Sustain Sci (2017) 12:641–656
DOI 10.1007/s11625-017-0460-2

SPECIAL FEATURE: ORIGINAL ARTICLE

Sustainability Science for Meeting Africa's Challenges

Constraints to the adoption of fodder tree technology in Malawi

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Received: 23 August 2016 / Accepted: 29 July 2017 / Published online: 4 August 2017

Abstract The declining availability of grazing land and the increasing prices of commercial dairy feed threaten the sustainability of traditional smallholder livestock farmer (SLF) practices across sub-Saharan Africa. Fodder tree technology (FTT), an agroforestry approach that entails the cultivation of multipurpose fodder trees on farmlands, could help address such challenges. However, the adoption rate of FTT has been low, especially in Malawi, where dairy processing plants usually operate at 20% capacity and milk consumption is less than half the African average. This paper investigates the role of 20 possible determinants of FTT adoption. It uses binary logistic regression to analyze primary data collected through two extensive household surveys conducted during the Agroforestry Food Security Program (AFSP) in different regions of Malawi. This data is complemented with qualitative information extracted through in-depth interviews with SLF. The general lack of knowledge regarding FTT was identified as the largest constraint to adoption. It was further confounded by other factors such as the lack of market access, inconsistent emphasis of training organizations during extension efforts, gender disparities, poor land quality, and issues of land tenure. The "extension environment" created by the AFSP influenced the perceptions of SLF for some adoption determinants. In particular it reduced the influence of sociological and geographic factors such as relationships with lead farmers, and shifted financial focus from the cost and availability of inputs, to the means of capitalizing on outputs (such as market access). This improved FTT adoption by 53% overall. Some suggestions for future extension efforts on how to improve the perceptions of the expected utility of FTT include the careful evaluation of farmer-led extension models, assurance of seed supply, and the consideration of institutional/sociological factors in project design. Examples of such factors include divorce rates, conflicts between formal and customary laws/rules, and infrastructure.

Keywords Agroforestry · Extension environment · Farmer-led extension model · Food security · Smallholder livestock farmers

Abbreviations

AFSP	Agroforestry Food Security Program
BLA	Binary logistic regression
CIE	Center for independent evaluations
FTT	Fodder tree technology
SLF	Smallholder livestock farmer
ICRAF	World agroforestry centre

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Introduction

Most countries within Sub-Sahara Africa are expected to double their 2005 population by 2050 (UNPD 2015). The growing demand for food has forced smallholder livestock farmers (SLF) to plant crops on land normally reserved for animal grazing (Jayne et al. 2014). The resulting "minimum" or "zero" grazing (i.e., cutting and carrying grass from elsewhere to penned animals) can severely restrict animals' diets (Chakeredza et al. 2007). Unfortunately, animal feed supplements are often prohibitively expensive (Franzel and Wambugu 2007), having negative consequences for animal health, milk production, and reproductive capabilities (Bach 2012). This has ramifications for livestock (and the human populations that depend upon them), as each subsequent generation of cattle becomes more unfit and the amount and quality of milk declines over time (Rukkwansuk 2011).

Malawi is such an example, where dairy processing plants often operate at 20% capacity (Changunda et al. 2011). At the same time milk from all local producers only meets 60% of the national milk demand (Revoredo-Giha et al. 2015), necessitating reliance on external sources (Banda et al. 2012). The consistent lack of a dependable milk supply has led to an estimated average milk consumption in Malawi of only 4–6 kg per capita per year, which is far below the estimated annual average of 15 kg per capita per year for Africa (DAHLD 2005; Tebug et al. 2012a). With an estimated 47% of children in Malawi being stunted or malnourished (UNICEF 2013), removing these limitations could have important public health benefits.

Considering the above, addressing the low quality and quantity of feed resources is a high priority for Malawi's dairy sector (Mpofu 2005; Kebreab et al. 2005). Fodder tree technology (FTT) can be a sustainable strategy for addressing the limited (and possibly declining) fodder-and-feed supplies in Malawi that has proven to be successful in some parts of Africa (Chakeredza et al. 2007). The term "Fodder Trees" refers to typically multipurpose leguminous tree or shrub species grown specifically for feed, and whose leaves are nutrient-rich and frequently cut and carried to penned animals (Nair 1993).

In SSA a number of research and extension programs have introduced various indigenous species (e.g., *Sesbania sesban*) and exotic multipurpose trees (e.g., *Calliandra calothyrsus*) as fodder sources (Franzel et al. 2014). For example, ICRAF has a voluminous database of agroforestry species that contains over 600 entries including information on the management, use, and ecology of these plants (Kindt et al. 2016). And, several studies from across SSA have documented some of the positive impacts of FTT on human livelihoods. In Tanzania, Kabirizi (2009) found that 1 kg per day of fodder supplement resulted in an average increase of 0.7 L per day of milk yields for cows. Place et al. (2009) found that the amount of fodder intake directly corresponded to significant gains in animal weight. In Embu, Kenya, fodder fed as a supplement to cows (2 kg per day) resulted in a 12% increase in milk yields (Roothaert et al. 2003). Franzel (2004) also found that the financial benefits of FTT exceeded costs by up to 13 times, increasing by 48% the annual net profits per cow after the 1st year. Wambugu et al. (2006) report that across East Africa SLF annual incomes increased by between USD 62–115 when supplementing with fodder. As of 2005 it has been estimated that over 200,000 farmers in East Africa had successfully incorporated FTT into their livestock systems, realizing significant improvements (Place et al. 2009).

Despite such success elsewhere in SSA, the adoption of FTT in Malawi has been very low (Makoka et al. 2010). One of the main reasons is its "knowledge intensive" nature, which means that SLF need to acquire new skills for its successful implementation. Many farmers may not be willing (or even be able) to meet these requirements, especially when considering the intricacies related to raising the seedlings, pruning the trees, and feeding the leaves to livestock (Franzel and Wambugu 2007). As these methods lie outside traditional livestock management practices, the adoption of FTT relies heavily on outside facilitation (Wambugu et al. 2011). This is because, as with any technology adoption process, it is the result of user perceptions about the impacts, risks, and practicalities of the technology, as formed over multiple instances of exposure (Giger et al. 2015). As exposure to new technologies rarely arises from SLF experimentation, the interaction with other actors (e.g., guidance from other farmers or extension officers) is important for the promotion of FTT (Franzel and Wambugu 2007). Such instances, in an economic sense, are opportunities for SLFs to witness the benefits and costs of a particular technology, and thus determine its expected utility (Batz et al. 1999).

