Barriers to sustainable intensification: overlooked disconnects between agricultural extension and farmer practice in maize-legume cropping systems in Tanzania

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ABSTRACT

Effective extension systems are vital to smallholder agriculture. Education on sustainable management involves complex interactions and communication flows among information providers and practitioners. Farmer practice is often overlooked within extension knowledge systems, resulting in incompatible recommendations and barriers to sustainable agriculture. This study investigates the diversity of smallholder agricultural practices, with a focus on maize-legume systems in Tanzania, including seasonal cropping patterns and management, as well as linkages to extension recommendations and information flows. We used a mixed methods approach to assess the state of extension and farmer practice around maize-legume production in Tanzania. Household and plot-level survey data ($n = 220$) and focus group discussions ($n = 5$) and extension information was ascertained through interviews with key stakeholders ($n = 12$) and a survey of village-based extension advisors ($n = 193$). We found legume management practices were highly local. In the Southern Highlands for example, farmers produced from one to three bean crops per year, using a range of planting arrangements. Further, extension recommendations often did not take into account the varieties, fertilizer or plant spacing used by farmers. This comprehensive study of extension knowledge systems in Tanzania highlights the persistent disconnects that occur at multiple levels, acting as a barrier to sustainable intensification of smallholder farming.

Introduction

Extension of sustainable agricultural practices is a key component to achieving sustainable intensification (SI) of smallholder cropping systems, but there are many barriers to achieving effective extension (Pretty et al., 2011). This can be seen in disconnects between support provided by extension and farmer practices, whereby extension provides information and services that may be incompatible with current farming systems (Meijer et al., 2015). In order to identify and disseminate sustainable practices, local farming systems and conditions must be understood. Contextualizing practices and understanding local conditions is essential in sub-Saharan Africa where most agricultural production is undertaken by smallholder farmers spanning diverse land, climatic, and cultural conditions (Aune et al., 2017). As such, local adaptation of farmer practices is key, and requires flexible extension systems facilitating local knowledge exchange.

Local farmer knowledge, including practices and priorities, has commonly been overlooked in extension knowledge systems (Biggs, 1990; Scott, 1998). Linear dissemination of input-oriented solutions and technologies has until recently been a dominant agricultural extension mode (Koutsouris, 2018;

Leeuwis, 2004). This model addresses farmers as a homogenous entity, overlooking the diversity of needs and priorities of farmers. This has served to marginalize farmer knowledge, particulary ignoring the conditions of women, who account for a large portion of smallholder farming labour (Farnworth et al., 2015). Participatory research approaches attempting to counteract this historical approach and prioritize farmer knowledge have received considerable attention, and are a key component for developing sustainable agriculture (Nerbonne & Lentz, 2003; Pretty et al., 2011; Snapp et al., 2002a). Despite this, a linear technology transfer model still dominates (Neef & Neubert, 2011). The ineffectiveness of this form of extension is often framed as insufficient knowledge transfer from extension to farmer (Lukuyu et al., 2012; Niu & Ragasa, 2018; Sekiya et al., 2015). This approach assumes that the technology being promoted would be effective if all information and resources were received by the farmer, rather than allowing for adaptation of practices to farmers' local conditions and needs.

Reviews of farming systems research and extension show that local farming context and farmer practice largely continue to be disregarded (Salembier et al., 2018). While the value of local farming knowledge has been promoted in participatory research, there have been limited attempts to systematically incorporate this knowledge source into research and extension systems (Glover, 2007; Snapp et al., 2003). The consequences of excluding farmer knowledge from agricultural research is demonstrated by Schindler et al. (2016) which evaluated farmer and researcher knowledge for a project on improved agricultural practices in central Tanzania. The authors found that farmers reported potential negative effects, risks and incompatibilities of practices, which had not been previously identified by researchers.

Strengthening extension systems for sustainable agriculture requires critical examination of current information pathways. Extension systems include many actors, ranging from government, research, NGOs, to industry (Agbamu, 2000). Given this diversity of information providers, there is need for understanding the interaction among these groups and identifying their knowledge sources. This is especially important in countries where public extension funding is limited, with high reliance on private extension sources (Coutts et al., 2019; Lowder et al., 2012). While attention has been given to increasing public-private linkages in agriculture, there are concerns for how these linkages occur, and if they are supportive of sustainable agriculture. In order to be effective in supporting agricultural production, partner institutions must be complementary and transparent, honest brokers in facilitating knowledge exchange (Davis et al., 2018; Glover, 2007; Hall, 2006). This warrants an examination of current knowledge exchange to ensure effective functioning of extension systems.

An additional challenge for extension systems that address SI are the limitations in technical content and lack of hyper local advice that address the complexity of smallholder farming systems (Giller et al., 2011; Ronner et al., 2019). This is especially true of knowledge around the production of legumes within cereal based rainfed production, one of the pillars of SI. Legumes are widely grown by smallholder farmers and incorporating them with cereals production is a means to enhance biological nutrient cycling, resilient production, and family nutrition (Pretty et al., 2011; Snapp et al., 2018). A recent country-wide survey in Tanzania highlighted SI benefits including child nutrition gains associated specifically with maize-legume cropping systems (Kim et al., 2019). However, legume crop production is a knowledge-intensive, complex aspect of smallholder farming systems, often influenced by gender and resource constraints and therefore may not be well served by hierarchical extension systems (Ferguson, 1994; Waldman et al., 2016). As such, there has been limited extension support that acknowledges the complex cropping systems within which legumes are produced (Giller et al., 2011; Muoni et al., 2019). A key SI gap to translating research into practice is thus understanding how extension systems function in relation to smallholder grain legume intensification on smallholder farms.

In Tanzania, the government extension system operates under a hierarchical structure whereby research generated by institutes under the Ministry of Agriculture is reported to regional level government officials responsible for disseminating the information down to extension workers who operate at the village level (Mattee, 1994). In addition to the government, NGOs and private companies are also involved in the generation and dissemination of agricultural knowledge, partly as a response to insufficient reach by poorly resourced government extension (Birner et al., 2009). NGO and agro-industry extension services in Tanzania, however, are not formally integrated into the public sector, and it is unclear how they are influencing local extension and farming

practices (Rutatora & Mattee, 2001). In a review of agricultural extension research globally, characterizing advisory services within a particular country has been identified as a priority area for research (Faure et al., 2012).

To understand disconnects and connections across research, extension and farmer practices, multiple levels must be considered, from farmer practice to extension recommendations, including the sources of such recommendations. This study considers the extension system in Tanzania, in relation to farming practices and extension recommendations around maize-legume cropping systems. Specifically, we focus on the two main legumes grown in rainfed cropping systems of Tanzania, common bean (*Phaseolus vulgaris*) and pigeonpea (*Cajanus cajan*). The objectives of this study were to: (1) understand the diversity of smallholder agricultural systems in Tanzania through identifying seasonal cropping patterns and practices on legume and maize-legume plots; (2) document extension knowledge systems and information sources in Tanzania, specifically for the Southern Highlands, and (3) elucidate extension recommendations and farmer practices to better understand connections and disconnects as they relate to legume production within maize-based systems.

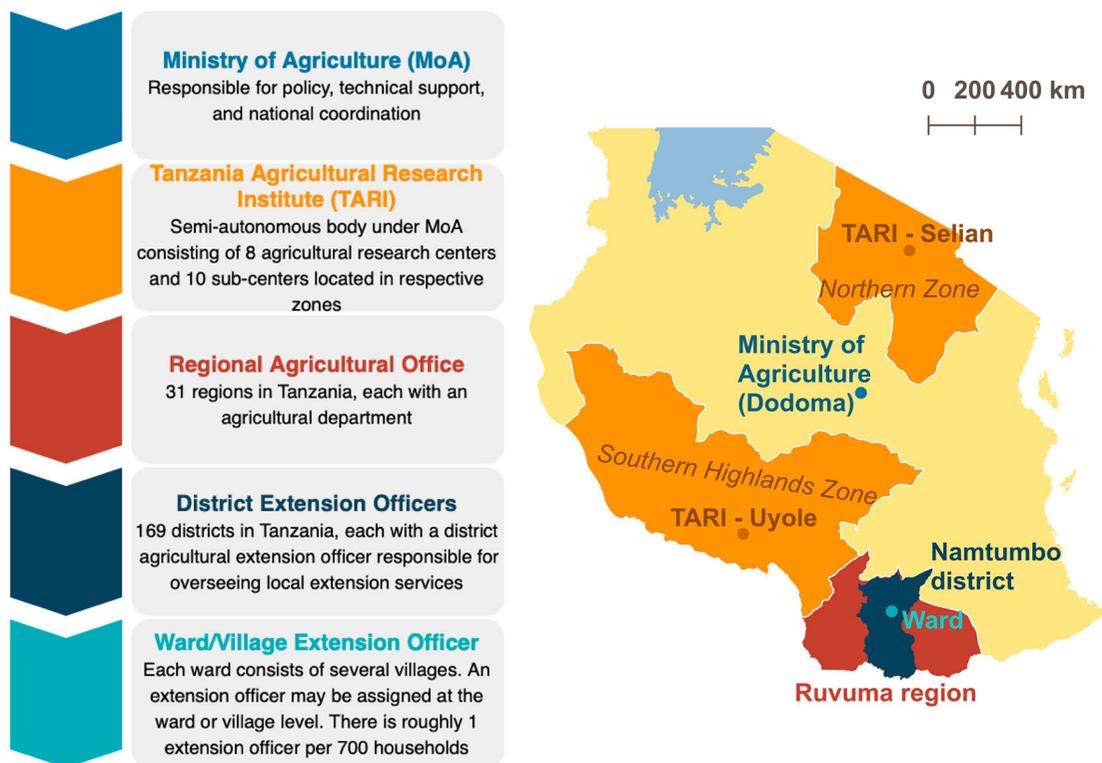## Materials and methods

Research area

This study is focused on the regions of Tanzania dominated by rainfed maize-legume cropping systems (Mnenwa & Maliti, 2010). Administratively, Tanzania is divided into regions which are further divided into districts made up of wards, each one representing several villages (Figure 1). Agricultural extension is divided into eight zones in the country, each of which includes several regions and thus hundreds of wards (Tanzania, 2012). The main areas of research in this study focus on legume agricultural activities within maize-legume cropping systems in the North and Southern Highlands agroecological zones. Within each zone is an agricultural research centre, being a constituent of the Tanzania Agricultural Research Institute (TARI) that is responsible for conducting research related to the agricultural needs across the country. TARI-Uyole is the research centre responsible for covering the Southern Highlands zone and TARI-Selian represents the North zone.

