand low causing prices for the surplus crops to be low. In this scenario every system at Musanze was more valuable than the GM ($170–$2310).

At Rwerere, the RI was more lucrative ($200–$720) than any other system in most scenarios. The GM was much more profitable than either the TI or the SC in all scenarios ($150–$770) because of the favorability of growing conditions for beans in Rwerere.

Discussion

Smallholder coping mechanisms

Interviews revealed that smallholders in northern Rwanda are looking for diverse services from cropping systems, many of which are overlooked by criteria shaping government policy. The services include the following: to provide the family with sufficient, nutritious and diverse foods; products to sell in exchange for other goods or to cover expenses; and to have preferred traditional foods to build social cohesion. These last services included diverse, culturally valued foods to share with neighbors and bring family members together, which notably are not addressed by sole-cropped systems promoted by recent agricultural policies in Rwanda. It is also evident from the interviews that collectively, these things contributed to farmers being "rich" and having "a good life." Thus, farmer priorities corresponded with definitions of food security, refined in 1996 to include concepts of access and availability as, "when all people, at all times, have physical and economic

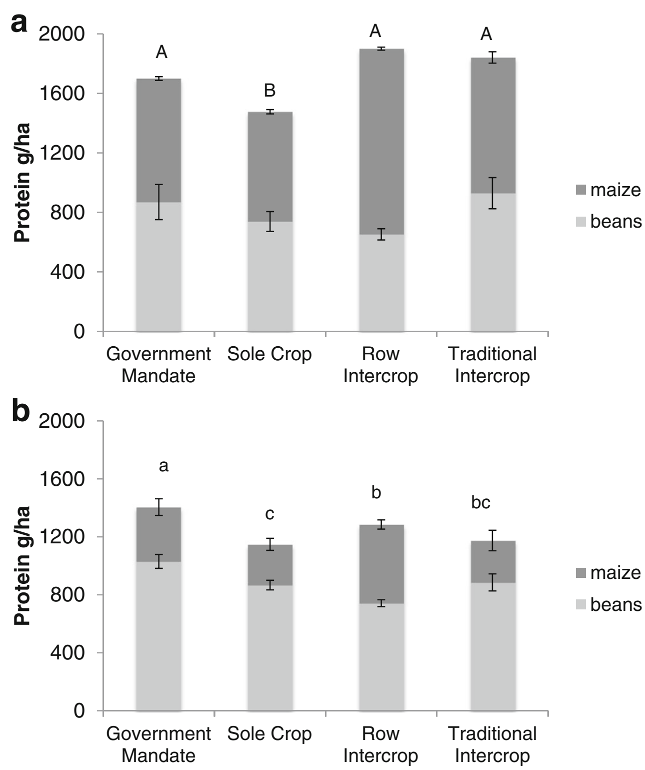

Fig 3 Protein content on an annual basis of four cropping systems added over two seasons at Musanze (**a**) and Rwerere (**b**) stations for Seasons B and A, 2011–12. Cropping systems with different upper-case letters were statistically different at Musanze and cropping systems with different lower-case letters were statistically different at Rwerere (<0.05 - <0.001). Error bars are the standard errors

Table 3 Market value price scenarios on an annual basis for four cropping systems added over two seasons at Musanze and Rwerere Stations for Seasons B and A, 2011–12

Price Scenarios		Base	1*	2	3	4	5
Output Prices (RWF/kg)							
Beans	Season B	200	300	200	300	200	200
	Season A	200	300	200	200	300	300
Maize	Season B	200	200	300	300	200	300
	Season A	200	200	300	200	300	200
$ value/ha = Cropping System - Government Mandate							
Cropping systems		Musanze					
Row Intercrop		$1169	$1016	$1907	$1809	$1115	$2308
Traditional Intercrop		$276	$334	$357	$762	-$71	$1458
Sole Crops		-$579	-$671	-$776	-$349	-$1098	$173
Row Intercrop		RWERERE					
		$197	-$6	$499	$100	$393	$718
Traditional Intercrop		-$451	-$553	-$574	-$554	-$573	-$3
Sole Crops		-$566	-$682	-$732	-$765	-$650	-$153

Simulation of five price scenarios relative to a base scenario of equal prices of maize and beans constant across seasons. $ value/ha represents the difference in economic value between alternative cropping systems and the Government Mandate (GM) cropping system. The GM system value was subtracted from the alternative cropping system value. Positive values indicate the alternative cropping systems is more valuable than the GM

*At the time of the research, values on the local market and historical retail prices were most similar to Scenario 1. Scenario 5 represents a situation where the value of one crop is low because supply is high. This is a situation that could occur under the mandate to grow only beans in Season 1 and only maize in Season 2

access to sufficient safe and nutritious food to meet their dietary needs and food preferences for a healthy and active life" (FAO 1996).