Considering the above, agroforestry systems (and FTT in particular) sit at the confluence of several pressing sustainability challenges in Africa, such as enhancing food security, reducing environmental degradation, and improving rural livelihoods. At the same time, FTT can link social and ecological systems, having positive ripple sustainability impacts (Nair and Toth 2016). Examples include, erosion control, nitrogen fixation, and carbon sequestration, as well as improved animal productivity and milk quality (Dawson et al. 2014; Franzel 2004).

The aim of this paper is to identify the causes of low levels of FTT adoption in Malawi as means of understanding its true potential in SSA. Understanding the reasons behind the adoption (or not) of sustainable agricultural practices, such as FTT, can contribute significant knowledge about the potential of interventions at the interface of food security, environmental sustainability, and human wellbeing (Poppy et al. 2014). The data analyzed in this study was collected through three different surveys conducted by the World Agroforestry Centre (ICRAF) during a 2007–2012 extension project called the Agroforestry Food

Security Program (AFSP). The present study thus offers unique insights about technology adoption, as it is part of a large-scale extension effort.

Methodology

Study context

Malawi is a landlocked tropical country with five main landform areas, the Highlands, Plateaus, Escarpments, Lakeshore and Upper Shire Valley, and the Lower Shire Valley. Its altitude ranges between 300 and 3000 m above sea level. Parts of the country are considered dry with the annual rainfall varying between 800 and 2400 mm, and with 90% of the rains received during December–March and little-to-no rains during May–October.

Agriculture is the mainstay of livelihoods in Malawi, with the vast majority of farmers being smallholders with average land holdings of 1.2 ha in the North and 0.7 ha in the South (NORAD 2014). Only a fraction of these smallholders are engaged in dairy production from cows and goats (Place and Otsuka 2001). These SLF are responsible for most of the national milk supply despite logistical difficulties, such as poor market access (Benson et al. 2016). For many Malawian SLF, purchasing feed supplements is not possible, which contributes to 94% of milk-producing livestock being under-fed (Banda et al. 2012). Moreover, due to high illiteracy rates, many farmers depend on extension services for obtaining agricultural information and training (Thangata and Alavapati 2003). To compensate for this, some SLF have been organized into Milk Bulking Groups (MBG). Such pooling of resources can be viewed as a form of risk reduction, as it protects farmers from individual catastrophes and increases bargaining power for milk price determinations and procurement of inputs such as supplements and seeds. Moreover, the presence of such groups helps to facilitate extension. This occurs through provision of a centralized means of information, training, and project benefits dissemination (Kiptot et al. 2007). Conversely, those who are not allowed (or choose not) to participate in MBG are often deprived of both information access and bargaining power (Mloza-Banda 2005). Reaching such "non-participants" can be a challenge to development efforts.

Another challenge in Malawi is the conflict between tribal and national law concerning property rights and tenure scenarios (Degrande et al. 2012). Without guaranteed land or tree tenure, farm level decision makers in Malawi hesitate to dedicate time and resources to sustainable technologies they perceive as risky (Place 2009). Uncertainty surrounding property rights decreases motivation to invest in agroforestry because farmers worry they may not own the same property when the benefits and outputs finally manifest (Place and Otsuka 2001). Therefore, perception of secure tenure typically results in greater adoption of sustainable technologies than the converse (Mercer 2004).

Research approach and data collection

Through an extensive literature review we identified variations in the definition and treatment of determinants related to the adoption of agroforestry systems. We considered mainly the variables used and the assumptions made by Pattanayak et al. (2003) (Table 1). For the purpose of this study "determinants" refers the 20 investigated drivers of FTT adoption (e.g., income), "variables" are the operational representation of each determinant (e.g., MKW/year for income), and "factors" are other attributes of the system not considered as a driver of adoption but considered influential (e.g., divorce rate or institutions).

The present study was conducted in two stages, the Baseline Study and the Impact Study. The AFSP Baseline Study was administered in 2008, using a multi-staged stratified sampling based on Extension Planning Areas determined in collaboration with regional extension offices. The participating villages were selected randomly from six districts participating in the program, namely Karonga and Mzimba (in the North), Ntcheu and Salima (in the Center), and Mulanje and Chikwawa (in the South) (Fig. 1).

The data were collected via household surveys using a structured questionnaire, the development of which was informed by focus group discussions and literature review. Participating households were selected randomly from name lists at the municipality level. A total of 1134 households (556 male-headed and 578 female-headed) were interviewed, but only those that owned cattle and/or goats were considered in the present study ($n = 415$; 331 male-headed and 84 female-headed households).

In 2013 the follow-up Impact Study was conducted to measure the influence of AFSP on rural development in the intervention areas. While the same villages were surveyed, households within those villages were once again randomly selected from lists at the municipality level. Respondent households during the Baseline Survey were not necessarily the same in the Impact Survey due to privacy concerns (i.e., names and household locations were not recorded during the Baseline Study to ensure anonymity). During the Impact Study 501 households were interviewed in total, using a standardized survey and face-to-face interviews. For the purposes of this paper only cow and goat owners are considered ($n = 262$; 211 male-headed and 51 female-headed households).

Furthermore, 15 SLF in the Northern region agreed to provide supplementary interviews that focused explicitly

Table 1 Determinants of agroforestry adoption in Malawi

Categories	Mechanisms
1. Farmer preferences	Perceptions of a technology's utility are influenced by education, age, and technology awareness[a,b] (e.g., youth and schooling increase odds of technology adoption)[b,c,d]
	Male-headed households in patrilocal settings are more likely to adopt an agroforestry technology than those in female-headed households or in matrilocal settings[e,f]
	Agricultural duties are often delegated to women with associated investment decisions made by men[f,g]
2. Resource endowment	Higher income, as well as farmers' access to land, labor, seeds and appropriate animal breeds, affect agroforestry uptake[h]
	Households with larger family sizes (i.e., larger household workforce) are more likely to adopt labor-intensive agroforestry technologies[i]
	Wealthier farmers generally have more plots in highland areas (i.e., better-quality plots) and access to water, allowing for a greater margin for experimentation[j,k,l]
3. Institutional impediments	Lack of market pathways, communication, subsidies, and information adversely affect agroforestry adoption[m,n,o]
	Dissemination efforts often have difficulties related to the presence of extension workers, farmer-to-farmer exchange systems, targeting women groups, and on-farm trials[m,n,o]
	Lack of functioning seed supply systems, species diversification, financing resources, and dairy commercialization confound agroforestry extension efforts[m,n,o]
4. Risk/uncertainty	Opportunity costs, market reliance, and land tenure could all have positive or negative influences on agroforestry adoption depending on circumstances[p,q,r]
	Factors related to institutional environment (e.g., inadequate research, inhibitive policies and politics, and poor monitoring and evaluation) can affect the expected utility related to the adoption of agroforestry technologies[p,q,r]