Data collection methods

The mixed methods study conducted in Tanzania involved primary and secondary data sources to capture farmer cropping systems, management practices, extension information sources, and extension recommendations. Data collection on farmer management included a survey carried out by the Taking Maize to Scale in Africa Project (TAMASA) during the main 2017 maize harvest season within the North and Southern Highlands agroecological zones of Tanzania and farmer focus group discussions in two districts (Mbeya and Mbozi) of the Southern Highlands. Extension recommendations were obtained through interviews with extension officers in both the North and Southern Highlands zones conducted between June-July 2016, a survey in February 2019 in the Southern Highlands zone with village-based agricultural advisors (VBAAs), and printed material supplied by the Ministry of Agriculture (Figure 2). Printed material included a book published by the Department of Research and Training under the Ministry of Agriculture which provides detailed extension recommendations for all major agricultural crops grown in Tanzania (Kanyeka et al., 2007). The research in this study was granted an exemption by the Michigan State University (MSU) Institutional Review Board (IRB# x16-362e) for human subjects research.

Farmer practice – survey

A country-wide survey to generate data on household socio-economic factors and on focal plot management was conducted by the International Maize and Wheat Improvement Center (CIMMYT) under the Taking Maize to Scale in Africa (TAMASA) project with support from the Sustainable Intensification Innovation Lab (SIIL). The survey targeted the main maize producing areas in Tanzania with the goal of identifying detailed management practices on smallholder maize production. A stratified spatial sampling frame was used to identify the survey areas selecting major maize production areas across a range of soil types and diverse agro-ecologies. A detailed description of this sampling frame has been previously described in Andrade et al. (2019). From this sampling frame 75 1×1 km grid locations, with 3 grids per district (25 districts total), were randomly chosen for identifying survey households. Within each grid a list of all households actively farming land was collected, and 8 households randomly selected to be
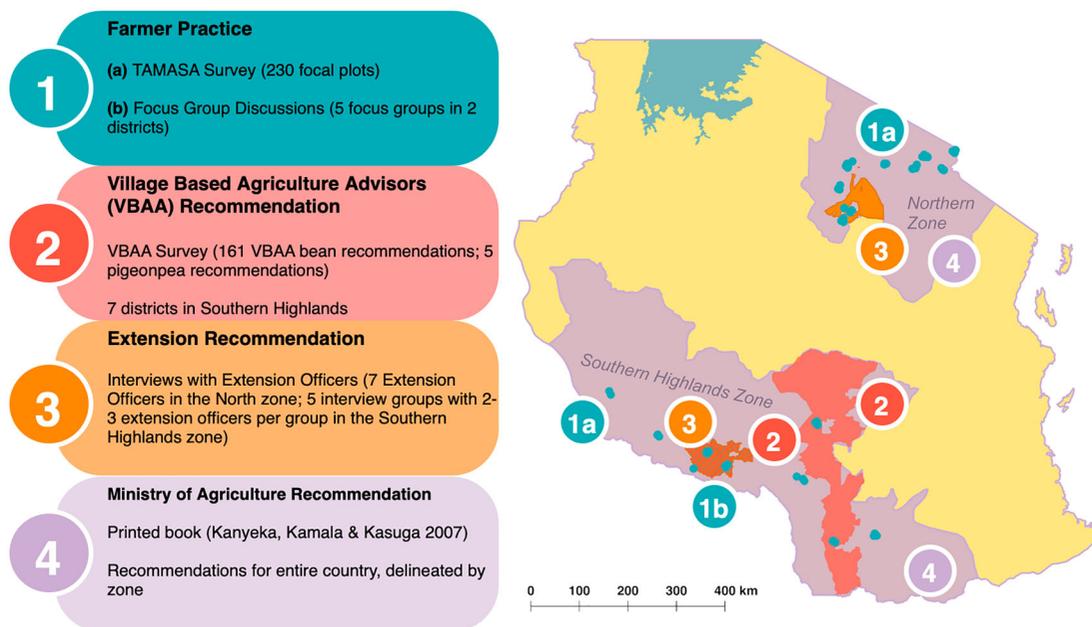
Figure 1. Extension diagram demonstrating different levels of public extension organization in Tanzania. Order of oversight starts with the Ministry of Agriculture, which oversees the Department of Research and Training under which is the Tanzania Agricultural Research institute (TARI), a semi-autonomous body with 8 centres and 10 sub-centres throughout the country. Regions (e.g. Ruvuma) are administrative units which comprise of several districts (e.g. Namtumbo) within which are wards made up of several villages.

surveyed. The household member interviewed for the survey identified a focal plot in the first year of the project (2016), defined as the maize plot most important to a household's maize production, from which detailed plot management information and plant samples were collected. The same focal plots were revisited in 2017 with the same management questions covered regardless of whether maize was the primary crop that year. This allowed for capturing detailed management practices around legume production, with pigeonpea and common bean being the two most common legumes grown on the focal plots. The survey was conducted in May–July 2017 during the main maize harvesting period, a time when pigeonpea is still present in the plot. As such pigeonpea plant measurements were also taken on the focal plots where pigeonpea was present, allowing for measurements to be recorded on plant spacing and density. Survey responses resulted in 557 focal plots with crop management information,

with 220 (46%) of these including legumes, the majority being common bean or pigeonpea. From the 220 plots, management practices were summarized by the cropping system in which the legumes were grown and by zone (North vs. Southern Highlands). Pigeonpea was always grown as an intercrop with maize, and so the pigeonpea system refers to intercropping of pigeonpea with maize. Common bean was found to be grown as both a sole crop (rotated with maize across years) and intercropped with maize, and plots were delineated as such (sole bean vs. maize-bean) for descriptive analysis.

Farmer practice – focus group discussions

To capture detailed legume management information, focusing on common bean in particular, and expanding upon information collected through the TAMASA survey, five farmer focus group discussions were conducted in 2016 in the Southern Highlands, across five

Figure 2. Diagram illustrating information sources used for bean and pigeonpea farmer management and recommendations in this study. Each source represents a different level at which information was collected, ranging from the highly local farmer practice (1a & b) to country-wide Ministry of Agriculture (4).

wards that were visited in the TAMASA survey and are known to be major bean producing areas. These five wards covered two different districts representing two regions in the Southern Highlands. They are Magamba and Itumpi wards in Mbozi district, Songwe region and Mapinduzi, Itawa, and Mshewe wards in Mbeya Rural district, Mbeya region. Focus groups included 10–12 farmers representing multiple villages within the ward. The ward agricultural officer selected farmers who primarily grew beans to be participants, including both men and women farmers in each group. Focus group questions focused on bean management practices within the ward, including questions concerning the utilization of bean across harvests, family food sources, and food security. Given that beans are planted multiple times throughout the growing season in each ward, bean management questions included identifying the timing of the main bean management practices such as land preparation, planting, weeding, and harvest for each of the bean plantings.

Agricultural extension – interviews

Extension recommendation information was collected through a total of 12 semi-structured interviews in 2016 from village, ward and district level government extension officers as well as from one researcher at the Tanzania Agricultural Research Institute in Uyole (TARI-Uyole). In the Southern Highlands zone five interviews were conducted across five wards with groups of 2–3 ward and village level agricultural extension officers. In the North zone five ward level extension officers were interviewed individually. Respondents were asked to detail the recommendations for beans in the Souther Highlands zone and pigeonpea in the North zone with a focus on varieties, spacing, fertilizer type and amount, method and timing of fertilizer application. Questions also included how the legumes are typically grown by farmers, if farmers follow the recommendations mentioned, source of information for extension recommendations and whether farmers ever provide feedback on recommendations. The same set of questions were asked in interviews conducted with three district level extension in Mbeya district in the Southern Highlands and two extension staff in the Babati district in the North zone. For these respondents additional questions were asked concerning how recommendations were compiled.

Agricultural extension – survey

In addition to government extension officers, recommendations were documented for village-based agricultural advisors (VBAAs) of the non-profit organization Farm Inputs Promotions-Africa (FIPS-Africa). The purpose of using VBAA recommendations as an extension source was to gain a better understanding of field level recommendations provided to farmers from a public-private entity and to see if this source differs from traditional extension knowledge sources. The VBAA extension approach is a new model being promoted as a scalable support system that supplements government extension by providing training to farmers to act as local extension advisors. Public-private linkages are created through this model, as VBAAs are trained to be village-based agricultural input providers. VBAAs are selected by their communities and trained in good agricultural practices and entrepreneurship.

VBAAs' primary activities involve setting up 'mother demos' and distributing free small packs of improved seed varieties or inputs (e.g. fertilizer or seed treatments) to farmers in their communities. The demonstration plots highlight improved varieties, efficient application of inputs and good agricultural management practices being promoted. Distributing small packs allows for farmers to experiment with the inputs being promoted on the mother demos on their own farms. Similar to mother and baby trials, this participatory approach aims to improve farmer learning and engagement around the management practices (Snapp et al., 2002a). In 2017, 216 VBAAs from six regions in the Southern Highlands area received additional bean agronomy training highlighting improved bean varieties and the use of the fungicide-insecticide seed treatment ApronStar. Prior to receiving training, an initial baseline survey of VBAAs was conducted and responses on bean recommendations, specifically recommended bean varieties, were used for this study. In 2019, 193 of these VBAAs were reached for a follow-up survey to assess their activities as VBAAs and the recommendations that they provided to farmers in the previous growing season. From these responses, VBAA recommendations on bean and pigeonpea were summarized and compared to legume recommendations from government extension and farmer practice (Figure 2).

