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Measuring household legume cultivation intensity in Sub-Saharan Africa

Barnes, A.P.[1]*, Muoni, T[2,3]., Öborn, I[2,3], Bergkvist, G[2]., Nziguheba, G[4]., Watson, C.A[5]., Vanlauwe, B. [4],Duncan, A.J.[6].

[1]Rural Economy, Environment and Society, SRUC, Kings Buildings, West Mains Road, Edinburgh, EH9 3JG

[2]Department of Crop Production Ecology, Swedish University of Agricultural Sciences, P.O. Box 7043, SE-750 07 Uppsala Sweden

[3]World Agroforestry (ICRAF) P.O. Box 30677-00100, United Nations Avenue, Nairobi, Kenya

[4]International Institute of Tropical Agriculture (IITA), c/o ICIPE, Kasarani, P.O. Box 30772-00100, Nairobi, Kenya

[5]Crop and Soil Systems, SRUC, Craibstone Estate, Aberdeen AB21 9YA, UK

[6]Global Academy of Agriculture and Food Security, The Royal (Dick) School of Veterinary Studies and The Roslin Institute, University of Edinburgh, Easter Bush Campus, Midlothian EH25 9RG, UK; International Livestock Research Institute, PO Box 5689, Addis Ababa, Ethiopia

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*Corresponding Author: Andrew.Barnes@sruc.ac.uk

Abstract

Legumes form part of an ecological based solution to intensification in areas with limited access to external inputs or to support increased efficiency of available fertiliser nutrients. Despite a number of decades of intervention, uptake of legumes has been slow within smallholder farming systems in Sub-Saharan Africa. This paper explores the drivers behind adoption of legumes by developing an indicator of household legume cultivation (HLC) from a bespoke survey of 274 small-scale farm households in Kenya and the Democratic Republic of the Congo.

We decompose this indicator using a beta regression framework and find a range of intensities across sites and farms, indicating limited influence of agro-ecological zones and formal institutions on uptake. There was some commonality in drivers across sites, though age, income and gender have positive but very marginal effects. Farm households with more intense legume cultivation were less driven by commercial growth objectives and have limited access to markets. There was little interest in expanding farm area which reflects the lack of assets available to these farmers and, as a consequence, promotes the use of legumes in providing home nutrition, or supporting farm fertility and provision of livestock feed.

Further development of this HLC metric would be enabled by consistent data gathering across regions, or at least equally detailed studies of legume uptake. Overcoming constraints to increasing use of legumes should be a significant component of local and international agricultural intervention as countries experience increasing environmental and social pressures and the need to commercialise as farming develops.

Keywords: Legume adoption; ecological intensification; sub-Saharan Africa; beta regression

1.0 Introduction

The population of Sub-Saharan Africa (SSA) is currently estimated to be over 1 billion and this is expected to continue to increase over the next few decades. As countries in SSA develop there will be sustained pressures on food production related to urbanisation and population growth (Calderon *et al*., 2019). Over the last decade there has been evidence of growing commercialisation occurring in the farming landscape (Hall *et al*., 2017). SSA is still mostly populated by smallholder farms, with an average area of around 2 ha per household (Moyo, 2016). In general, farms rely on natural rainfall and are managed under customary ownerships (Biazin *et al.*, 2012; Yang *et al*., 2015). Productivity rates remain low (Rosegrant *et al*., 2009), tempered by increased frequency of drought, lack of institutional support and market development, as well as erratic policy towards the rural poor and food security (Mugunieri and Omiti, 2007; Goyal and Nash, 2017; Takeshima *et al*., 2020).

To improve the food security status of smallholder farms land expansion or intensification of these farming systems has been recommended (Descheemaeker *et al*., 2016; Vanlauwe *et al*., 2014; 2019; Jindo *et al*., 2020). As SSA has constraints in relation to chemical or machinery inputs, ecological intensification (EI) may be seen as a sustainable support pathway for developing these small farms (Rusinamhodzi *et al*., 2012; Belmain *et al*., 2013; Vanlauwe *et al*., 2013). Moreover, Tittonell and Giller (2013) argued that EI has seldom been addressed in the context of smallholder farming systems of rural Africa. One aspect of this is the difficulty in quantifying and benchmarking progress towards EI due to limits in data availability (Barnes and Thomson, 2014; Jayne *et al.,* 2018). Legumes address ecological as well as social-cultural aspects of farming (Altieri and Nicholls, 2012; Wezel *et al*., 2015; Altieri *et al*., 2017). The multiple uses provided from legumes are consequently a platform for supporting both crop and livestock systems (Kermah *et al*., 2018; Giller and Cadisch, 1995; Muoni *et al*., 2019; Foyer *et al*., 2019; Day, 2013; Watson *et al*., 2017; Edelman and Colt, 2016; Simbaya, 2002).