[a] Blatner et al. 2000
[b] Meijer et al. 2015
[c] German et al. 2009
[d] Mignouna et al. 2011
[e] Place and Otsuka 2001
[f] Place et al. 2009
[g] Oino and Mugure 2013
[h] Pattanayak et al. 2003
[i] Thangata and Alavapati 2003
[j] Muraguri et al. 2004
[k] Sirrine et al. 2010
[l] ECA 2004
[m] Kwesiga et al. 2003
[n] Wanyoike 2005
[o] Franzel et al. 2014
[p] Ajayi et al. 2008
[q] Wambugu et al. 2011
[r] Giger et al. 2015

on FTT use and the factors that facilitate and impede its adoption. These interviews were semi-structured as participants were given the opportunity to elaborate freely on any question and interviewers could ask follow-up questions to more thoroughly explore certain responses. Given the small sample size but in-depth information collected, responses from the supplementary interviews were only intended to inform the discussion of results from the Baseline and the Impact surveys (rather than make statistical inferences).

It should be mentioned that although many of the FTT species disseminated during the AFSP had high coppicing ability, due to a scarcity of fodder seed in Malawi, AFSP had difficulty meeting demand. Therefore, seed was sometimes imported from Mozambique. Overall, approximately 925 seed sachets specific to multipurpose fodder trees (*Acacia angustissima*, *Sesbania sesban*, *Leucaena pallida*, and *Calliandra calothyrsus*) were distributed to participant farmers (Akinnifesi 2010) (Table 2).

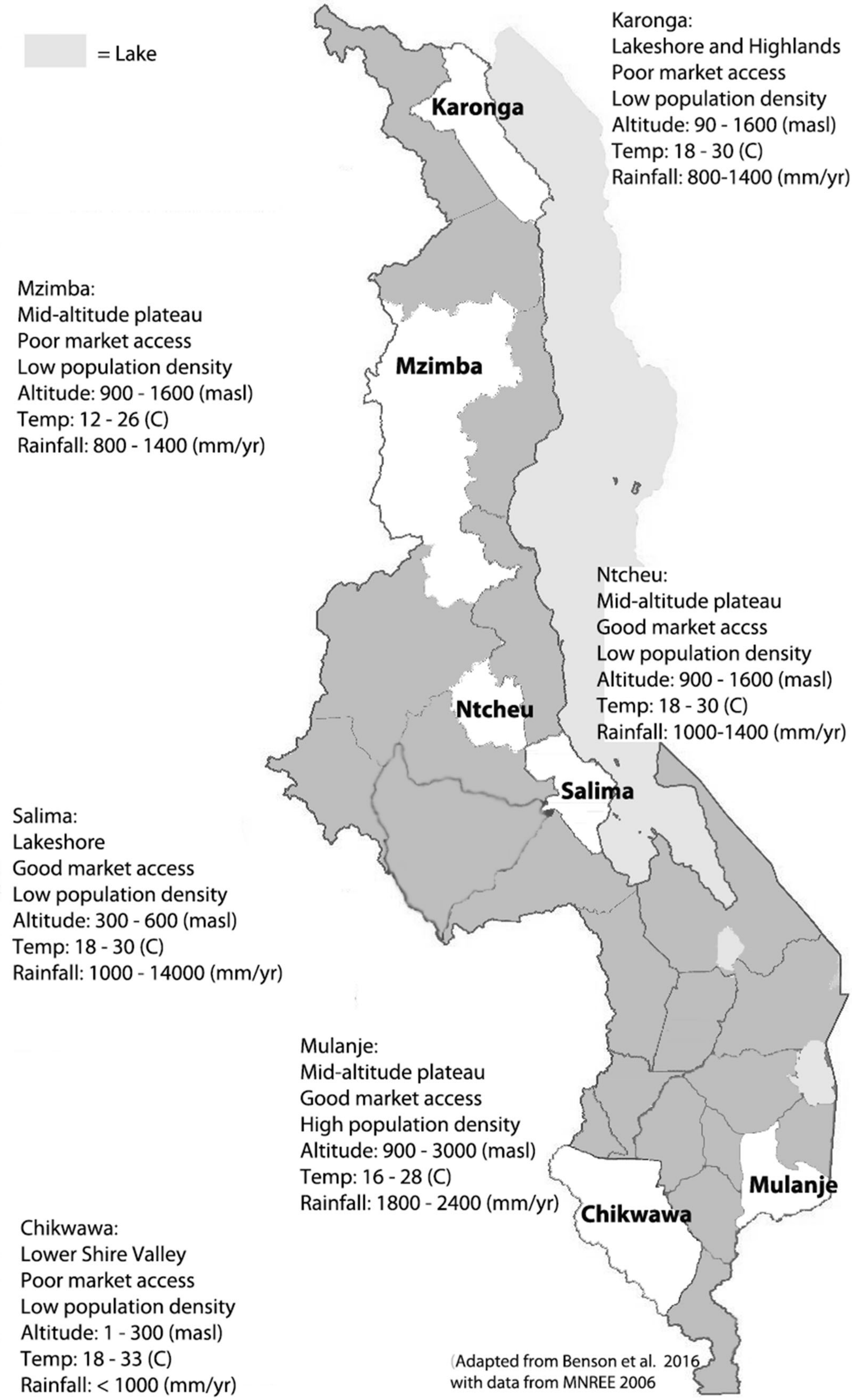


Fig. 1 Location and characteristics of Malawi's districts where the baseline and impact studies were conducted

Table 2 Characteristics of tree and shrub fodder species distributed during the agroforestry food security program in Malawi Source: (ICRAF 2016)

Species	Uses	Fodder characteristics	Nutritional value	Fuelwood characteristics
Calliandra calothyrsus (Shrub)	Shade, hedge, stakes, erosion control	Leaves can be fed to all types of ruminants	Leaves and pods are rich in protein Does not contain any toxic substances	Yields 15–40 t/ha (after first year) Annual coppice harvests continuing for 10–20 years
Leucaena pallida (Tree)	Timber, post, hedge, terrace boundary	Considered high quality fodder tree in the tropics	High nutritional value. Can increase live weight by 70–100% compared to grass	Excellent firewood with a specific gravity of 0.55–0.61 High calorific value (4200–4600 kcal/kg)
Sesbania sesban (Shrub/Tree)	Green manure, post, shade, improved fallow	Attains a height of 4–5 m in 6 months Yields of 4–12 t/ha dry matter per year	Crude protein content of 25–30% of dry matter Variable digestibility. High nitrogen retention	Soft, relatively smokeless and quick kindling High calorific value (4350 kcal/kg)
Acacia angustissima (Shrub/Tree)	Dry season forage, green manure, improved fallow	Produces 2–12 t/ha/year of dry matter depending on season and soil Poor soil tolerant	Average nutritional value Low palpability but high availability during dry season	Utilized as fuelwood but its combustion characteristics can vary