Results

Farmer practice of maize-legume cropping systems

The TAMASA survey recorded maize-legume cropping systems in focal study plots where a wide range of cropping systems were observed, with marked differences between the North and Southern Highlands zones (Table 1). Common bean and pigeonpea were the most common legumes present, with pigeonpea plots always grown as an intercrop with maize and common bean grown either as an intercrop or in rotation with maize (sole bean). Household members involved in the decision making of plot management did not differ across cropping system or area. Decision making was split between either solely the head of the house, usually the husband, or shared jointly between husband and wife (44% of focal plots). Female headed households were rare, accounting for only 9% of the households included in this study.

Pigeonpea plots were found in both the North and Southern Highlands, with the majority (87 out of 114) in the North zone (Table 1). Pigeonpea plots in the North had the highest average plot size (1 ha) compared to the plots in the Southern Highlands (0.69 ha), and all bean plots in the North and Southern Highlands zones ranged from 0.49 to 0.65 ha. Planting characteristics also differed in pigeonpea plots in the North versus Southern Highlands, with pigeonpea in the North planted at a much higher density (18,800 plants ha^{-1}) than in the Southern Highlands (8400 plants ha^{-1}). Pigeonpea was broadcast planted around maize in about half of the plots, and in rows for the remainder (Table 1). In the North, pigeonpea tended to be planted between maize rows (33 out of 46) whereas in the Southern Highlands pigeonpea planting occurred within maize rows in all 14 plots. Seed types were mainly local seed varieties at all locations, with only five plots in the North and one in the Southern Highlands reporting use of improved pigeonpea seeds. Recycled seeds dominated, with only 13 out of 87 plots reporting use of purchased seed. Fertilizer was applied widely to pigeonpea, particularly for Southern Highlands plots (74%), which had high application rates (141 kg ha^{-1}) compared to Northern plots (18% use, 111 kg ha^{-1} average urea application). In both areas the majority of inorganic fertilizer applied was urea, suggesting fertilizer use was targeted to maize. The

Table 1. Farmer practice of pigeonpea and bean cropping systems collected from TAMASA survey focal plots.

	North			Southern Highlands		
	Maize-bean intercrop	Sole bean	Pigeonpea	Maize-bean intercrop	Sole bean	Pigeonpea
$n_{focal\ plots}$	51	4	87	13	38	27
Focal plot size (ha)	0.57	0.65	1.0	0.49	0.61	0.69
Focal plot decision making (n = # plots)	26 (7 Female)	4 (0 Female)	42 (6 Female)	8 (3 Female)	16 (2 Female)	13 (1 Female)
Head only	23		40	4	21	9
Male Head + Spouse	2	0	5	1	1	5
Other	0	0				
Seed types[a]						
% Local	39 (95%)	4 (100%)	62 (93%)	10 (100%)	31 (82%)	19 (95%)
% Improved	2 (5%)	0	5 (7%)	0	7 (18%)	1 (5%)
Legume plant spacing[b]	–	–	78 cm × 57 cm	–	–	103 cm × 106 cm
Maize plant spacing	85 cm × 51 cm	–	80 cm × 46 cm	79 cm × 46 cm	–	86 cm × 45 cm
Plant density (plants ha^{-1})[b]	–	–	18,800	–	–	8400
Fertilizer Use (Organic/Inorganic)	17 (33%)	0	16 (18%)	5 (38%)	21 (55%)	20 (74%)
Type (n = number of plots)	Urea (14); Manure (4); DAP (2)	N/A	Manure (7); Urea (6); Compost (2); SA(1)	Urea (4); DAP (2); CAN (2)	DAP (20); Yara (2); Urea (1)	Urea (16); SA (13); CAN (2); Yara (1)
Inorganic Fertilizer Rate[c]	Urea	N/A	Urea	Urea	DAP	Urea
Average (kg ha^{-1})	180		111	32	161	141
Range (kg ha^{-1})	54–558		4.9–195	15–69	37–417	20–333
Pesticide (Insecticide, Herbicide, etc)	1 (2%)	0	2 (2%)	0	6 (16%)	0

Notes: Pigeonpea systems refer to pigeonpea intercropped with maize, but for simplicity are referenced as pigeonpea.
[a]Of reported seed types – not all respondents reported source of seed, therefore number of responses do not sum to number of plots in each cropping system.
[b]Legume plant spacing and density reported for pigeonpea only due to common bean being already harvested at time of data collection.
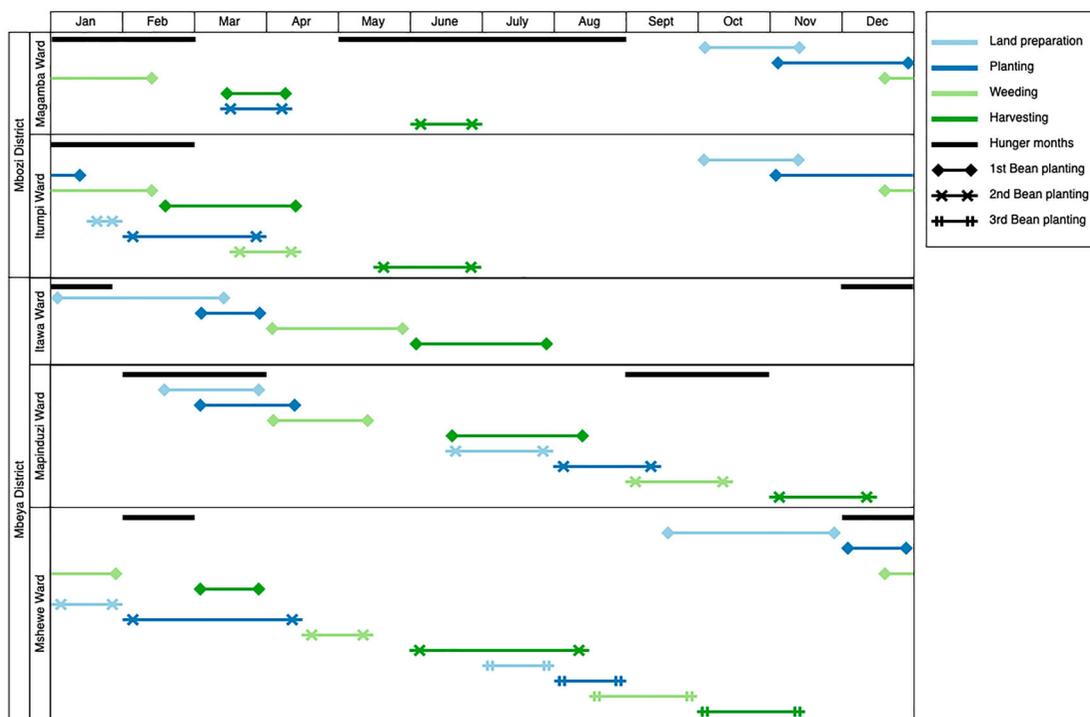[c]Of most reported inorganic fertilizer.

main fertility amendment applied in North pigeonpea plots was manure, reflective of high manure use in the North zone in general.

Common bean plots were characterized as either maize-bean intercrop or sole bean (Table 1). Sole bean plots were mostly found in the Southern Highlands area (n = 38), where they were continually rotated with maize as indicated by the reported five-year land use history of the plots. North zone sole bean plots were few (n = 4) and were less consistently rotated with maize and more commonly included other crops in the previous growing seasons. Instead, common bean plots in the North were more often intercropped with maize (n = 51) than in the Southern Highlands. Similar to pigeonpea, common bean seed varieties used were mostly local and recycled. Sole bean plots in the Southern Highlands had the highest use of improved varieties (n = 7), but even these were mostly recycled (4 out of 7). Fertilizer use differed between maize-bean plots and sole bean plots, with 31% of maize-bean plots having fertilizer applied of which most was urea. In contrast, 55% of sole bean plots (not including the 4 North plots) had fertilizer applied, most of which was diammonium phosphate (DAP) (20 out of 21). Fertilizer rates varied, with the largest range found amongst urea application on maize-bean plots in the North (54–558 kg ha^{-1}), averaging 180 kg ha^{-1}. Maize-bean plots in the Southern Highlands in contrast had an average of 32 kg fertilizer ha^{-1} with a range of 15–69 kg ha^{-1}. DAP application on sole bean plots in the Southern Highlands had the second highest application rate, at 161 kg ha^{-1} per plot and range of 37–417 kg ha^{-1}. Pesticide use, including herbicides and insecticides, was overall low (0-16% of plots across cropping system), with the highest occurrence in sole bean plots in the Southern Highlands.

Common bean systems in Southern Highlands

A crop calendar was constructed from the Southern Highlands focus groups displaying the different management practices across the year for each common

Figure 3. Calendar detailing the main bean crop activities of land preparation (light blue), planting (dark blue), weeding (light green), and harvesting (green) across five wards in the Southern Highlands zone for each bean planting (delineated by symbols) that occurred in the ward throughout the year. Line colour and symbol identify crop activity for a specific bean planting with length of line showing months that activity typically occur (e.g. In Magamba ward blue diamond line denotes land preparation for 1st bean planting occurring from October to mid-November). Solid black line indicates typical food-scarcity months ('hunger months') in the ward to demonstrate overlap of hunger months with bean crop activities. Data collected from interviews with farmers in these wards.

bean planting that commonly occurred in a ward (Figure 3). Many areas within the Southern Highlands have multiple plantings of common beans (four out of five wards), and number of plantings and timing of plantings varies widely. Within wards where multiple plantings of beans were common, some farmers did not plant multiple times. For some, if the first bean planting is delayed, the harvest will not occur early enough to plant the second bean crop before the rains end. Low soil moisture was a main reason cited for not supporting multiple bean plantings. This could be due to insufficient rainfall or due to local soil conditions that did not retain a sufficient level of moisture to support an additional bean crop.