Although there are multiple benefits from integrating legumes within these smallholder farms Foyer *et al*. (2016) argued that legume production has declined globally since the 1960s due to the release of agro-chemical fertilisers*.* More recently, Vanlauwe *et al.* (2019) found, using FAO data covering 1980 to 2016, that for SSA the proportion of cropland under legumes has only slightly, yet erratically, increased from 12 to 16%.

Legumes have a long history of intervention in SSA which are aimed at integrating and increasing their use within these farming systems (Wittwer *et al*., 2017; Vanlauwe *et al*., 2019). Past interventions at a local or international level, providing genetic material, information and peer support have also led to signals on how legumes could be sustained within SSA farming systems (Benzer-Kerr, 2007; Farrow *et al.,* 2019) and leads to the support of examining socio-cultural factors around why farmers do not grow legumes (Ojiem *et al.* 2006). Moreover, a further tranche of literature has focused on the enabling institutional structures needed to increase uptake, such as legume seed supply chains (Sperling *et al*., 2020) and end markets for legume products (Mulder, 2018; Snapp *et al*., 2019). In addition, the provision of information, and the integration with local knowledge around legumes is also an identified weakness (Mulder, 2018; Atlin et al., 2019). Amongst these are also household factors which generate mixed results and are site specific, specifically gender and age categories (Chianu et al., 2011). However, whilst a number of reviews have focused on these institutional and eco-zone factors, farmer motivation and personal factors has been relatively underexplored in past research, though some have focused on cropping risk with legumes, finding theses to be significant (Apata *et al.,* 2009; Meijer *et al*., 2015).

The majority of crop adoption studies have taken an over simplified approach to the management decision (Jones-Garcia and Krishna, 2021). Generally, crop adoption, including legumes and conservation practices , are handled as binary decisions (Wauters & Mathijs, 2014; Akudugu, Guo & Dadzie, 2012; Mulder, 2018). There are only a few studies which have applied more complex models. Ghadem *et al*. (2005) and Kassie *et al*. (2013a) applied an ordered model to include the degree by which cropping practices are adopted, or models which account for joint related decision-making across practices (Teklewold *et al*., 2013; Kassie *et al*., 2013b). Analysis of the intensity of activiy has tended to focus on the adoption of sets of discrete practices which could infer some level of intensification (Kassie *et al*., 2015; Ndiritu *et al*., 2014). However, intensity itself suggest an increasing proportion of activity. Hence, a framework which examines adoption as a continuous, as oppose to a discrete, variable would seem more appropriate as we focus on a particular practice, namely increased uptake of legumes at farm level. Examination of continuous data allows us to understand the variance between farms and agro-ecological zones at a more granular level compared to discrete packages of practices adopted by the farm household.

Accordingly, this paper develops a framework for understanding the range of institutional, climatic, economic and personal factors behind legume cultivation. We apply this through an indicator of household legume cultivation, which relates to the proportion of land cropped under legumes relative to the whole farm area (Marinus *et al*., 2018). We then explore the relationship between our framework and this intensity variable utilising a bespoke household survey conducted within 8 sites across Kenya and the Democratic Republic of the Congo (DRC). Further academic insights emerge from the adoption of a beta regression framework which, to date, has not been applied to the issue of intensification of agricultural practices globally, and is appropriate when applying to proportionate land data.

The paper is set out as follows. The next section describes the data collection and identification of key variables to derive intensity as well as to decompose these varying intensities. Then the beta regression framework is described and this is followed by a discussion of results and how they compare with past studies on legume intensification. Finally, a discussion and policy section is included.

2.0 Materials and Methods

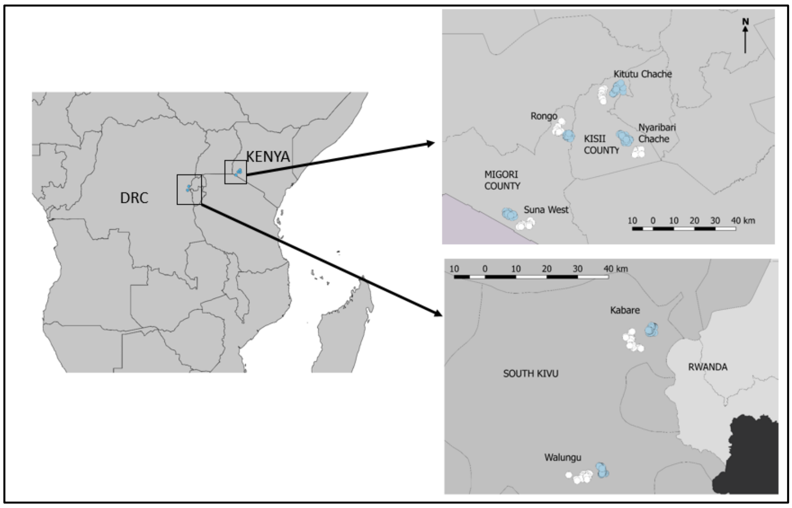
2.1 Sites

Data were collected in Western Kenya and eastern Democratic Republic of the Congo.