Data analysis

Binary logistic regression (BLR) is used in this paper to analyze the quantitative data collected from the Baseline and Impact surveys. It has been used extensively to analyze the potential adoption of agroforestry technologies (Mercer 2004). This type of regression entails modeling a binary outcome dependent on a set of hypothesized behavioral determinants, and taking note of the signs of the regression coefficients and their practical significance (Shideed 2005; Zerihun et al. 2014). For research in an agricultural extension context this means analysis with cross-sectional data collected through household surveys related to ex-post (available technologies) and ex-ante (new technologies with similarities to existing ones) studies across varied geographical regions (Useche et al. 2012; Alavalapati et al. 1995; Ayuk 1997; Adesina and Chianu 2002). This is considered appropriate for analyzing household survey data of the nature contained in this study, as it is capable of predicting the presence of a characteristic based on the values of a set of predictor variables (Polson and Spencer 1992). The objective of this analysis being the delineation of "boundary conditions" that should allow farmers to deem an innovation "profitable, feasible, and acceptable" (Franzel and Scherr 2002).

To this end, the underlying focus of many agroforestry adoption models is expected utility, an economic framework particularly adept at dealing with uncertainty (i.e., perceived risk) (Mercer and Pattanayak 2010; Ayuk 1997; Baidu-Forson 1999; Jamison and Moock 1984). Expected utility supposes that the adoption of a technology (e.g., agroforestry practices) is a function of unconscious and conscious information processing (van Raaji 2002). In agricultural contexts this information processing involves the perceptions of the profitability of a technology when faced with constraints (e.g., implement availability, labor requirements, credit access). This evaluation process leads to the determination of adoption during the comparison of the old and new technologies through the correlation of risks, feasibility, and potential profits (Marra et al. 2003). However, it should be noted that the acceptable levels of each are individually and culturally influenced (Stern 2000; Blatner et al. 2000; Douglas 1985).

Based on the above, the data collected from the Baseline and Impact surveys were analyzed separately through BLR using SPSS 22 with statistical differences tested at the 95% confidence level. The analysis included descriptive statistics to assess the mean, median, and standard deviation for the quantitative variables. Moreover, all data was treated as reflecting the fact that respondent perceptions are the primary influencing determinant of adoption (Gould et al. 1989). For example, "Market Access" reflected the respondents' perception of their own ability to access relevant markets, not necessarily the logistical reality. All responses were binary, or were transformed thereto. Univariate and bivariate analyses were then performed and multicollinearity was tested using variance inflation factors (VIF). No collinearity was found, with the highest VIF being 2.4, which is well below acceptable limits (Allison 2012).

Based on the determinants of agroforestry adoption outlined in Table 1 and the results of the household surveys, a conceptual framework and a statistical model were developed for testing the binary dependent variable "FTT Use" (Fig. 1), where 0 = "non-use" and 1 = "use." This was defined as growing fodder trees specifically for animal feed and represented FTT adoption as follows (Eq. 1):

$$\ln[(P_i/(1-P_i))] = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \beta_3 X_{3i} + \ldots + \beta_K X_{Ki}. \quad (1)$$

The framework was then tested against independent variables in four categories:

- *Sociological* (X_1 through X_5): i.e., "Age", "Patrilocality", "Lead Farmer Training", "Education", and "Female HouseHead";
- *Geographic* (X_6 through X_{10}): i.e., "Cultivate Lowland" (dambo), residing in the "North", residing in the "South", "Water Access", and "Cultivate Highland";
- *Financial* (X_{11} through X_{15}): i.e., "Financing Access", "Labor Availability", "Income", "Land Tenure", and "Market Access";
- *Extension* (X_{16} through X_{20}): i.e., "Ag. Dept. Training", "ICRAF Training", "Seed Availability", "Lack of Information", and "Subsidies".

Results

For the entire sample there was an increase of FTT use by 53% from the time of the Baseline Study (2008) to that of the Impact Study (2013), with some variations, however, between regions (Table 3). Several variables also saw a large percentage increases with regard to "FTT Use" between the two survey periods (Fig. 2).

For ease of comparison, the findings for the Baseline and the Impact studies are highlighted in Fig. 3 and Table 4. Circles abutting the various quadrants in Fig. 3 contain the odds ratio of the variables for the Baseline and Impact studies respectively. If no odds ratio is mentioned for a variable (indicated by "—") for the Baseline Study, Impact Study, or both, then this variable was not found to be statistically significant.

The results of the Baseline Study (Table 4; Fig. 3) indicated that "Lead Farmer Training" increased the odds of current "FTT Use" by 570% and feeling confident in "Land Tenure" increased the odds of "FTT Use" by 93%. Being in the "North" or "South" region was found to have a negative relationship with "FTT Use," reducing the likelihood of adoption by 94 and 87%, respectively compared to the central region. The remaining variables did not have any significant effect during the Baseline Study.

Table 3 Number of livestock owners per study district in Malawi and fraction using fodder tree technology

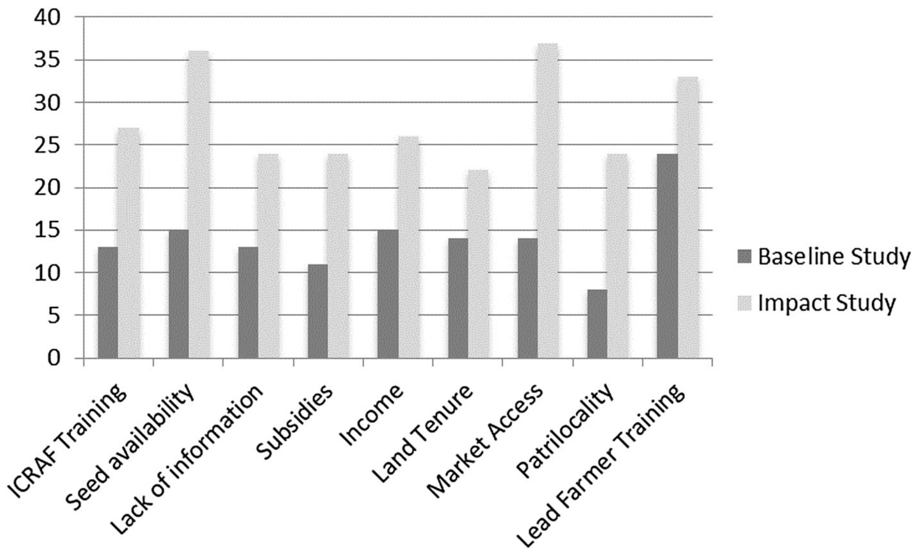
Districts	Baseline study ($n = 415$)			Impact study ($n = 262$)		
	Total	FTT use	%	Total	FFT use	%
North	146	6	4	98	27	28
Karonga	93	5	5	58	14	24
Mzimba	53	1	2	47	13	28
Central	141	37	26	62	16	26
Salima	72	15	21	45	8	18
Ntcheu	69	22	32	25	8	32
South	128	13	10	83	11	13
Mulanje	36	8	22	24	4	17
Chikwawa	92	5	5	52	7	14
Total	13.5%			20.6%		