In this study, farmers identified crop diversity as key to providing the range of services they valued, and one of the main ways that farmers coped with socio-ecological fluctuations. This was supported by the agronomic findings from the research station trial that compared sole and mixed cropping systems, and concurs with ecological research on agricultural diversity and intercropping systems which has shown that more diversity increases functional ecosystem services (Vandermeer et al. 1998). Crop diversity was clearly about risk reduction and managing their farm as a portfolio to gain different assets that are all useful for direct consumption and that vary in their value. Others have come to similar conclusions, in that crops are chosen for multiple reasons including nutritional, agronomic, social, or economic considerations (Berti and Jones 2013).

The preferences for crops that provide nutritional and marketable goods, important for family well-being, were all expressed by women farmers in this study. There is evidence in the literature that men and women have different roles in the household, particularly in the provisioning of care to children (Quisumbing 1996, 2003) and they often have different priorities in the types of crops they grow, how they manage crop and varietal diversity, and allocation of household resources (Momsen 2007). But there is also evidence that the number of crops and varieties households decide to plant is not gender specific (Brush 2000). The respondents in this study associated crop diversity with being able to provide healthy and nutritious foods to their children and they indicated that a loss of diversity affected child health. This study shows that the health and well-being of the household are the principle concern of women farmers in Rwanda, but whether or not this is different from other household members is not discernable.

In the absence of well-developed market infrastructure, farmers in Rwanda are at risk of not being able to purchase diverse foodstuffs or sell products. Market prices fluctuate over the season and the year, and sudden shifts in food prices due to external forces are not uncommon. Crop diversity, however, allowed farmers to choose which crop they consume or sell, depending on the relative price of the crops at the time of sale. The price scenario analyses demonstrate the value of the intercropping system under volatile prices. It also demonstrates that the row intercrop was clearly the most valuable system at Musanze and appears to be superior to the government mandate system at Rwerere under various price scenarios.

The largest economic difference between the cropping systems is the transaction costs that would be involved in exchanging one crop for another if a farmer is sole cropping. Omamo (1998) found that households in Kenya incur average transport costs of about 12% of the market price of the crop. In addition to transport costs farmers would suffer a loss in profits extracted by middlemen when buying and selling crops and the government mandated cropping schedule could also lead to collinear price movements, which would depress prices if everyone is producing the same crop at the same time (De Janvry et al. 1991). Finally, there are differences and trade-offs in labor inputs between types of intercropping systems (Mucheru-Muna et al. 2010) and between intercrop and sole crop systems (Waddington et al. 2007). For example, intercropping can increase the need for careful weeding operations (Mucheru-Muna et al. 2010; Rusinamhodzi et al. 2012) while sole crop climbing bean systems require the procurement of stakes, a significant labor and cost constraint to bean production in Rwanda.

This shift from local production systems to market oriented production may contribute to the loss of crops that underpin traditional dietary diversity (Johns and Eyzaguirre 2006). Dietary diversity is a key component of healthy diets and is associated with nutritional status (Ruel 2003; Arimond and Ruel 2004). Our results from farmer interviews indicate that farmers perceived diminished market value for the mandated sole crops they do have, and less access to diverse foods for household consumption. In regions where market systems are weak and farmers are principally subsistent, diverse food crops are important for nutrition and well-being, although empirical evidence is somewhat limited (Johns and Eyzaguirre 2006). Remans et al. (2014) looked at three indices of diversity and found that, in low-income countries, the diversity of foods produced is a strong predicator of the diversity of foods available for human consumption at the national level, and Jones et al. (2014) found a positive relationship between production diversity and dietary diversity at the household level. This study adds qualitative evidence that smallholder farmers value crop diversity at the production level because it improves their access to diverse foods and contributes to family well-being. The loss of such diversity, if not replaced via effective and accessible market-oriented mechanisms, could have serious nutritional implications.