Democratic Republic of the Congo: The sites were Bushumba (Mulengeza and Bushumba Center) in Kabare territory and Mushinga (Madaka and Luduha) in Walungu territory, all located in the province of South Kivu. The sites receive rainfall in a bimodal pattern (1100 – 2700 mm per annum) and the annual average temperature is between 18 and 21ºC. The dominating soils are *Umbric Ferrasols* (Jones *et al.*, 2013). Mixed crop-livestock farming is dominant in the areas although most farmers have small livestock units and small land holdings. Crops grown include cassava (*Manihot esculenta* Crantz.), common bean (*Phaseolus vulgaris* L.) and maize (*Zea mays* L.) usually planted with first effective rains. Land preparation and weed management are practiced using ox-drawn mouldboard plough or hand hoes. Livestock owned include cattle, goats, sheep, guinea pigs and chickens. In total 110 responses were returned from DRC.

Western Kenya: The sites are located in Migori (Rongo and Suna West) and Kisii (Nyaribari Chache and Kitutu Chache) Counties which receive 1000-1600 mm per annum in a bimodal pattern. The altitude of both counties lies between 1200 and 2000 m above sea level. Most farmers grow crops in both seasons and own small parcels of land. All sites are dominated by *Acrisols*, except for Suna West with *Planosols* (Jones et al., 2013). Annual average temperature is about 20ºC. Most crops, including maize, sugarcane, cassava, common bean and tea, are established after receiving the first effective rains in each cropping season. Land preparation, weed management and livestock ownership is similar to the DRC sites. In total 164 responses were returned from Western Kenya.

Figure 1. Data collection sites across Kenya and the DRC



2.2. Data Collection

A sampling frame was developed based on the *Legume*CHOICE sampling protocols (see Duncan *et al*., 2016). The sample consisted of equal numbers of farmers who were in the LegumeCHOICE project (LC), which ran from 2014 to 2017, and those who were at least 5 km away from the LC farmers at a random walk. Selection criteria for farmers outside LC project was; a) lack of awareness about LC, b) only household heads and c) farmers willingness to participate.

A structured household questionnaire was used for data collection covering i) detailed background information on the farm, ii) overall farm, livestock and cropping plans, iii) detailed current use of legumes, iv) influences on use of legumes, and v) knowledge and perceptions on legumes. The questionairre and engagement protocol were approved through SLU's social science ethics committee. The questionnaire was piloted at three field sites in Kenya (Rongo, Kitutu Chache and Nyaribari Chache) with 15 farmers. Enumerators were then trained on how to use the survey instrument before interviews commenced. All enumerators were either research technicians or interns at the International Institute for Tropical Agriculture (IITA) in DRC, the Kenya Agriculture and Livestock Research Institute (KALRO) in Kenya. In each country, the same enumerators participated at all sites. Data were recorded on paper survey forms by enumerators. The interviews were carried out in Luo, Kisii, Swahili, Mashi or French languages and the results were translated into English. Farmers were given a chance to consult other family members who were present during the interviews and this level of consultation was recorded as part of the data collection exercise. In total this returned a response of 274 completed surveys. Data were checked with enumerators and cleaned of obvious outliers. These were then analyzed using STATA 16.0 (Stata Corp., 2019).

Measuring Household Legume Cultivation

Within the technology adoption literature legumes, and conservation practices generally, are handled as binary decisions (Wauters & Mathijs, 2014; Akudugu *et al*., 2012; Mulder, 2018). This is recognised in recent literature with the application of ordered models, thus indicating degrees of adoption of practices (Ghadem *et al*., 2005; Kassie *et al*., 2013a), or models accounting for related decision-making across practices (Teklewold *et al*., 2013; Kassie *et al*., 2013b). Understanding intensity of practice has tended to focus on the adoption of sets of discrete practices which could infer some level of intensification (Kassie *et al*., 2015; Ndiritu *et al*., 2014). However, intensity itself infers increasing proportions of activity.

Hence, a framework which examines adoption as a continuous variable would seem more appropriate as we focus on a particular practice, namely increased cultivation of legumes at farm household level. Examination of continuous data allows us to understand the variances between farms and agro-ecological zones at a more granular level, as the division into discrete packages of practices observed in past studies does not accommodate the relative intensity at which this practice is adopted by the farm household.