The results of the Impact Study (Table 4; Fig. 3) indicated that those who received "ICRAF Training" increased their odds of "FTT Use" by 226% over those who did not receive such training. "Seed Availability" was found to significantly increase "FTT Use" by 153% over those who did not perceive seeds as available. "Patrilocality" increased the odds of "FTT Use" by 142% over those who did not follow a patrilocal tradition. The remaining variables did not have any significant effect during the Impact study.

Over the course of AFSP there were no farmers who only "Cultivate Lowland" and claimed "FTT Use." Conversely, there was a 33% increase in "FTT Use" among those who only "Cultivate Highland." For farmers that both "Cultivate Highland" and "Cultivate Lowland" there was a 92% increase in "FTT Use" between the two studies.

The supplementary interviews of SLF in Northern Malawi revealed several insights not directly discernible in the datasets collected from the two surveys. The SLF interviews suggested that the main constraints to the expansion of dairy herds were the lack of feed, the lack of animals available for purchase, and disease. Moreover, another major constraint seemed to be the general lack of information regarding technologies such as FTT. In this regard, many of these farmers were not part of a MBG, and few acknowledged receiving training from a source other than lead farmers. Worthy of note, however, is the fact that in this small sample, none of the farmers who had planted FTT in the 5 years before the interview had chosen to abandon the practice.

Fig. 2 Percentages of key determinants associated with fodder tree technology adoption in the baseline and impact studies (and percentage change for each)



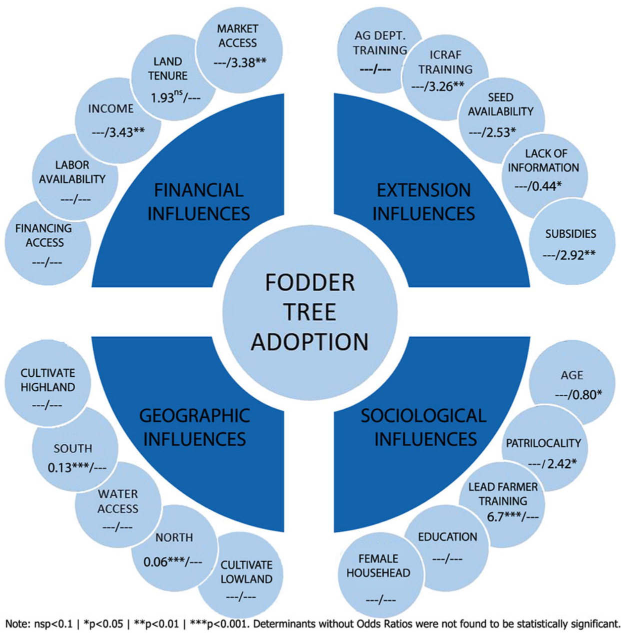


Fig. 3 Determinants of the adoption of fodder tree technology and corresponding odds ratios for the baseline and impact studies

Discussion

Rates of adoption

Over the course of AFSP there was a positive shift in perceptions regarding FTT in both the Northern and Southern regions of Malawi. This corresponds to the findings of Tebug et al. (2012b) that showed the adoption of dairy innovations increases significantly in relation to extension visits. Both the "North" and "South" variables had significant negative relationships with "FTT Use" in the Baseline study but were not found to be significant in the Impact study (Table 4). This is seen in the overall increase in the adoption rate of FTT, from 13.5% in the Baseline Study to 20.6% in the Impact Study (Table 4). While this growth was quite large (50%), the fraction of potential adopters that actually claimed "FTT Use" by the time of the Impact Study was still relatively small (20%), especially when considering the potential benefits of FTT adoption. However, this is not surprising given the knowledge intensive nature of FTT and the general "Lack of Information" highlighted by the data.

It is important to emphasize that the present study was conducted as part of a large-scale extension effort, which had both advantages and disadvantages. Using the infrastructure of the extension program assisted with the complicated logistics, enabled better contact with local regulators, and allowed for the better definition of the study regions and participating villages. However, the research being directly associated with the extension effort led to the creation of what we call an "extension environment." In the broadest sense, this means that the research was not conducted under "natural" circumstances. Providing training and implements (e.g., seeds) for free (or reduced prices) through extension could have skewed positively the technology's expected utility by decreasing perceptions of cost associated risk. This is in fact the impetus of extension, i.e., repeated positive interactions with a technology to contribute to its acceptance (Bernet et al. 2001).

However, this familiarity with the technology built through extension alone is not sufficient to increase adoption rates in the long-term (Meijer et al. 2015). While the free provisions can reduce risk concerns, the effect can be only temporary. Not all those that experiment with a technology under such conditions are expected to continue using it. For example, Kiptot et al. (2007) describe as "pseudo-adopters" those farmers who participate in

Table 4 Descriptive statistics and binary logistic regression for fodder tree technology adoption in Malawi