Cropping system performance and the environment

To understand how the supply of these provision services varies with different cropping systems in a given context, we converted the yields into yield indices to reflect land-use efficiency, marketability, and one element of dietary quality, protein content, in two distinct environments. Some earlier research has converted direct yield into indices of yield that reflect economic or nutritional concerns (Mead and Riley 1981; Willey 1985; Mead et al. 1986; Federer 2012) because different species in intercrops have unique unit values (Mead et al. 1986) and may have differences in price stability, harvest times, (Connolly et al. 2001) and nutritional value. Our approach took the next step to evaluate farmer preference for cropping system services in relationship to these indices to more fully understand cropping system trade-offs in separate environments.

The intercrop systems analyzed in this study are a potential mechanism for maintaining on-farm diversity and increasing the quality of provision services acquired from the production system. The analysis of intercrops can be complicated due to the distinct components, but assessing them using farmer-driven criteria adds depth to our understanding. Farmers indicated that diverse crops give them the opportunity to change foods each day, and make them strong against disease. Beans are the principle source of protein in Rwandan subsistent households, an important nutritious food for young children (Asare-Marfo, D., Birol, E., Katsvairo, L., Manirere, J. d. A., Maniriho, F., & Roy, D. (2013). Farmer choice of bean varieties in Rwanda: lessons learnt for HarvestPlus delivery and marketing strategies. HarvestPlus. Unpublished project report), and also contribute dietary fiber, vitamins B2 and B6, zinc, iron, manganese, iodine, potassium, magnesium, and phosphorus (DeClerck et al. 2011). Conversion of the yield data to protein allows us to compare the different cropping systems in a single unit, and captures one aspect of nutritional value. The protein results demonstrate that an optimized bean-maize intercrop system provides more protein, more complete amino acids (Bressani 1983), and logically, more micronutrients than sole crops, even when both crops are grown in the same season. The consumption of legumes and cereals together can alleviate mutual deficiencies in amino acids, ensuring a more balanced diet (Broughton et al. 2003) and legumes are better sources of micronutrients than cereals (Welch et al. 2000).

The field trials conducted in two northern Rwanda research stations over two seasons illustrate how environment can strongly affect yield responses and other services provided by different cropping systems. This is not surprising as Rwanda is a highly heterogeneous country, with ten recognized agroecological zones (MINIAGRI et al. 2009b) and growing conditions can vary markedly from one valley to the next, increasing the complexity of developing resilient farming systems. The bimodal rainy season adds another layer of complexity in that farmers report that specific crop species tend to perform better in one season while others do better in the other. More specifically, maize performs best in Season A and beans in Season B. The government mandated cropping system adheres to this pattern and our agronomic results confirm these findings. Sole crop bean yields were 1–1.5 mt/ha higher in Season B than A and sole crop maize yields were 2–2.4 mt/ha higher in Season A than B (Table 1). In a review of multi-species agriculture in India, Trenbath (1999) observed that in two contrasting species of crop, the differing responses to environmental fluctuations might cause individual yields to be negatively correlated, as we observed here. In such a situation, farmers will get a more stable food supply over time when they plant intercrops, as was the case at Musanze; or when they plant a combination of intercrops and sole crops, as was the case at Rwerere (Fig. 2). Variability in yield was also the lowest in row intercrop (Table 1), indicating better yield stability over the year than for the sole cropped systems and other research has shown multi-crop systems have greater stability (Wolfe 2000).

Generally, both sole crop systems failed to meet smallholders' expectations of farming systems, although the government mandate system was sometimes comparable to the row intercrop. In terms of yields alone (Fig. 2), at Musanze the row intercrop was the highest and the government mandate was similar to the farmers' traditional intercrop. At Rwerere, the row intercrop and the government mandate were advantageous. However, the farmers indicated they want to produce more than one crop in the same season because multiple crops provide more options for meeting household needs. The sole crop was designed to accommodate this by planting two sole crops in the same season, but it performed the poorest across all environments and indices, because the off-season crop did poorly and did not have the additive yield advantage often found in bean-maize intercrops (Tsubo et al. 2005). While the sole crop system had the same elements of seasonal diversity as the intercrop, it did not provide as many services as the intercrop systems and the government mandate system only provided one crop per growing season, which decreased the value on the market and limited food choices. In this sense, both types of sole crop systems failed to meet farmer criteria and the row intercrop provided more services than any other system.