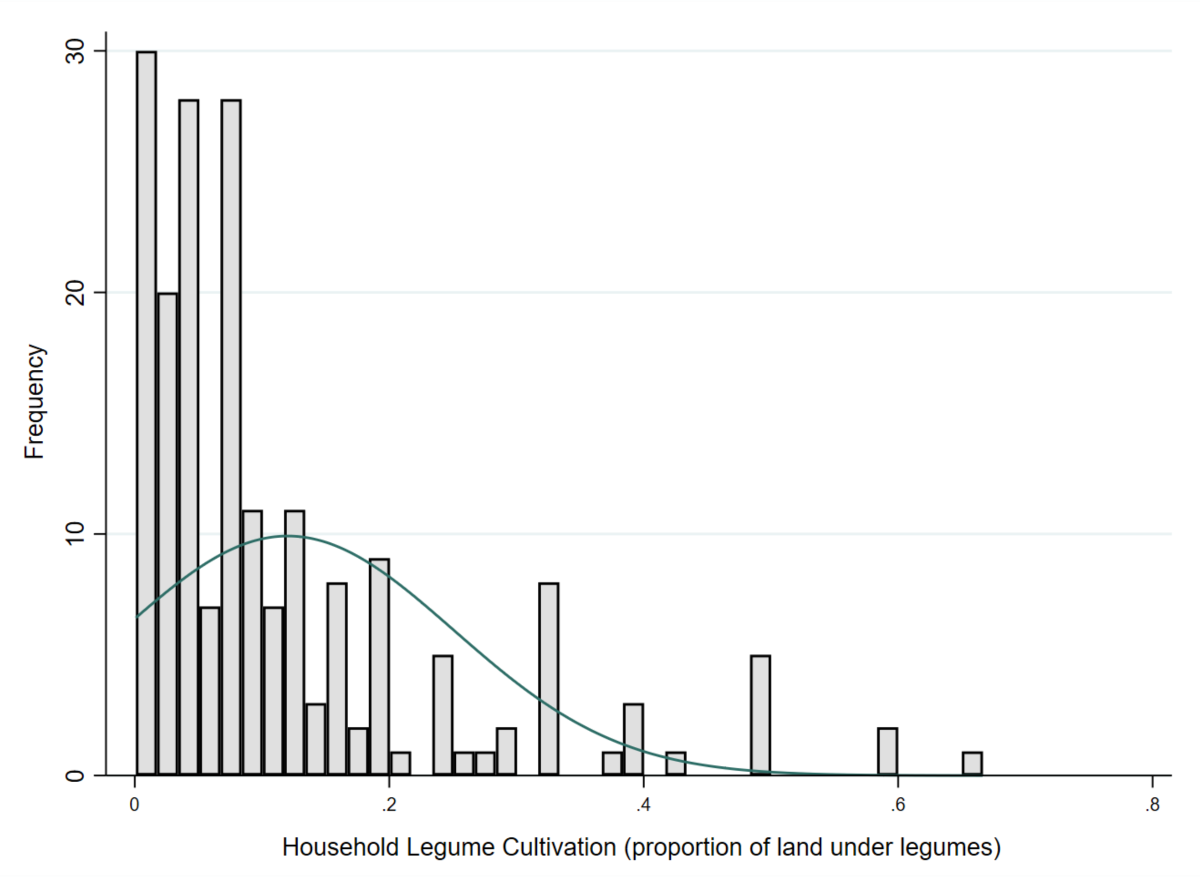
Within the planning of a cropping system, legumes can play a primary or a secondary role, the latter in terms of intercropping with starchy staples, such as maize, providing a second crop. Farmers were asked to identify their crops grown and the area of each crop grown over two seasons for ease of recall. Accordingly we measure household legume cultivation as a ratio of legume plot area, where *I* is the intensity for farm *i*, composed of the sum of *n* areas under legumes (*L*), over the sum of the *m* areas of total farm area (*A*).

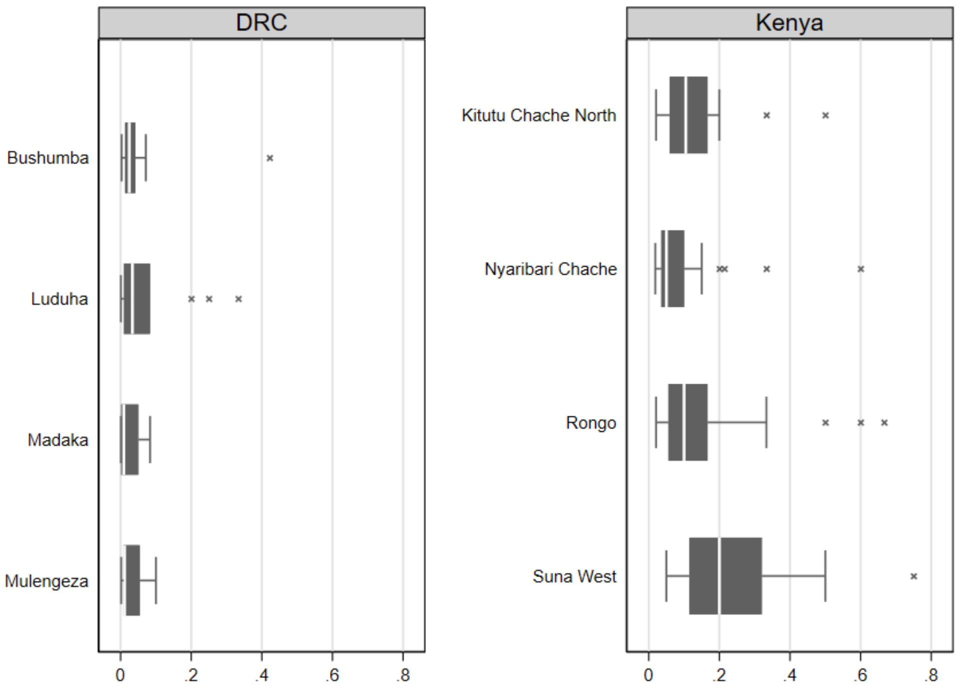
$$I_i = \frac{\sum_n^N L_i}{\sum_m^M A_i} \qquad (1)$$