Variables	Freq.	Baseline study ($n = 415$)				Freq.	Impact study ($n = 262$)			
		%	Use FTT %	OR	SE		%	Use FTT %	OR	SE
Ag. Dept. training	253	61	13	0.70	0.359	189	72	23	1.00	0.463
ICRAF training	76	18	13	1.18	0.497	157	60	27	3.26**	0.433
Seed availability	33	8	15	1.36	0.584	47	18	36	2.53*	0.426
Lack of information	394	95	13	0.56	0.621	94	36	24	0.44*	0.421
Subsidies	36	9	11	0.44	0.661	161	62	24	2.92**	0.434
Cultivate lowland	12	3	0	0	0	4	2	0	0	0
Cultivate highland	234	56	15	0.84	0.381	189	76	20	0.54	0.453
North	146	35	4	0.06***	0.633	105	40	28	2.06	0.497
South	128	31	10	0.13***	0.493	76	29	14	0.43	0.565
Water access	323	78	13	1.55	0.406	188	72	21	1.18	0.398
Financing access	95	23	10	0.52	0.431	79	30	23	0.92	0.411
Labor availability	276	67	14	0.97	0.387	179	68	20	0.71	0.425
Income	329	79	15	1.23	0.508	174	66	26	3.43**	0.463
Land tenure	305	74	14	1.93ns	0.403	139	53	22	1.02	0.372
Market access	63	15	14	1.03	0.451	38	15	37	3.38**	0.467
Patrilocality	237	57	8	0.88	0.401	127	49	24	2.42*	0.410
Lead farmer training	38	9	24	6.7***	0.545	6	2	33	1.12	1.02
Education	352	85	13	0.68	0.447	232	89	21	0.90	0.671
Female house head	84	20	20	1.14	0.438	51	20	22	1.45	0.495
Age	43[a]	15	NA	1.02	0.068	47[a]	14	NA	0.80*	0.116
Intercept				0.50	1.70				3.94	2.53
X^2				57***					57***	

OR odds ratio, *SE* standard error

Two tailed: $^{ns}p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

[a] Age is a continuous variable presented with the mean and standard deviation

research programs to take advantage of benefits such as free seeds and access to credit. Place et al. (2005) similarly describe as "research farmers" those that move from one research project to the next for the related benefits. When extension projects end, or supplements are in short supply, such "testers" have the tendency to abandon the said technology (Kiptot et al. 2007). To understand this situation further the relative importance of various factors affecting technology adoption need to be further examined, as discussed in the following sections.

Training and information

Farmers who receive appropriate training in an agroforestry technology typically experience more benefits than costs, and are thus more likely to have optimistic perceptions of its utility (Ajayi et al. 2008; Giger et al. 2015). The various entities involved in AFSP provided training in several different agroforestry practices (i.e., not exclusively FTT). The relationships between the various types of training (i.e., "Ag. Dept. Training", "ICRAF Training") and "FTT Use" highlight differences on the emphasis placed by each training organization, with the significance of each relationship depending on the provider of training. For example, the sole task of the extension agents of ICRAF during AFSP was to emphasize agroforestry practices. Alternatively, the staff of the Agricultural Department were responsible for offering training on a broad range of subjects beyond AFSP, and were less focused and technically trained to deliver agroforestry information effectively. So, while effort was made to provide the same type/level of training across villages, the quality of that training cannot be accounted for. Ultimately, this means that training in FTT may have received less attention from the staff of the Agricultural Department during the extension effort, as manifested by the lack of significance of "Ag. Dept. Training" in both surveys, while "ICRAF Training" was significant in the Impact Study (Table 4).

Another facet of training is that the extension environment may have reduced the significance of "Lead Farmer

Training" over the course of AFSP. Studies have shown that while the lead farmer extension model has limited reach, it can be extremely effective (Franzel et al. 2015). In fact, it has been widely observed that smallholders tend to accept advice more readily from their peers, than from anyone else (Kiptot and Franzel 2014). Only 9% of SLF from the Baseline study reported having consistent interaction with lead farmers, yet the "Lead Farmer Training" variable had the highest odds ratio (6.7) and significance ($p < 0.001$) amongst all variables (Table 4). At the same time, "Lack of Information" was not significant in the Baseline Study. By the time of the Impact Study, however, "Lead Farmer Training" was no longer significant and "Lack of Information" was significant and negatively correlated with "FTT Use" (0.44/$p < 0.05$). A similar finding has been reported for SSA in general (Meijer et al. 2015). An external appraisal of AFSP conducted by the Center for Independent Evaluations (CIE) reported that the program was successful in disseminating the focus technology (fertilizer tree systems), but less so in disseminating FTT (C.I.E. 2011; Ajayi et al. 2010).

To understand this shift it is important to emphasize that the "Lack of Information" variable measured farmers' access to information about FTT. A positive response for this variable meant a farmer knew that FTT information existed, but not necessarily how to access it. This was the case during the Baseline Study as lead farmers were primarily responsible for the flow of FTT information. Combining these circumstances, pre-extension environment farmers that received lead farmer training had greater awareness of FTT-related information than the general community. By the time of the Impact Study, the extension environment raised the general awareness of FTT but did not necessarily create an equally high quality of access to such information. This is manifested by the fact that "ICRAF Training" was the only form of training with a high odds ratio and significance (3.26/$p < 0.01$). The "Lack of Information" variable became significant as more farmers learned of the existence of FTT-related information, and only some were able to access it. Correspondingly, as access from other sources increased, the importance of lead farmers decreased.

The farmer-led model of extension is far from new and can have some potentially negative effects. For example, it can contribute to elite capture (discussed below). Both the negative and positive impacts of this model have received a growing attention in the literature (Kiptot and Franzel 2014). However, further research is needed on how to maximize its effectiveness within larger extension efforts. The current results suggest that the effectiveness of the farmer-led model reduces significantly in the presence of other forms of extension. Further efforts could take this into account along with the specific characteristics of the target technology and geographical setting during the design process. For example, if potential adopters in a particular region are spread at a distance that makes visits between farmers unlikely or are located in villages that are frequently targeted by extension efforts, the farmer-led model may not be an appropriate choice.

Provision of seeds

"Seed Availability" was not found to be a significant determinant in FTT adoption during the Baseline Study, which reflects the finding of C.I.E. (2011) regarding seed shortages at that time. Despite the occasional seed shortages, the Impact Study results show a statistically significant relationship between the perceptions of respondents about "Seed Availability" and "FTT Use" (2.53/$p < 0.05$). This supports findings from the literature, which suggest that positive perceptions about input availability can improve expected utility (Franzel et al. 2003).

While the availability of seeds generally increased due to the extension effort, fodder seeds remained in short supply. The higher availability of *Tephrosia candida* and *Sesbania sesban* seeds (provided as fertilizer trees), could have helped address this issue but training focused exclusively on the fertilizer value of these species, rather than the multipurpose aspects of the plants (Table 2). In fact, there was an overriding focus on fertilizer trees throughout AFSP (Akinnifesi 2010). Farmers were trained to intercrop fertilizer trees, illustrating that these trees occupied minimal space. On the other hand training regarding fodder trees involved the use of "tree-banks" (i.e., areas of the farm dedicated to production of fodder trees rather than crops), potentially increasing the land requirement.