Overall, there were four bean planting patterns that varied due to local rainfall distribution and soil moisture (Figure 3). The first pattern, commonly seen in Mbozi district, involved planting beans at the start of the rainy season followed by a second bean planting around the time of the first planting's harvest, which corresponded with the last two

months of seasonal rainfall. Another pattern included delaying the first bean planting until the middle of the rainy season, followed by a second planting during the dry season. This system depended on sufficient residual soil moisture and occurred in areas where rainfall in the beginning of the season was of high intensity thus preventing a successful early bean crop (e.g. Mapinduzi ward). A third pattern, observed in Mshewe ward, included three bean planting times: one at the beginning of the rainy season, a second after that harvest, and a third carrying over into the first planting of the following rainy season. Interestingly, an area with just one bean planting during a growing season is located in the same region as the ward with three bean plantings demonstrating the highly local nature of bean cropping patterns in areas such as the Southern Highlands where local topography creates highly differentiated microclimates.

Bean crop management sometimes differed by planting period, with less labour and inputs

commonly given to the second bean planting. One ward (Magamba) noted that the first bean planting was expected to produce higher yields than the second. Most often respondents noted that the second bean planting was weeded less or not at all and land preparation was often not done at all in comparison to the first. Herbicides were used by at least some farmers at all locations. When used in areas where farmers planted multiple bean plantings, herbicides were generally applied during the first bean planting, and not necessarily at the second planting. Insecticides were commonly noted as being applied around the time of weeding.

In addition to bean production activities, respondents identified the months when food security is an issue, and coping strategies used. While periods of food insufficiency and bean cropping varied, within each area hunger periods commonly occurred just before bean harvests and sometimes after (Figure 3). The alignment of food insecure periods with bean harvests highlight the potential contribution of gains in bean production to directly address household food insecurity. Coping strategies mentioned by respondents also included borrowing food to be repaid with future harvests and selling cash crops such as beans. Generally, utilization of bean harvests was for both home consumption and market.

Similarly, for bean varieties grown, generally there was no preference for planting certain varieties during one planting time versus another. Some bean varieties were seen as desirable based on early maturity, which allowed for planting multiple times. The first bean harvest was often used as seed for the second, which has important sustainable intensification implications given the key role that informal seed systems play in Africa.

Local extension recommendations (VBAAs)

Extension advice by VBAAs to farmers in the Southern Highlands is reported based on the VBAA survey (Table 2). The recommendations primarily focused on bean production (161 out of 193 VBAAs), with a few VBAAs ($n = 5$) additionally making recommendations on pigeonpea (Table 2). Advice included recommendations on spacing, fertilizer use, seed varieties, and other inputs, with some VBAAs providing recommendations for all topics and others for just a few. Of the VBAAs providing spacing recommendations, all recommended planting beans in rows but recommended row spacing distance varied. The majority (54%) of VBAAs recommended a spacing of 50 cm between rows and 10 cm within row, while 16% of respondents recommended

Table 2. Village-based agricultural advisors (VBAA) recommendations from VBAA survey.

Pigeonpea	n_{VBAAs} providing recommendations	5
	Recommended planting sole cropped	100%
	Spacing	75 cm × 30 cm (1)
		75 cm × 60 cm (1)
		80 cm × 30 cm (1)
		80 cm × 40 cm (1)
	Fertilizer	DAP (2)
	Seed	Local, white variety (2)
Common Bean	n_{VBAAs} providing spacing recommendations	161
	Recommended planting in rows	100%
	Bean spacing	50 cm × 10 cm (86) 54%
		30 cm × 10 cm (26) 16%
		Others (49) 30%
	Bean fertilizer – Recommend (Y/N)	Y – (156) 81%
	Bean fertilizer – Types[a]	DAP – (115) 74%
		Yara – (44) 28%
		Others – (19) 12%
	Bean fertilizer – Rate	50 kg/acre – (103) 66%
		5 gm/hole – (19) 12%
	Bean varieties	Uyole 96 – (150) 82%
	(183 respondents)	Njano Uyole – (145) 79%
		Calima – (47) 26%
		Wanja – (39) 21%
	Bean seed treatment (Y/N)	Y – (147) 76%
	Bean insecticide/ fungicide (Y/N)	Y – (149) 77%

Notes: Values in parentheses represent number of respondents. Total $N_{VBAAs} = 193$.
[a]Respondents reported recommending multiple fertilizer types, therefore numbers do not add to total VBAAs providing recommendations.

30 cm between rows instead (Table 2). The remaining 30% of respondents recommended another spacing combination other than 30 or 50 cm by 10 cm. The majority of VBAAs (81%) recommended fertilizer application for beans, 63% of which recommendations were for DAP only. In addition to DAP alone, another 10% of VBAAs provided recommendations for DAP as well as other fertilizer types (primarily the Yara Cereal NPK (23-10-5) fertilizer type). Fertilizer rates were most commonly recommended in kg per acre, and specifically in the amount of 50 kg/acre (66% of recommendations). A few respondents reported rates in grams per planting hole instead, with 12% of recommendations recommending 5 grams/hole (Table 2). Specific bean varieties were also recommended, most commonly the varieties Uyole 96 (recommended by 82% of VBAAs), Njano Uyole (79% of VBAAs), Calima (26% of VBAAs) and Wanja (21% of VBAAs) (Table 2). Many VBAAs also recommended a number of other inputs for beans, such as seed treatments (76%) and insecticide/fungicides (77%).

While pigeonpea recommendations were few, those recorded provide key insights (Table 2). All five of the VBAAs who provided recommendations on pigeonpea recommended that it be sole cropped instead of intercropped with maize (as grown by farmers). Four out of five of the VBAAs recommended spacing for pigeonpea, although each noted a different spacing arrangement. This ranged from 75 to 80 cm between rows and 30–60 cm within row. Only two VBAAs recommended fertilizer application to pigeonpea, as well as a specific, local variety of pigeonpea.

Extension legume recommendations across multiple levels compared to farmer practice

Farmer practice for growing bean and pigeonpea was compared to extension recommendations at three levels, village level VBAAs, district level extension officers, and country level Tanzania Ministry of Agriculture published recommendations. A Venn diagram listing practices versus recommendations demonstrates areas of overlap and disconnect among the sources (Figures 4 and 5).
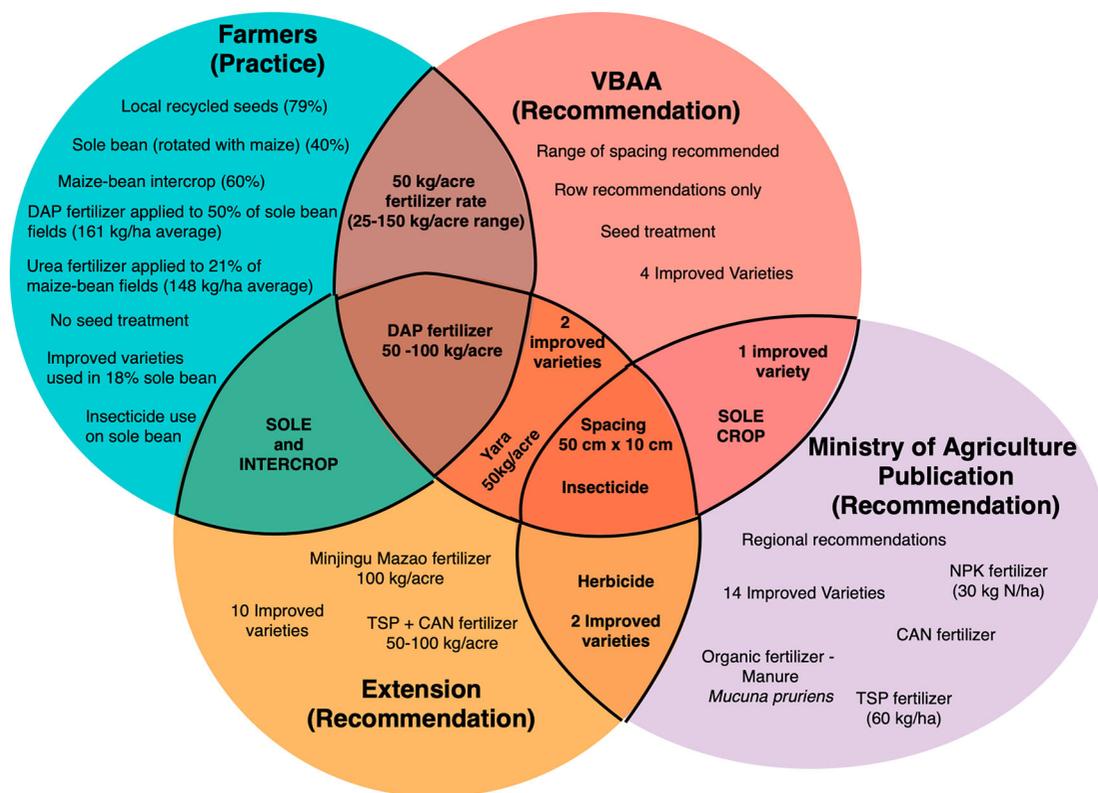
For bean management, few of the farmer practices overlapped with extension recommendations (Figure 4). All sources of recommendations (VBAAs, extension, and Ministry of Agriculture) recommended a spacing of 50 cm × 10 cm. This is in contrast to farmer practice,

as reported by local extension, which either followed a sole crop planting system commonly achieved through broadcast planting (common in Southern Highlands) or as an intercrop with maize (North). In the case of intercropping with maize, maize row spacing was the major determinant of spacing (Table 1). Additionally, all sources recommended applying insecticide and herbicides in bean production, but there was limited evidence of farmers using insecticides (a few applied to sole bean plots) and almost nil herbicide use.

Fertilizer use in bean was the one area where some synchrony was observed between recommendations and farmer practice. A wide range of farmer fertilizer application rates was observed, and VBAA recommendations for fertilizer rates varied as well; however, there was overlap. For example, DAP fertilizer for bean recommendation rates ranged from 50 to 100 kg/acre (124–247 kg/ha). Farmer practice in the Southern Highlands for DAP applied to sole bean cropping systems varied, but an average rate of those who applied fertilizer (161 kg/ha) was within the recommended range. Yara fertilizer brand (NPK fertilizer type) was recommended by both VBAAs and extension staff at a rate of 50 kg/acre, but this fertilizer brand was not an observed farmer practice. Fertilizer rates in general were reported in hectares by the Ministry (Kanyeka et al., 2007), which also listed recommendations by nutrient (e.g. amount N), whereas extension reported rates as kg per acre and by fertilizer type (not the nutrient content of the fertilizer).