Where $L_i \in A_i \; and \; I_i > 0 \; and < 1$

This indicates the relative proportion of legume cultivation between each farm. As the beta regression model takes proportionate data then the dependant variable simply measures relative positions of each farm in terms of their intensity. Legumes were identified on the questionnaire using common identifiers such as 'beans' or 'common beans', 'soybeans', 'green grams' and 'groundnuts'. Figure 2 shows the distribution of intensity by frequency, alongside per site. This shows a high early skew and indicates that the majority of households have intensities of less than 0.2, equating to 20% HLC over two seasons. In addition, the highest intensities emerge within Kenya. However, it is notable that there are within site variances across all sites, indicating the relevance of farm level factors driving the HLC metric.

Figure 2. Household legume cultivation index showing a) frequencies with normal-density plot, b) boxplots showing ranges per country

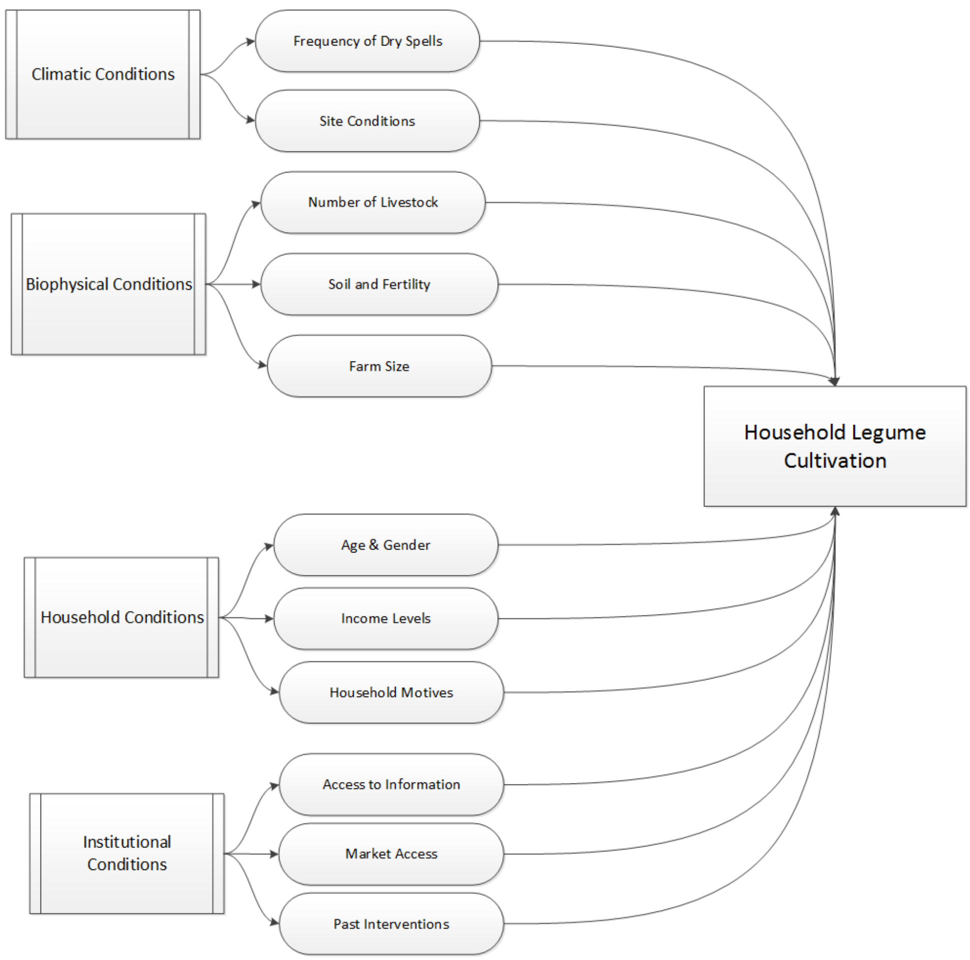




Explanatory variables

A number of categories of external and internal factors have been proposed for understanding uptake of legumes. Ojiem *et al*. (2006) categorised these as i) socio-cultural factors, ii) agro-ecological factors, and iii) socio-economic factors, with the third category including institutional context. In a meta-analysis of uptake of grain legumes, Mulder (2018) elaborated these categories further to specify market factors, namely i) distance to market, ii) household factors, iii) policy and institutional levels, which includes access to extension, and iv) economic factors, around income and education. We add to this framework by including personal motives. These are shown in Figure 3 and described below.