Considering the above, future FTT extension efforts should ensure seed availability and incorporate appropriate training. This should involve offering knowledge about the possibility to intercrop fodder species to prevent instilling perceptions that may be difficult to reverse (e.g., unavailability of inputs and necessity of extra land for FTT production). Moreover, policies that enhance the coordination between seed nurseries should be considered to ensure the future availability of adequate amounts of appropriate seeds.

The role of subsidies

The Impact Study supported the premise that "Subsidies" positively influence the adoption of a related conservation practice, in this case "FTT Use" (2.92/$p < 0.01$), and reduce the perceptions of associated risks (Ngwira et al. 2014; Ward et al. 2016). The manner in which sociological factors (e.g., elite capture and community involvement in multiple extension efforts) attenuate subsidy effectiveness is, however, less well defined.

Elite capture occurs when extension resources are funneled through social elites who direct them in a manner that maintains social disparities (Sitko and Jayne 2014; Feder et al. 2010; World Bank 2007). For example in Malawi, chemical fertilizer subsidies are often used as political tools to win favor in elections (Dionne and Horowitz 2013; Brazys et al. 2015). Additionally, the provision of inputs (e.g., fertilizer, plows, seeds) can sometimes be viewed as a means of influencing farmers to participate in one type of extension effort over another (Kiptot et al. 2007). For farmers in SSA these examples can contribute to the development of short-term benefit mentality, to the detriment of long-term self-dependency and sustainability (De Wolf 2010). In the same manner that subsidies relevant to FTT can lead to the adoption of the technology, subsidies for management techniques that compete with FTT (e.g., coupons for alternative feeds) can possibly limit FTT adoption, or even lead to its abandonment. This was noted in the supplementary interviews where some respondents suggested that they had feigned interest in extension to increase the likelihood of receiving some sort of accouterment, or others who suggested they had negative perceptions about an agroforestry practice because they were not selected to receive extension support.

It should be noted that the effects of this competition may be more detrimental than they first appear. Abandonment may represent the incomplete testing of a technology and, as such, the perceptions of the expected utility of that technology may be negatively influenced (Gurung 2010). Given that adoption is often the result of repeated positive interactions with a technology (Wejnert 2002), ill-formed perceptions may impede future extension efforts.

Preferably, the recognition of this situation will lead to policy prescriptions that prevent, or even align, disparate development efforts and subsidies. Future research should focus on these interactions and the economic and attitudinal impacts of abandonment (particularly for those who adopted based on subsidies). Such research could identify what aspects of an agroforestry technology need to be adjusted or if technology abandonment is the result of sociological or logistical factors that should instead receive more focus. The present research failed to capture such effects, as it did not follow individual farmers from the Baseline Study to the Impact Study.

Gender effects

The literature about the adoption of agroforestry is not consistent with regards to the influence of "Female HouseHead." Yet, many development efforts target female-headed households (Takane 2009). In our study, having a "Female HouseHead" did not increase the likelihood of "FTT Use." Conversely, there is a general agreement in the literature that in patrilocal settings males have a greater incentive to pursue long-term investment strategies like FTT, if these are pursued on property that will remain in their possession after divorce (Place and Otsuka 2001). This corresponds with the findings of our study as when residing in the husband's village male-headed households are more likely to adopt FTT, as confirmed by the positive relationship in the Impact Study between "Patrilocality" and "FTT Use" (2.42/$p < 0.05$).

The extension environment of the current work is not expected to cause much variation from what is discussed in the agroforestry literature, as the evaluation of utility in this scenario would focus on opportunity costs. Males with a "Female HouseHead" making long-term investment decisions would be less focused on the cost of inputs and training (i.e., elements inherent to the extension environment) rather than bringing the greatest benefit in the short-term. Specifically, using parts of the same farm for long-term agricultural investments such as agroforestry, could reduce the available space for crops that have a faster profitability. This makes the reduced costs of FTT inputs (e.g., subsidies, training, and seeds provided by AFSP) inconsequential.

Furthermore, while the extension environment might not be effective in influencing males in matrilocal communities to adopt FTT, a reduction of the high divorce rate in Malawi (estimated at 40–65%) (Reniers 2003; Cherchye et al. 2016), possibly could. If the perceived risk of losing long-term agricultural investments due to divorce reduces, then men living within their wife's village may become keener on making long-term investments similar to agroforestry. In this sense, relationship security can serve as a type of proxy for secure land tenure, the importance of which is described below.

Access to land and land tenure

Access to land and stable land tenure are important determinants of the adoption of agroforestry technologies, as several studies have shown (ECA 2004) (Table 2). For example, land tenure can determine a household's access to water and thus its irrigation capabilities (Bohringer et al. 2003). In this study, while "Land Tenure" is an important variable, it is defined rather loosely. During the baseline and the impact studies no legal proof of land ownership was required, so respondents were simply asked their perception if they felt safe that their land belongs to them, and will continue to do so in the future. A positive response indicated the existence of "Land Tenure."

However, for agroforestry adoption it is not only stable tenure that is an important determinant of adoption, but also in which type of area households have access to land. For example in Malawi, like much of SSA, highland areas have long been associated with more fertile soil and wider availability of tree species than lowland (dambo) areas (Muraguri et al. 2004; Thorpe et al. 1993). Thus, the distinction between "Cultivate Lowland" (dambo) and "Cultivate Highland" essentially marks a proxy for land quality. The result is a greater demand for highland areas to cultivate, and an associated reduction of space for free grazing in the highlands. These conditions necessitate the penning and stall-feeding of animals in highlands and thereby increase the likelihood of FTT adoption, with the opposite being true for lowland areas (Thorpe et al. 1993; Muraguri et al. 2004). In fact, in their metanalysis of agroforestry adoption studies, Pattanayak et al. (2003) found that land quality and tenure are two of the most consistent and significant influences of agroforestry adoption. Our results, as discussed below, somewhat confirm such findings.

During the Baseline Study, "Land Tenure" was nearly significant ($1.93/p < 0.1$), while "FTT Use" was non-existent for farmers that only "Cultivate Lowland." As the extension environment developed during AFSP this latter correlation remained at zero, while for farmers that "Cultivate Highland" it increased by 33%. At the same time, "Land Tenure" ceased to be statistically significant. Based on this, the relationship between the cultivation of lowlands and "FTT Use" appears to be a matter of geography, but, much like "Land Tenure," it is also the result of financial and sociological factors. For example, farm size and location in Malawi are often determined by factors beyond farmer control. This is true in settings where formal laws are followed, but is even more prevalent in areas where customary rules are widely used to determine inheritance and land allocation. The latter is true for large areas of Malawi (75%), encompassing most of the areas that have a high prevalence of SLF (Chirwa et al. 2012). In such settings, land tenure is often determined by social status in relation to tribal/village elites, and can be altered by traditional leaders (Chirwa 2008). As some customary land arrangements are recognized in Malawian law and others are not, access to recourse (i.e., ability to appeal to an authority for assistance) can be an important factor for smallholder farmers who are not favored (Place and Otsuka 2001). The outcome, as confirmed here, is that highland owners are typically better equipped for technology adoption.