Interestingly, farmers adjusted their management practices to reflect distinct bean cropping systems (intercropped vs sole cropped), whereas this variation was rarely acknowledged by extension sources, and not accounted for in any recommendation. The Ministry of Agriculture publication divided some recommendations by extension zone (e.g. North vs Southern Highlands). Additionally, the Ministry of Agriculture recommendations did not overlap in any way with farmer practice (Figures 4 and 5). Earlier publications by the Ministry of Agriculture have delineated multiple agroecologies with tremendous diversity of systems and farmer practices, but these historical records were not taken into account in current materials (De Pauw, 1984).

Farmers mostly used local recycled seeds, with sole bean systems in the Southern Highlands having the highest use of improved varieties at 18%. In contrast, the Ministry recommended 14 improved varieties that

Figure 4. Venn diagram of farmer practice and extension recommendations for common bean management. Farmer practice determined by survey 1 focal plot responses (*n* = 106). Extension recommendations compared across three different levels, with VBAA recommendations (*n* = 193), government extension officers (*n* = 5), and an official Ministry of Agriculture publication (Kanyeka et al., 2007).
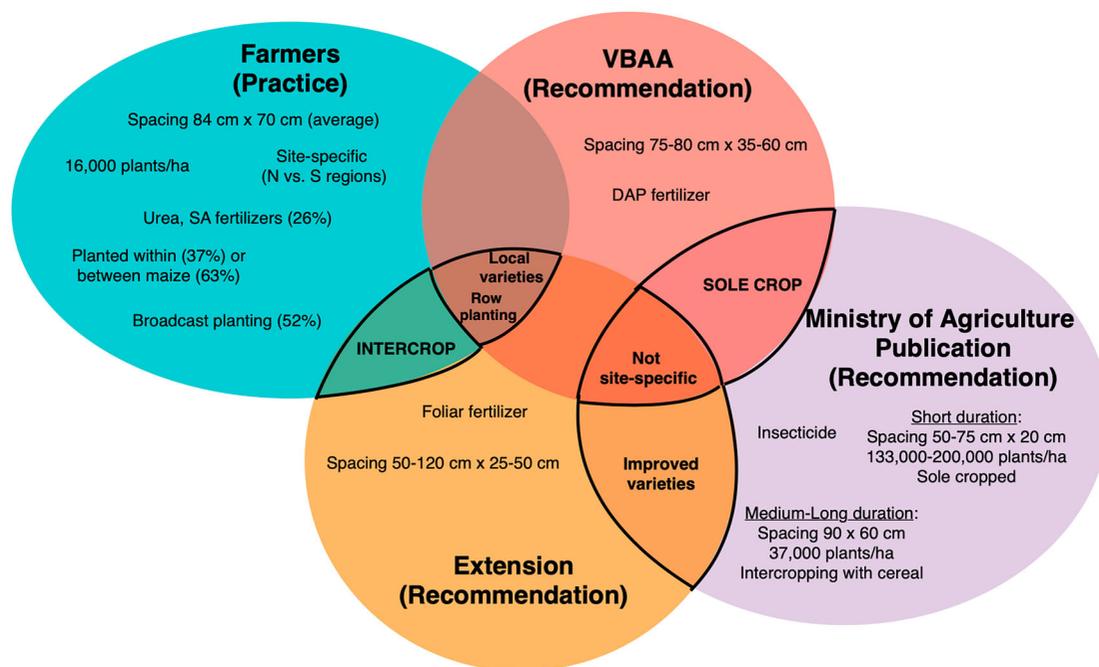
have been developed in various agricultural research institutes across the country. Extension officers listed ten improved varieties that were common in the Southern Highlands, of which only two overlapped with the Ministry list. There were only four common varieties promoted by VBAAs, of which two were also mentioned by extension and one was listed in the Ministry booklet.

Pigeonpea management generally had few recommendations, and almost none that were matched to farmer practice, despite the prevalence of this crop in study focal plots. One extension officer interviewed in the North noted that pigeonpea production recommendations are not a priority, as their focus was on maize. An example disconnect is that all farmers produced pigeonpea as an intercrop with maize, whereas recommendations were almost all for sole pigeonpea (Figure 4). Ministry recommendations specified that sole cropping should be used for short duration varieties, whereas medium to long term duration varieties could be intercropped. No

other recommendation source differentiated variety types. There were also planting arrangement differences between farm plots in the North and Southern Highlands. Recommendations, however, were not site specific, and focused on intensive spacing and chemical input use. Inorganic fertilizer application by farmers occurred in only 26% of pigeonpea plots and the types of fertilizer applied were high in nitrogen content (urea, SA) which suggests the target was maize production, as maize is a nitrogen responsive cereal.

Extension sources of information

An information flow diagram was constructed to provide an overview of sources of agricultural recommendations and information as it is received by extension officers at the ward level (Figure 6). While this diagram is not an exhaustive list of all sources and flows of information to farmers and extension, it provides a summary of information sources from the
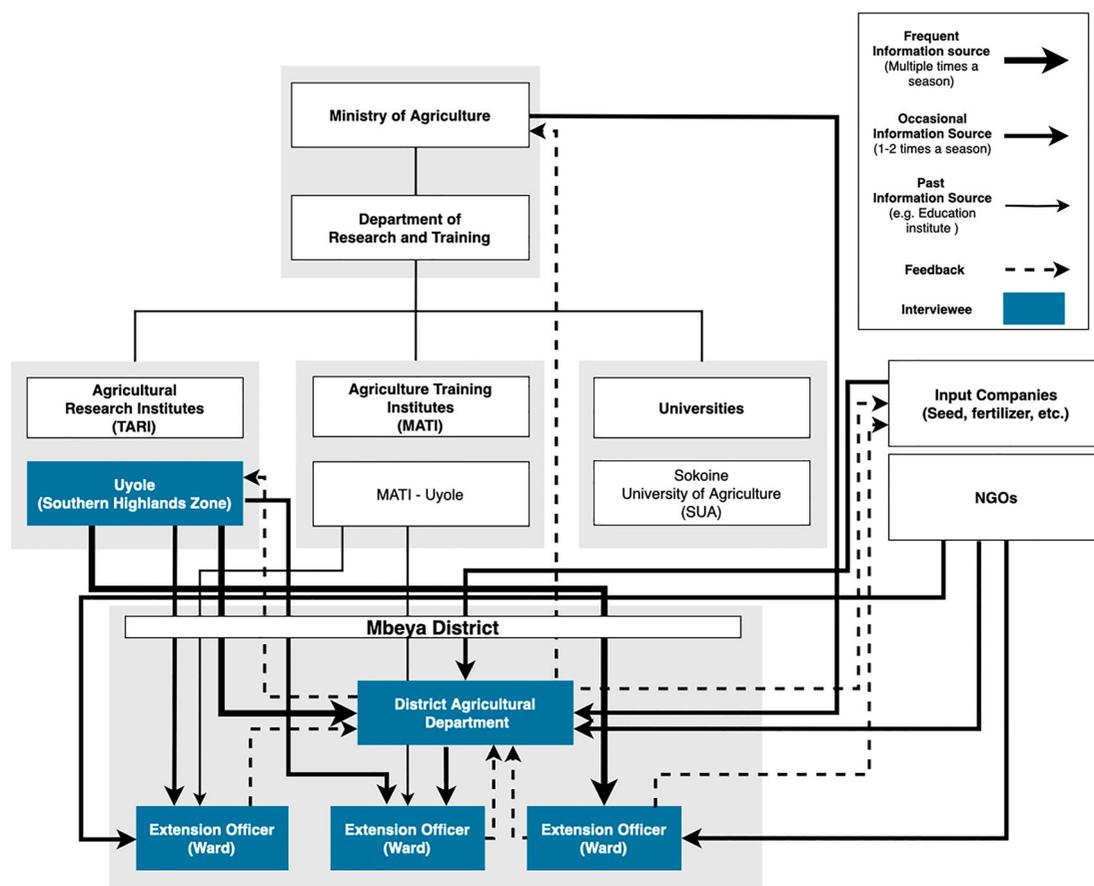
Figure 5. Venn diagram of farmer practice and extension recommendations for pigeonpea management. Farmer practice determined by survey 1 focal plot responses ($n = 114$). Extension recommendations compared across three different levels, with VBAA recommendations ($n = 5$), government extension officers ($n = 5$), and an official Ministry of Agriculture publication (Kanyeka et al., 2007).

perspective of key informants interviewed to gain an understanding of agricultural knowledge transfer as it is being currently applied amongst actors. Five extension officers in the Southern Highlands area were interviewed, with those located in Mbeya district shown in Figure 6 to illustrate the flow of information. The diagram illustrates where information most frequently comes from (solid arrows with three widths, increasing size representing frequency of information), where feedback is delivered (dashed arrow), and the discrepancies in access to information across areas. The most common sources of information that extension officers used for their recommendations were TARI-Uyole research, NGOs, and their formal (certificate or higher degree programme) education from training institutes. Extension officers at the ward level reported that both TARI-Uyole researchers and NGOs regularly set up demo plots in their area and held other activities such as farmer field schools, ward level trials, and trainings for both farmers and extension. District level extension officers also noted the role of TARI-Uyole researchers and NGOs in providing recommendations, as well as the Ministry of Agriculture as a source of information at the district level. The district level officers noted

that many NGOs were focused on fertilizer and seed inputs and contributed to recommendations. Fertilizer and seed companies also had a large presence in the area, with companies regularly hosting demo plots on-farm, to promote their products. While no ward level extension officer directly mentioned private companies as a source of their recommendations, one reported regularly bringing farmer feedback to companies and noted that negative farmer feedback was not well received. On occasion this negative feedback resulted in threats being made by the company towards extension. Extension officers in some areas reported only receiving information from a few sources (TARI-Uyole or NGOs), but reported frequent delivery of this information. Others mentioned their formal education training as a major source of information for recommendations, a source of information which could become outdated.