Figure 3. Conceptual Framework for understanding household legume cultivation drivers



Climatic Conditions

As for all staple crops, the influence of climatic conditions has been found to be an important influence on the adoption of legumes (Craufurd *et al*., 1998; Shiferaw *et al*., 2014; Rippke *et al*., 2016). Given the reliance on rain-fed practices the incidence of drought or heat stress, as well as floods, is likely to affect decisions around cropping portfolios (Niles *et al*., 2016; Ramirez-Villegas *et al*., 2012; Beebe *et al*., 2014; Daryanto *et al*., 2015). Adaptation towards these climatic effects can emerge from support towards farm capital improvements, e.g. for agro-chemical use, or through seeds which are more heat tolerant (Ramirez-Villegas *et al*., 2012; Feola *et al*., 2014; Acevedo *et al*., 2016).

Biophysical Conditions

Farrow *et al*. (2019) identified biophysical conditions as a major effect on adoption of legumes. The agro-ecological zone or the response to specific problems within that region are common examples of factors influencing legume uptake. Muoni *et al*. (2020) identified intercrops with maize and common bean helped reduce soil erosion. The structural soil enhancing properties of legumes (Jian *et al*., 2020; Vanlauwe *et al*., 2019) should make them a key driver for the uptake of legumes to tackle identified soil problems.

Household Conditions

Standard drivers of uptake of technologies tend to revolve around the effect of age or gender, generally finding mixed effects dependant on the practice applied (Arslan *et al*., 2014; Barnabas *et al*. 2018; Ronner *et al*., 2018). Moreover, knowledge of the legumes themselves, although an aspect of the institutional conditions of that region, are also a driver to understanding the level of uptake across farmers between regions (Muoni *et al*., 2019; Farrow *et al*., 2019).

Income conditions have an effect on the decision to intensify with legumes with higher incomes allowing access to capital and also more legume varieties. Ronner *et al.* (2018) found poorer farmers to be more likely to cultivate climbing beans due to restricted options through low income. Shelton *et al*. (2005) also identified profitability to be a key driver of uptake of legumes. Income is a facet of farming assets, as it supports investment into farm capital, such as increasing land area. Larger farms are less likely to grow legumes intensively, as they begin to commercialise, preferring to only include legumes as part of their crop and animal diversification planning (Sharp *et al*., 2007; Wiggins *et al*., 2012). Moreover Bamire *et al.* (2002) and Ajewole (2010) found that producers with more land are less likely to invest in soil fertility improvements. Hence, the opportunity costs of household labour, compared to hired labour, and the complexities of cropping legumes tends to make this more attractive to small scale households.

Farmer motivation and objectives has been, relative to these other factors, underexplored in past research. A small number of studies have examined perceptions towards risk and profit, finding them to be significant in terms of dictating decisions over whether to crop legumes, as well as overall diversification of cropping plans (Apata *et al.,* 2009; Meijer *et al*., 2015; Omotilewa *et al.,* 2016; Brush, 2008; Antwi-Agyei *et al.,* 2014).

Institutional Factors

Knowledge of the practices around legumes have been found to be a significant driver of the uptake of legumes generally, and the type of legume cropped (Muoni *et al.,* 2019; Farrow *et al*., 2019). Provision of that knowledge emerges from multiple sources and a common driver of uptake explored in past studies is access to information support networks. These are through both informal means, such as peer-to-peer knowledge exchange, and access to extension networks and farmer co-operatives, which have been found to be important (Waldman *et. al.,* 2016; Muoni *et al*., 2019). Given the poor reach of public extension services in many developing countries development projects are often important means of transferring and exchanging knowledge around legume related topics to farmers. This relationship usually consists of establishing test sites, the free provision of seeds and advice on the biophysical or community-based issues around legume production (Casley and Lury, 1982; Adams and Graham, 1981; Davis, 2008; Ngwira *et al.,* 2014; Woomer *et al.,* 2014).

Common communication pathways within the agricultural technology sector have been found to be positively related to adoption. Although ICT is developing across regions in SSA, and rural mobile phone ownership is becoming standard in certain countries (Sennuga *et al*., 2020), traditional approaches such as radio and newspapers are still important mechanisms for transfer of information around farming practice (Meijer *et al*., 2015; Aker, 2011; Hudson *et al*., 2017).