Given that prior to AFSP "Land Tenure" was positively correlated with "FTT Use" and had the second largest influence on adoption (Fig. 3), gaining an awareness of both the financial and sociological factors that affect tenure should be part of extension efforts focusing on lowland areas. Promoting fodder trees that are better suited for poorer soils could address geographical constraints, while increased training and access to implements/tools/seeds or subsidies could help with the financial implications. Unfortunately, as the sociological factors regarding land tenure are embedded in the institutional landscape of Malawi, significant policy changes would be required to address some of the other factors that affect land tenure scenarios.

Market access and income

During the Impact Study, "Market Access" was found to be a statistically significant determinant influencing "FTT Use" (Fig. 1). This is in accordance with existing literature from Eastern and Southern Africa (Kwesiga et al. 2003; Wanyoike 2005; Franzel et al. 2014). The lack of statistical significance for this variable in the Baseline Study could be because, even for SSA standards, Malawi has exceptionally weak infrastructure both physically (e.g., roads, storage, transportation) and systematically (e.g., value chains and system pathways) (Benson et al. 2016).

Milk production during the Baseline Study seldom exceeded personal consumption levels, and those farmers that did produce surplus milk and had market access (e.g., MBG) were relatively few. As the AFSP progressed, those areas that had greater "Market Access" prior to the Baseline study such as Ntcheu, Salima, and Mulanje (according to Benson et al. 2016), experienced lower increases in "FTT Use." As FTT awareness and milk production increased by the time of the Impact Study, having the means of selling surplus milk increased in importance to those farmers that previously had less market access. The implication being that as farmers began using FTT their cows began producing more milk, making the means of selling surplus milk (i.e., "Market Access") increase in importance. By the time of the Impact Study, the perceived importance of "Market Access" increased in all study areas by 160%, alongside the growth of "FTT Use" in the remaining three districts (Chikwawa, Karonga, and Mzimba).

Growing awareness of FTT could also explain why "Income" was significant in the Impact Study, but not the Baseline Study. Possibly, as the general awareness of FTT increased, the ability to purchase the necessary implements and labor gained importance. Determining this definitively, however, requires further research to exclude endogeneity. For example, income itself can be considered an impact of adoption (rather than a driver), especially considering that "Market Access" also correlates strongly with "FTT Use." Finally, another possible reason why "Market Access" appeared to grow in significance may be that the variable was not properly specified. If we had measured access to milk markets specifically, "Market Access" might have been a significant variable in both studies. Future research efforts about the adoption of agroforestry technologies should take such a distinction into consideration.

Gaps and future research

Most of the determinants that affect FTT adoption overlap, with their interactions varying in intensity (Ajayi et al. 2008). However, it is not always clear how sociological and financial factors affect the determinants of FTT adoption. Financial and geographic determinants are often highly correlated as, for example, financial means influence the ability to purchase productive land and access to productive land leads to greater financial means. Additionally, sociological factors can influence extension efforts as elites, such as lead farmers and patriarchs, often control the manner in which extension is disbursed. So while the extension environment likely shifted the influence of the extension/financial factors, the sociological factors played a role in guiding the process. As noted, the intent of extension is to create shifts in the perceived value/utility of a technology by creating familiarity with its benefits, but the moderation of this shift by sociological factors is not fully understood. Future research could incorporate a control group and use statistical tests for moderation and mediation to establish how some of these factors influence determinants and quantify resultant shifts (Toth 2016).

"Wealth" was not considered as a possible determinant of FTT adoption, because of the study's focus on perceptions and not economic reality. While perceptions are too abstract, wealth is too volatile. "Wealth" is frequently measured as a distinct determinant in adoption studies, most often inferred from other variables, such as land holdings, assets, and ownership of cows (as opposed to just goats) (Doss 2003). "Wealth" is also commonly encapsulated in many studies by the gender variable, with nearly always the same inference made, i.e., women adopt technologies significantly less because they are poorer than men (Kiptot and Franzel 2011). While "Income" is not the same as "Wealth," it could be considered a close proxy for those interested in the latter's effects (Mercer and Pattanayak 2010), but, as noted, using income as a variable has its own set of shortcomings. In any case, "Wealth" can be an important determinant of FTT adoption that merits consideration in future studies.

Conclusion

This study attempted to identify the determinants that influence FTT adoption among SLF in six regions of Malawi. Data was collected through household surveys during a large-scale extension effort in Malawi and were analyzed through binary logistic regression. Results suggest that a general "lack of knowledge" was the overarching determinant preventing FTT adoption. The study also revealed that distinctions among the adoption constraints defined in the literature (classified as geographic, social, financial, and extension) are not always clear-cut. Some of the factors that had a substantial influence on FTT adoption included the lack of uniformity among the various training organizations, variations in matrilocal/patrilocal traditions, land quality and tenure, and the extent of market awareness.

A significant outcome of the Agroforestry Food Security Program (AFSP) that provided the basis of this study was the creation of an "extension environment." As AFSP progressed, elements of extension (that is consistent provision of seeds, training, subsidies, and information related to FTT) reduced the influence of sociological and geographic factors, while shifting financial focus from inputs to outputs. The implication is that farmers' relationships with lead farmers, quality of farmland, or ability to obtain implements did not weigh as heavily in expected utility determinations. During the extension period, these determinants were more visible. Thus, the importance of market awareness and ability to sell increasing outputs grew in importance, while that of input costs and availability shrank.

Multi-faceted extension efforts could reduce the effectiveness of farmer-led extension models, the efficacy and value of which would depend on the sociological and geographic setting. The method of FTT production and the consistent availability of seeds during the extension effort should be carefully planned. Future FTT adoption studies during and after an extension effort should place equal weight on constraints to adoption and causes of abandonment, taking note of institutional/social issues such as divorce rates, poor infrastructure, and legal discrepancies between formal and traditional land tenure rules. Constraints related to matrilocality appeared unaffected by 5 years of extension efforts.

While the results and recommendations of this work relate to the specific conditions of smallholder farmer livestock production in Malawi, they are also to an extent applicable to other similar agricultural settings of Africa. Ultimately, curbing FTT adoption constraints could help improve human and animal health, ecosystem resilience, and economic conditions in different parts of Africa.

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