The interviews indicated farmers were concerned about potential crop failure from seasonal variability and thus, they managed planting dates for a staggered harvest and seed savings to ensure there were alternative production sources to meet household needs. They also planted varietal mixtures, which ensure that at least one variety would survive climatic and edaphic variability (Voss 1992; Sperling and Berkowitz 1994), and households planted across the landscape (from valley bottoms to hilltops) to utilize different environmental niches. Conelly and Chaiken (2000) reported that farmers in west Kenya consciously diversified cropping systems through the use of varietal mixtures, cultivation of multi-purpose crops, and the exploitation of micro-environmental variation. Research from human ecology shows that different varieties and crops are assembled to satisfy consumption preferences, farming in diverse environments, or fulfilling marketing requirements (Bellon 1996; Smale 2005). Furthermore, these different roles of crop diversity are not mutually exclusive (Bellon 1996) and may provide complementary provision services. Management of diversity at the genetic (Smithson and Lenne 1996; Hajjar et al. 2008), field, intermediate and landscape level can confer additional ecosystem services and can contribute to more resilient farming systems (Blarel et al. 1992; Swift et al. 2004). In this setting, farmers apply these principles of diversity to manage environmental heterogeneity in such a way that they can cope with shocks to the system. The current sole-cropping government policy may undermine this diversity and thus provision services produced over the year. Loss of this diversity reduces the buffering capacity of smallholder farmers to respond to household and environmental shocks.

Farmers believed that their multi-cropping systems were more effective at meeting their food and income expectations than the government mandated cropping system, but interestingly the traditional intercrop had more complex results than the researcher designed row intercrop and did not always perform better than the government mandate. Most literature on bean-maize intercropping systems confirm that mixed cropping systems are more productive (Smith and Francis 1986; Vandermeer 1992; Graham and Ranalli 1997; Connolly et al. 2001; Tsubo et al. 2005; Malézieux et al. 2009; Li et al. 2014), so it would follow that they might provide more provisioning services than conventional systems. But often intercrop systems are not optimized to the environment (Vandermeer 2011). Results from the field trials indicate that the row intercrop performed well across both environments but the traditional intercrop, the system farmers typically grow, had mixed results. At Musanze, the traditional intercrop provided as many or more services than the sole crops in terms of land-use efficiency (Fig. 2 and Table 2), protein (Fig. 3), and price scenarios (Table 3). At Rwerere, it provided more or comparable services than the sole crops in terms of yield and protein (Figs. 2 and 3) but wasn't advantageous in land-use efficiency (Table 2), nor on the market (Table 3). That the traditional intercrop had a very high bean density and performed poorly at Rwerere where beans grow exceptionally well indicates the system may not be optimized for this environment and there are opportunities to adapt the systems to better suit the environment.

Conclusions

The Rwandan CIP agricultural policy identified the important notion of regional specialization - that growing one crop in a given region could maximize total profit to the household and place the country in a position to be a net exporter of a given crop. However, the policy neglected to consider that intercropping beans does not necessarily depress maize yield and is in some cases additive. The policy may need to consider that any gains from specialization and trade are lost due to the high transaction costs common in developing countries as a result of market failure (De Janvry et al. 1991). Furthermore, the provision services that the diverse cropping systems provide to households are integral to farmer livelihood strategies and careful consideration of these needs is necessary to build a sustainable and productive agricultural sector.

Farmers have an extensive and unique understanding of their environments and the resources that they need to obtain from their farming systems, but this knowledge base is an overlooked and underutilized resource. Smallholder farmers are also innovators that have their own criteria for system performance (Ansoms 2008; Huggins 2013), but because of strict enforcement of government policies in Rwanda, there is little room for farmers to make choices or experiment. Future policies may consider both smallholder preferences and innovation to further develop resilient farming systems that contribute to agricultural growth. A key principal of resilient farming systems is adaptability, or "the capacity of a socio-ecological system to learn, combine experience and knowledge, adjust its responses to changing external drivers and internal process" (Folke et al. 2010). In the current policy environment there are limited opportunities for farmers to practice innovation and adaptation with their farming systems and a less restrictive policy might generate more resilient systems with potential for economic growth.

It has been argued that combining traditional scientific knowledge with traditional indigenous knowledge could result in innovative strategies that improve smallholder systems (DeWalt 1994; Snapp et al. 2002) and potentially increase system resilience. Researchers designed the row intercrop with input from farmers, and it performed exceptionally well on the research stations. The next step could be to engage further with farmers, combining experience and knowledge to adjust the intercrop systems to fit both the environment and system expectations. Unfortunately, a barrier to this approach is government policies that prevent farmers from intercropping or even growing different crops than the ones mandated for a specific season. Without the flexibility to experiment and adapt systems and species grown in response to changing processes, the chances of developing efficient and resilient systems is minimal.

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