The main flows of feedback from extension officers to other areas of government extension were from ward extension officers to the district, and district feedback to TARI-Uyole and Ministry of Agriculture (Figure 6). Feedback from extension officers was often in the form of a written report: ward extension

Figure 6. Diagram illustrating flow of information to ward level government extension officers as reported by ward extension officers (*n* = 3), district agricultural extension officers (*n* = 3), and a researcher at TARI-Uyole. Solid lines denote sources of information and width of line corresponds to frequency of information delivered to extension officers. Dotted lines show which entities receive feedback from extension officers. Arrows indicate direction of information flow.

officers are instructed to report their activities and challenges that they've encountered on a monthly, quarterly, and yearly basis. The district addresses such challenges either directly, through advice from the agricultural department, or these issues are raised with researchers, NGOs, or the Ministry.

Discussion

Smallholder field management

This is the first study we know of detailing legume production practices as they relate to extension recommendations. Generalizations and assumptions about farmer practice have often been a limitation of reports on extension effectiveness (Scoones, 2009). This could be an important knowledge gap,

given the key role that legumes play in SI of crop production. Farmer practice differed across the North and Southern Highlands regions, and by cropping system. Hyper local variations were observed in intercropping, sole cropping, and planting periods, reflecting farmer adaptation to local conditions. Pigeonpea was always grown with maize, whereas common bean was grown either as a sole crop or intercropped with maize. Sole cropped plots included multiple sequential plantings of common bean within a season. Yet recommendations often presumed that sole cropping was the dominant production system, for all crop species.

Pigeonpea systems in particular reflect the inadequacy of current extension, and opportunities to improve recommendations. Literature on pigeonpea production in Tanzania often focuses on the main production areas in the North where it is grown primarily

as a cash crop sold for export (Amare et al., 2012). This commercial importance is reflected in the two-fold higher plant densities measured in the Northern plots (18,800 plants ha^{-1}) compared to the Southern Highlands (8,400 plants ha^{-1}). Planting arrangements also differed; pigeonpea in the North was planted between maize rows whereas in the Southern Highlands it was planted within maize rows. These management differences between regions have implications for the type of extension support needed in each, as placement and doses of inputs should be adjusted accordingly.

Pigeonpea production studies in Tanzania have focused on improved seed use over planting arrangements, and have found a major constraint to yield gains is the lack of access to quality seed (Amare et al., 2012; Simtowe et al., 2011). Simtowe et al. (2011) surveyed farmers in the North and found use of improved pigeonpea varieties was around 19%. We found lower levels of use, as improved varieties were planted in 7% of pigeonpea plots in the North and in only one plot in the Southern Highlands. Additionally, seeds, both local and improved, are often recycled from the previous year, which is in accord with a comprehensive assessment of seed systems on smallholder farms (McGuire & Sperling, 2016). This reduces the incentive of the private sector for delivery of improved varieties, and thus provision is highly dependent on public institutions. Rusinamhodzi et al. (2017) addressed this seed quality issue by testing ratooning effects on pigeonpea as a way to reduce the financial burden of buying improved seeds every year. Ratooning involves cutting back the pigeonpea plant at the end of the first harvest, leaving behind a stem base from which the plant can re-sprout; this has been found to be a cost-effective strategy which did not reduce the productivity of maize-pigeonpea intercrops (Rusinamhodzi et al., 2017). Despite the persistence of ratoon management by some smallholders in East Africa, this practice was not mentioned in any Tanzania extension recommendation (Rogé et al., 2016).

Pigeonpea yields on farms are currently well below potential yields, as shown here and as observed earlier in value chain asssements (Mponda et al., 2014). Yet, there is a wide range of environmental services that can be derived from this species, as well as intensification opportunities (Snapp et al., 2018). Surveys have reported high potential for pigeonpea intensification in the Southern areas, as demand is increasing and a pigeonpea market exists through its proximity to northern Mozambique (Mponda et al., 2014). Pigeonpea cultivation in this area has the potential to be intensified, and a ratooning system may fit with the current low population density, an opportunity that has been overlooked to date (Rogé et al., 2016; Rusinamhodzi et al., 2017).

Farmer practice around bean management showed many variations. In the North it was intercropped with maize whereas sole cropping with multiple planting periods was common in the Southern Highlands. Plots in the Southern Highlands also had higher input use than the North, but low use of improved seeds was found across all systems and regions. Previous characterization of bean production in Tanzania using national panel survey data found that across the country 85% of bean plots are intercropped, and that the North and Southern Highlands zones have some of the highest proportions of households growing beans, with 40% and 52% respectively (Stahley et al., 2012). This national panel data also found that few plots (2%) used improved seed but, in contrast, inorganic fertilizer use was relatively high (18%), which is a similar input use pattern found in our study.

Lack of use of improved seeds is often identified as the main cause of low legume production in the literature. Studies have highlighted extensive efforts in bean breeding, especially in Eastern Africa, to produce high yielding varieties with disease resistance and desirable market traits (Hillocks et al., 2006; Letaa et al., 2015). Despite the development and dissemination efforts for improved varieties, adoption rates are still low as shown here. Previous studies have shown that high seed cost, low awareness and access all contribute to low uptake of improved legume seed generally, and specifically for beans in the region (McGuire & Sperling, 2016) (Snapp et al., 2002b). We observed here that multiple plantings of bean is used to multiply a desired seed type, which may be an overlooked practice that influences adoption of SI technologies.

The importance of considering the whole cropping system is reflected through an observation in our study, consistent with one earlier study (Stahley et al., 2012), that application of inorganic fertilizer was much more frequent than improved seeds. This is consistent with maize production being a high priority, and maize being a fertilizer responsive crop, where bean fertility enhancement is a secondary benefit in a maize-bean intercrop system. An early on-farm study of bean nutrition in Malawi found

that phosphorus fertilizer application to a maize-bean intercrop was a profitable and farmer preferred technology (Snapp et al., 1998). This is suggestive that SI recommendations should take into account the complexity of multiple cropping systems.

Previous bean production studies in Tanzania have addressed total bean production over a season, which obscures the complex bean management patterns found in this study (Letaa et al., 2015; Piikki et al., 2017; Silvestri et al., 2020; Stahley et al., 2012). Recommendations need to take into account planting sequences, household member involvement, and production objectives. Interestingly, a finding here was that while legume production is often reported as a 'woman's crop', the majority of plots in this study were managed by men (Monyo & Varshney, 2016). Focus group discussions also reflected complex, gendered use of bean as both a food and market crop. Taken together, there was evidence of a changing culture of legumes, from a food security crop to one with market value. Male household heads may be increasingly making decisions for bean production as market orientation rises. While this study was unable to directly test gender differences in legume production, this mix of men and women as joint managers in bean production has implications for legume management practices and potential marginalization of women farmers (Acosta et al., 2020). Limited decision making by women in bean production has possible negative consequences. Local knowledge of legumes is often held with women, and thus is at risk of being lost if women become less involved (Ferguson, 1994).

Interaction of extension knowledge sources for improved agriculture recommendations

A key result from this study is that extension sources of information are few and are based on inconsistent input from research, with almost no input from farmers. The limited sources of extension information are also from separate institutions, ranging from government to NGOs, with no coordination of extension messages. This is evident in the large disconnects we found between extension levels, and with farmer practice. It is consistent with no discernable progress having been made towards participatory extension, and weak linkages among actors (Aflakpui, 2007). A failure to address researcher-extension-farmer disconnects has been found previously (Schindler et al., 2016; van Crowder & Anderson, 1997)**.** Rees et al.

(2000) examined extension systems in Kenya and similarly found inadequate information being provided by government extension, yet at the same time this was a major source of information for farmers.

A surprising finding is that the structural organization of Tanzania's extension system has remained remarkably stable for a quarter of a century. As reported by Mattee (1994), the Tanzanian extension system in the early 1990s had an organization structure with the same number of levels and many of the same information flows we report here. Overall, it has not changed functicly, despite investments to increase the number of extension officers assigned to rural areas (United Republic of Tanzania, 2013). Mattee highlights similar challenges to those highlighted here, such as the issue of providing quality support to extension officers and the need to improve flow of information. He argues that the hierachical structure of this system is a major barrier to extension knowledge system function, an argument that has been reiterated in other African countries (Aflakpui, 2007).

Although the hierachical structure of extension has not appeared to change, we identified new actors, specifically NGOs and private industries, that also serve as knowledge sources. The expanding role of non-government entities within agricultural extension in Tanzania comes amidst increasing emphasis upon private-public partnerships in agricultural investments (Sulle, 2020). Despite this policy emphasis on such partnerships, information provided from non-government entities as of yet are not well integrated within the current extension structure. Our results highlight the potentially negative consequences of public-private partnerships that others have warned of, namely potential for bias in recommendations towards products sold (Glover, 2007; Hall, 2006). Improved integration of public and private actors, in a manner that supports farmer involvement, education and vetting of recommendations, could well improve the ability of extension to engage farmers with up to date information.

Post-secondary agricultural education institutes could play an important role in overcomming disconnections within the extension system. Most extension officers in our study mentioned their education at Ministry agricultural training institutes (MATIs) as major sources of information. As Spielman et al. (2008) note in their assessment of agricultural education training institutes in sub-Saharan Africa, these institutions often follow a top-down structure to

education and are isolated from understanding local demand for agricultural knowledge. Reforms of these institutes show potential for capacity building, and to improve the connections among researchers, extension and farmers. Reform has been proposed that connects Tanzania research insitutes with MATIs, to support up-to-date training courses for lead farmers and extension (Sekiya et al., 2015). A pilot was implemented by Sekiya and colleagues, and interviews with over 900 farmers found evidence for improved connection between research and farmers; however, quality of technical recommendations still needed improvement. The technologies being promoted often lacked relevance, as we found here; suggesting that extension-farmer feedback mechanisms to assess technologies remain inadequate (Spielman et al., 2008).