Access to seeds as well as markets for sale of leguminous products have been found to be important for driving adoption. In the case of input markets, access is defined by the seed supply chain and provision of varieties available, but also access to capital which allows farmers to secure access to improved seeds (Poulton *et al*., 2006; Croft *et al*.,2018; Farrow *et al*., 2019). Moreover, formal markets drive demand for the outputs from legumes. Efficiently functioning markets are cornerstone for economic growth (Barrett and Mutambatsere, 2008; Oduol *et al*., 2017; Barrett *et al*., 2017) and legumes serve multiple markets - from provision of dried beans to supporting animal production, as well as medicinal products from tree legumes. Enabling these markets, helps to drive uptake of legume production (Ndambiri *et al*., 2013; Tesfaye and Seifu, 2016). These main variables are shown in Table 2, identifying the type of variable and the categories or ranges of value taken.

Table 1. Main Explanatory Variables

Category of Driver	Name of Variable	Description of Variable
	Region	A dummy variable representing each of the 8 sites (*Bushumba, Kitutu Chache North, Luduha, Madaka, Mulengeza, Nyaribari Chache, Rongo, Suna West*)
Climatic	Long dry spell Frequency	A categorical variable indicating the number of long dry spells experienced in the year (0. None, 1. Once a year, 2. Twice a year 3. More than twice a year)
Biophysical	Soil Problems	A binary variable indicating whether the farm has noticeable erosion problems (0. No, 1. Yes)
	Farm Size	A continuous variable indicating the farm size in ha (average = 6.65 +/- 2.8 acres)
	Fertility ranking	A continuous variable normalised between 0-1 indicating farmer preference for the fertility function for legumes (average 0.440 +/- 0.204
	Livestock Density	The ratio of livestock units to land. Tropical Livestock units are composed of weighted units for cattle (0.7 LU), sheep and goats (0.1 LU) (Average= 0.24 +/- 0.30)
Household	Age	A continuous variable indicating the main farmer age in years (Average = 47 +/- 15 years)
	Gender	A binary variable indicating the gender of the main farm decision maker (0. Male, 1. Female)
	Commercial Objective	A binary variable, indicating farmer preference for commercialisation as a priority from the legumes grown, (0. No, 1. Yes)
	Income	A continuous variable indicating annual income for the farm based on local currency
Institutional	Source of Information	A set of dummy variables indicating the use of each information source they use frequently for farming advice (Use information from the radio; Use information from newspapers; Use information from extension organisations; Use information from farmers)
	Sell to Market	A binary variable indicating whether they sell produce to the market (0. Do not sell at market, 1. Sell at market)
	Past Project	A binary variable indicating whether they have been involved in past projects around legume adoption over the last 5 years (0. No involvement, 1. Involved with legume project)

Estimation Approach

Our index of household legume cultivation is unit interval data as it is bounded between 0 and 1. A standard linear regression approach, with the dependant variable transformed, does not accurately reflect unit interval data because, firstly these data are typically heteroskedastic, *as the variance will approach zero as the mean approaches either 0 or 1*

(Ferrari and Cribari-Neto, 2004) Moreover, our data are generally asymmetric and would violate assumptions around normality. Beta regression allows more flexibility when distributions are non-normal and have proven efficient at estimating a range of observed phenomena (Paolini *et al*., 2001). The beta regression parameterises densities within a dependant variable as it allows for flexibility in the mean and related parameters. Unlike linear regression, beta regression requires two link functions, one to link explanatory variables to the mean, and another to link to the 'precision parameters' within the distribution (Equation 2):

$$Y = f(h(X_i \dots . X_n), g(X_i \dots . X_n)) \qquad (2)$$

Where Y is between > 0 and < 1, f is a function explaining a vector of x variables to changes in the dependant variable (Y). Within this h explains the changes in the mean of Y, and g explains the changes in precision of Y. The two functions can accommodate different explanatory variables, though most studies apply the same vector of variables to explain both the variance and precision of *Y.*

We apply the beta regression formulation above using STATA 16 (Stata Corp, 2019) with standard errors clustered by country, to adjust for country-level effects. The choice of logit link function was identified through minimisation of the BIC values from the maximum likelihood approach. All categorical and binary variables were ordered from minimum to maximum to show relative degrees of effect and reference values reflected base values for the categorical variables.

3.0 Results

The results of the Beta regression are presented in Table 2. The regression fits well with a reasonable R^2 of 0.40 and most variables indicating a significant effect at $p<0.001$. The Wald statistic is significant, indicating that the fitted model exceeds the null model for explaining the dependant variables. Results are presented as marginal effects, along with their significance levels and standard errors. Marginal effects show the effect of a 1% increase in each variable, all other variables remaining unchanged, for continuous variables or a discrete change from 0 to 1 for categorical variables.