Improving agricultural knowledge transfer for sustainable intensification

Previous literature cites poor access to extension as a factor in low legume productivity (Muoni et al., 2019; Silvestri et al., 2020). Our study, however, highlights that farmers need legume extension advice that accounts for the biophysical conditions of their area, and the complexity of maize-legume systems that exist (Giller et al., 2011). Additionally, farmers, especially women, need access to resources they have identified rather than technologies promoted through a supply push pathway (Röling, 2009). The future of extension has recently been promoted as involving information communication technologies (ICT), particularly smart-phone based communications, yet many such projects further a linear transfer of technology approach (Dodson et al., 2012; Silvestri et al., 2020; Steinke et al., 2020). This despite the large body of literature that calls for systems-based participatory research and extension (Simmonds, 1986; Snapp et al., 2018). To support innovation for SI, institutions must be linked to producers and accomodate farmer knowledge and demands through client-oriented approaches (Witcombe et al., 2005). This is especially needed for supporting women farmers, whose extension needs and preferences for communication with extension may differ from men (McCormack, 2018). While ICTs may have a high potential for filling in communication gaps, our study highlights that tools are needed that allow two-way communication and incorporation of site-specific conditions and practices to support the full diversity of smallholder farmers.

Conclusion

Improved agricultural knowledge transfer is a key pathway for promoting gains in smallholder productivity through sustainable intensification that enhances the natural resource base by diversifying monocrop cereals with legumunious species. Our study documented the complex management practices observed in the main maize-legume cropping system regions of Tanzania and the disconnects with extension systems supporting them. The incompatibility of extension support to current farming systems found in our study bring to light the overlooked barriers to achieving SI within smallholder farming. The hierarchal structure of extension systems in Tanzania have been resistant to change, highlighting the need for integration of government, non-government, and private sector agricultural advisory services, and close attention to farmer priorities and practices. Given large inter- and intra- regional differences in legume production systems, future research and extension systems need to take into account hyper-local context, and support farmer adaptation. Innovations in ICT and in extension organization can either reinforce business as usual, or support the widespread reform needed for gains in extension relevance and researcher-extension-farmer linkages, thus enabling sustainable agriculture.

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References

Acosta, M., van Wessel, M., van Bommel, S., Ampaire, E. L., Twyman, J., Jassogne, L., & Feindt, P. H. (2020). What does it mean to make a 'joint' decision? Unpacking intra-household decision making in agriculture: Implications for Policy and practice. *The Journal of Development Studies*, 56(6), 1210–1229. https://doi.org/10.1080/00220388.2019.1650169

Aflakpui, G. K. S. (2007). Present outlook and transformation in the delivery of agricultural extension services: Implications for research-extension-farmer linkages. *Outlook on Agriculture*, 36(1), 35–39. https://doi.org/10.5367/000000007780223687

Agbamu, J. U. (2000). Agricultural research – extension linkage systems: An international perspective. *Agricultural Research and Extension Network*, 1(106), 1–7.

Amare, M., Asfaw, S., & Shiferaw, B. (2012). Welfare impacts of maize-pigeonpea intensification in Tanzania. *Agricultural Economics*, 43(1), 27–43. https://doi.org/10.1111/j.1574-0862.2011.00563.x

Andrade, J. F., Rattalino Edreira, J. I., Farrow, A., van Loon, M. P., Craufurd, P. Q., Rurinda, J., Zingore, S., Chamberlin, J., Claessens, L., Adewopo, J., van Ittersum, M. K., Cassman, K. G., & Grassini, P. (2019). A spatial framework for ex-ante impact assessment of agricultural technologies. *Global Food Security*, 20, 72–81. https://doi.org/10.1016/j.gfs.2018.12.006

Aune, J. B., Coulibaly, A., & Giller, K. E. (2017). Precision farming for increased land and labour productivity in semi-arid West Africa. *Agronomy for Sustainable Development*, 37(3), 1–10. https://doi.org/10.1007/s13593-017-0424-z

Biggs, S. D. (1990). A multiple source of innovation model of agricultural research and technology promotion. *World Development*, 18(11), 1481–1499. https://doi.org/10.1016/0305-750X(90)90038-Y

Birner, R., Davis, K., Pender, J., Nkonya, E., Anandajayasekeram, P., Ekboir, J., Mbabu, A., Spielman, D. J., Horna, D., Benin, S., & Cohen, M. (2009). From best practice to best fit: A framework for designing and analyzing pluralistic agricultural advisory services worldwide. *The Journal of Agricultural Education and Extension*, 15(4), 341–355. https://doi.org/10.1080/13892240903309595

Coutts, J., Koutsouris, A., & Davis, K. (2019). Evaluation of rural advisory and extension services. *The Journal of Agricultural Education and Extension*, 25(2), 99–101. https://doi.org/10.1080/1389224X.2019.1583810

Davis, K. E., Bohn, A., Franzel, S., Blum, M. L., Rieckmann, U., Saravanan, R., Hussein, K., & Ernst, N. (2018). *What works in rural advisory services? Global good practice notes, global forum for rural advisory services (GFRAS)*. Global Forum for Rural Advisory Services (GFRAS).

De Pauw, E. (1984). *Soils, physiography and agro-ecological zones of Tanzania*. Minist. Agric. Dar-es-Salaam, Tanzania/FAO.

Dodson, L. L., Sterling, S. R., & Bennett, J. K. (2012). Considering failure: Eight years of ITID research. *ACM Int. Conf. Proceeding Ser*, 9(2), 19–34. https://doi.org/10.1145/2160673.2160681

Farnworth, C. R., Baudron, F., Andersson, J. A., Misiko, M., Badstue, L., & Stirling, C. M. (2015). Gender and conservation agriculture in East and Southern Africa: Towards a research agenda. *International Journal of Agricultural Sustainability*, 14(2), 142–165. https://doi.org/10.1080/14735903.2015.1065602

Faure, G., Desjeux, Y., & Gasselin, P. (2012). New challenges in agricultural advisory services from a research perspective: A literature review, synthesis and research agenda. *The Journal of Agricultural Education and Extension*, 18(5), 461–492. https://doi.org/10.1080/1389224X.2012.707063

Ferguson, A. E. (1994). Gendered science: A critique of agricultural development. *American Anthropologist*, 96(3), 540–552. https://doi.org/10.1525/aa.1994.96.3.02a00060

Giller, K. E., Tittonell, P., Rufino, M. C., van Wijk, M. T., Zingore, S., Mapfumo, P., Adjei-Nsiah, S., Herrero, M., Chikowo, R., Corbeels, M., Rowe, E. C., Baijukya, F., Mwijage, A., Smith, J., Yeboah, E., van der Burg, W. J., Sanogo, O. M., Misiko, M., de Ridder, N., … Vanlauwe, B. (2011). Communicating complexity: Integrated assessment of trade-offs concerning soil fertility management within African farming systems to support innovation and development.

Agricultural Systems, *104*(2), 191–203. https://doi.org/10.1016/j.agsy.2010.07.002

Glover, D. (2007). Farmer participation in private sector agricultural extension. *IDS Bulletin*, *38*(5), 61–73. https://doi.org/10.1111/j.1759-5436.2005.tb00409.x

Hall, A. (2006). Public-private sector partnerships in an agricultural system of innovation: Concepts and challenges. *International Journal of Technology Management & Sustainable Development*, *5*(1), 3–20. https://doi.org/10.1386/ijtm.5.1.3/1

Hillocks, R. J., Madata, C. S., Chirwa, R., Minja, E. M., & Msolla, S. (2006). Phaseolus bean improvement in Tanzania, 1959–2005. *Euphytica*, *150*(1-2), 215–231. https://doi.org/10.1007/s10681-006-9112-9

Kanyeka, E., Kamala, R., & Kasuga, R. (2007). Improved Agricultural Research Technology Recommended in Tanzania.

Kim, J., Mason, N. M., Snapp, S. S., & Wu, F. (2019). Does sustainable intensification of maize production enhance child nutrition? Evidence from Rural Tanzania. *Agricultural Economics*, *50*(6), 723–734. https://doi.org/10.1111/agec.12520

Koutsouris, A. (2018). Role of extension in agricultural technology transfer: A critical review. In N. Kalaitzandonakes, E. G. Carayannis, E. Grigoroudis, & S. Rozakis (Eds.), *From agriscience to agribusiness: Theories, policies and practices in technology transfer and commercialization* (pp. 337–359). Springer International Publishing. https://doi.org/10.1007/978-3-319-67958-7_16

Leeuwis, C. (2004). Fields of conflict and castles in the air. Some thoughts and observations on the role of communication in public sphere innovation processes. *The Journal of Agricultural Education and Extension*, *10*(2), 63–76. https://doi.org/10.1080/13892240485300111

Letaa, E., Kabungo, C., Katungi, E., Ojara, M., & Ndunguru, A. (2015). Farm level adoption and spatial diffusion of improved common bean varieties in Southern Highlands of Tanzania. *African Crop Sci. J*, *23*(3), 261–277.

Lowder, S. K., Carisma, B., & Skoet, J. (2012). *Who invests in agriculture and how much? An empirical review of the relative size of various investments in agriculture in low- and middle-income countries*. ESA Working Paper 12-09. https://doi.org/10.22004/ag.econ.288992

Lukuyu, B., Place, F., Franzel, S., Kiptot, E., & Taylor, P. (2012). Disseminating improved practices : Are volunteer farmer trainers effective? *The Journal of Agricultural Education and Extension*, *18*(5), 525–540. https://doi.org/10.1080/1389224X.2012.707066

Mattee, A. (1994). Reforming Tanzania's agricultural extension system: The challenges ahead. *Afr. Study Monogr*, *15*(4), 177–188. https://doi.org/10.14989/68127

McCormack, C. (2018). *Key factors in the use of agricultural extension services by women farmers in Babati district, Tanzania: The role of societal gender norms*. Swedish University of Agricultural Sciences.

McGuire, S., & Sperling, L. (2016). Seed systems smallholder farmers use. *Food Security*, *8*(1), 179–195. https://doi.org/10.1007/s12571-015-0528-8

Meijer, S. S., Catacutan, D., Ajayi, O. C., Sileshi, G. W., & Nieuwenhuis, M. (2015). The role of knowledge, attitudes and perceptions in the uptake of agricultural and agroforestry innovations among smallholder farmers in sub-Saharan Africa. *International Journal of Agricultural Sustainability*, *13*(1), 40–54. https://doi.org/10.1080/14735903.2014.912493

Mnenwa, R., & Maliti, E. (2010). *A comparative analysis of poverty incidence in farming systems of Tanzania*. Research on Poverty Alleviation (REPOA).

Monyo, E., & Varshney, R. (2016). *Seven seasons of learning and engaging smallholder farmers in the drought-prone areas of sub-Saharan Africa and South Asia through tropical legumes, 2007–2014*. International Crops Research Institute for the Semi-Arid Tropics.

Mponda, O., Kidunda, B., Bennett, B., Orr, A., & Mausch, K. (2014). A Value chain Analysis for pigeon Pea in the Southern regions of Tanzania. *Socioeconomics Discussion Paper Series Number*, *1*(17), 1–42. http://oar.icrisat.org/id/eprint/7955

Muoni, T., Barnes, A. P., Öborn, I., Watson, C. A., Bergkvist, G., Shiluli, M., & Duncan, A. J. (2019). Farmer perceptions of legumes and their functions in smallholder farming systems in east Africa. *International Journal of Agricultural Sustainability*, *17*(3), 205–218. https://doi.org/10.1080/14735903.2019.1609166

Neef, A., & Neubert, D. (2011). Stakeholder participation in agricultural research projects: A conceptual framework for reflection and decision-making. *Agriculture and Human Values*, *28*(2), 179–194. https://doi.org/10.1007/s10460-010-9272-z

Nerbonne, J. F., & Lentz, R. (2003). Rooted in grass: Challenging patterns of knowledge exchange as a means of fostering social change in a southeast minnesota farm community. *Agriculture and Human Values*, *20*(1), 65–78. https://doi.org/10.1023/A:1022417608796

Niu, C., & Ragasa, C. (2018). Selective attention and information loss in the lab-to-farm knowledge chain: The case of Malawian agricultural extension programs. *Agricultural Systems*, *165*, 147–163. https://doi.org/10.1016/j.agsy.2018.06.003

Piikki, K., Winowiecki, L., Vågen, T. G., Ramirez-Villegas, J., & Söderström, M. (2017). Improvement of spatial modelling of crop suitability using a new digital soil map of Tanzania. *South African Journal of Plant and Soil*, *34*(4), 243–254. https://doi.org/10.1080/02571862.2017.1281447

Pretty, J., Toulmin, C., & Williams, S. (2011). Sustainable intensification in African agriculture. *International Journal of Agricultural Sustainability*, *9*(1), 5–24. https://doi.org/10.3763/ijas.2010.0583

Rees, D., Momanyi, M., Wekundah, J., Kamau, M., Ndubi, J., Musembi, F., Mwaura, L., & Joldersma, R. (2000). Agricultural knowledge and information systems in Kenya – implications for technology dissemination and development. *Agricultural Research and Extension Network*, *1*(107), 1–16.

Rogé, P., Snapp, S., Kakwera, M. N., Mungai, L., Jambo, I., & Peter, B. (2016). Ratooning and perennial staple crops in Malawi. *Agronomy for Sustainable Development*, *36*(3), 1–18. https://doi.org/10.1007/s13593-016-0384-8

Röling, N. (2009). Pathways for impact: Scientists' different perspectives on agricultural innovation. *International Journal of Agricultural Sustainability*, *7*(2), 83–94. https://doi.org/10.3763/ijas.2009.0043

Ronner, E., Descheemaeker, K., Almekinders, C., Ebanyat, P., & Giller, K. E. (2019). Co-design of improved climbing bean production practices for smallholder farmers in the highlands of Uganda. *Agricultural Systems*, *175*, 1–12. https://doi.org/10.1016/j.agsy.2019.05.003

Rusinamhodzi, L., Makoko, B., & Sariah, J. (2017). Ratooning pigeonpea in maize-pigeonpea intercropping: Productivity and seed cost reduction in eastern Tanzania. *Field Crops Research*, *203*, 24–32. https://doi.org/10.1016/j.fcr.2016.12.001

Rutatora, D. F., & Mattee, A. Z. (2001). Major agricultural extension providers in Tanzania. *African Studies Monographs*, *22*(4), 155–173. https://doi.org/10.14989/68210

Salembier, C., Segrestin, B., Berthet, E., Weil, B., & Meynard, J. M. (2018). Genealogy of design reasoning in agronomy: Lessons for supporting the design of agricultural systems. *Agricultural Systems*, *164*, 277–290. https://doi.org/10.1016/j.agsy.2018.05.005

Schindler, J., Graef, F., & König, H. J. (2016). Participatory impact assessment: Bridging the gap between scientists' theory and farmers' practice. *Agricultural Systems*, *148*, 38–43. https://doi.org/10.1016/j.agsy.2016.07.002

Scoones, I. (2009). The politics of global assessments: The case of the International assessment of agricultural knowledge, Science and technology for Development (IAASTD). *The Journal of Peasant Studies*, *36*(3), 547–571. https://doi.org/10.1080/03066150903155008

Scott, J. C.. (1998). *Seeing like a state: How certain schemes to improve the Human condition have failed* (pp. 223–261). Yale University Press.

Sekiya, N., Tomitaka, M., Oizumi, N., Assenga, A. N., & Jacob, M. K. (2015). Farmer-to-Farmer extension facilitated by agricultural training institutions: A case of NERICA dissemination in Tanzania. *Plant Production Science*, *18*(3), 398–406. https://doi.org/10.1626/pps.18.398

Silvestri, S., Richard, M., Edward, B., Dharmesh, G., & Dannie, R. (2020). Going digital in agriculture: How radio and SMS can scale-up smallholder participation in legume-based sustainable agricultural intensification practices and technologies in Tanzania. *International Journal of Agricultural Sustainability*, 1–12. https://doi.org/10.1080/14735903.2020.1750796

Simmonds, N. W. (1986). A short review of farming systems research in the tropics. *Experimental Agriculture*, *22*(1), 1–13. https://doi.org/10.1017/S0014479700013995

Simtowe, F., Kassie, M., Diagne, A., Asfaw, S., Shiferaw, B., Silim, S., & Muange, E. (2011). Determinants of agricultural technology adoption: The case of improved pigeonpea varieties in Tanzania. *Q. J. Int. Agric*, *50*(4), 325–345. https://doi.org/10.22004/ag.econ.155537

Snapp, S., Aggarwal, V., & Chirwa, R. (1998). Note on phosphorus and cultivar enhancement of biological nitrogen fixation and productivity of maize/bean intercrops in Malawi. *Field Crops Research*, *58*(3), 205–212. https://doi.org/10.1016/S0378-4290(98)00100-2

Snapp, S. S., Blackie, M. J., & Donovan, C. (2003). Realigning research and extension to focus on farmers' constraints and opportunities. *Food Policy*, *28*(4), 349–363. https://doi.org/10.1016/j.foodpol.2003.08.002

Snapp, S., Grabowski, P., Chikowo, R., Smith, A., Anders, E., Sirrine, D., Chimonyo, V., & Bekunda, M. (2018). Maize yield and profitability tradeoffs with social, human and environmental performance: Is sustainable intensification feasible? *Agricultural Systems*, *162*, 77–88. https://doi.org/10.1016/j.agsy.2018.01.012

Snapp, S., Kanyama-Phiri, G., Kamanga, B., Gilbert, R., & Wellard, K. (2002a). Farmer and researcher partnerships in Malawi: Developing soil fertility technologies for the near-term and far-term. *Experimental Agriculture*, *38*(4), 411–431. https://doi.org/10.1017/S0014479702000443

Snapp, S., Rohrbach, D. D., Simtowe, F., & Freeman, H. A. (2002b). Sustainable soil management options for Malawi: Can smallholder farmers grow more legumes? *Agriculture, Ecosystems & Environment*, *91*(1–3), 159–174. https://doi.org/10.1016/S0167-8809(01)00238-9

Spielman, D. J., Ekboir, J., Davis, K., & Ochieng, C. M. O. (2008). An innovation systems perspective on strengthening agricultural education and training in sub-Saharan Africa. *Agricultural Systems*, *98*(1), 1–9. https://doi.org/10.1016/j.agsy.2008.03.004

Stahley, K., Slakie, E., Derksen-Schrock, K., Gugerty, M. K., & Anderson, C. L. (2012). *Tanzania national panel survey LSMS-ISA: Legumes*.

Steinke, J., van Etten, J., Müller, A., Ortiz-Crespo, B., van de Gevel, J., Silvestri, S., & Priebe, J. (2020). Tapping the full potential of the digital revolution for agricultural extension: An emerging innovation agenda. *International Journal of Agricultural Sustainability*, 1–17. https://doi.org/10.1080/14735903.2020.1738754

Sulle, E. (2020). Bureaucrats, investors and smallholders: Contesting land rights and agro-commercialisation in the Southern agricultural growth corridor of Tanzania. *Journal of Eastern African Studies*, *14*(2), 332–353. https://doi.org/10.1080/17531055.2020.1743093

Tanzania, N. B. S. (2012). *Population and housing census: Population distribution by administrative areas*. Minist. Financ.

United Republic of Tanzania. (2013). *National agriculture policy*. Ministry of Agriculture, Food Security and Cooperatives.

van Crowder, L., & Anderson, J. (1997). Linking research, extension and education: Why is the problem so persistent and pervasive? *European Journal of Agricultural Education and Extension*, *3*(4), 241–249. https://doi.org/10.1080/13892249785300061

Waldman, K. B., Ortega, D. L., Richardson, R. B., Clay, D. C., & Snapp, S. (2016). Preferences for legume attributes in maize-legume cropping systems in Malawi. *Food Security*, *8*(6), 1087–1099. https://doi.org/10.1007/s12571-016-0616-4

Witcombe, J. R., Joshi, K. D., Gyawali, S., Musa, A. M., Johansen, C., Virk, D. S., & Sthapit, B. R. (2005). Participatory plant breeding is better described as highly client-oriented plant breeding. I. Four indicators of client-orientation in plant breeding. *Experimental Agriculture*, *41*(3), 299–319. https://doi.org/10.1017/S0014479705002656