Table 2. Results of Beta regression on household legume cultivation, marginal effects

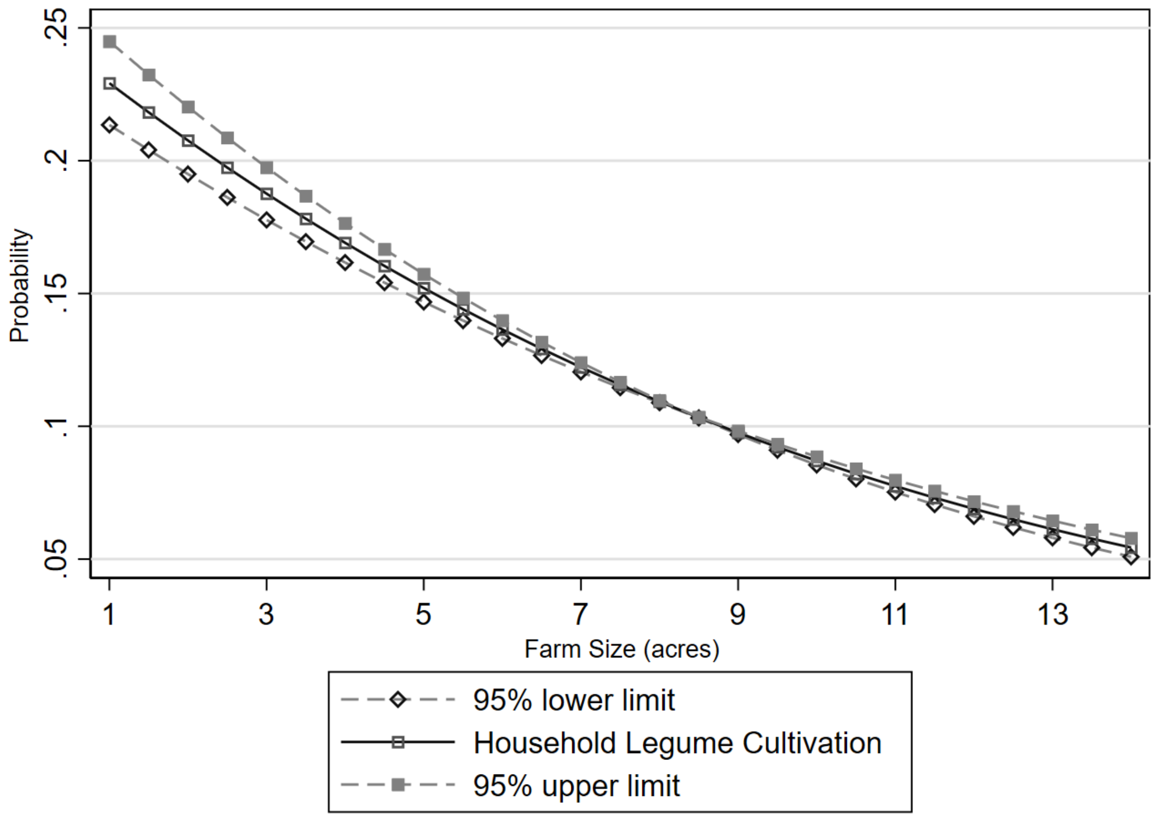
		Margins		SE
	Sites (Reference: DRC: Madaka)			
	DRC: Bushumba	0.138	***	*0.005*
	DRC: Luduha	0.011	***	*0.004*
	DRC: Mulengeza	0.030	***	*0.004*
	Kenya: Kitutu Chache North	0.094	***	*0.004*
	Kenya: Nyaribari Chache	0.049	***	*0.001*
	Kenya: Rongo	0.104	***	*0.000*
	Kenya: Suna West	0.178	***	*0.002*
Climatic	*Long dry spells (Reference: None)*			
	Once	0.012	**	*0.004*
	Twice	0.112	***	*0.001*
	More than twice	0.038	***	*0.002*
Biophysical	Identified soil problems	0.003	*	*0.001*
	Farm size	-0.015	***	*0.001*
	Livestock density	0.034	***	*0.001*
Household	Age of main decision maker	0.0005	***	*0.00003*
	Gender of main decision maker	0.023	***	*0.003*
	Ranking score of commercial intentions	-0.024	**	*0.008*
	Income levels	0.006	*	*0.003*
	Ranking of fertility objective in growing legumes	0.069	***	0.001
Institutional	Frequent use of radio information	-0.001		*0.004*
	Frequent use of newspaper information	-0.047	***	*0.006*
	Frequent use of extension information	-0.006	***	*0.001*
	Frequent use of farmer information	-0.011	**	*0.004*
	Whether they sell crops at the market	-0.013		*0.007*
	Engaged in past projects	0.007	**	*0.001*
	Log-Likelihood	198.436		
	Wald Chi^2	25.155***		
	BIC	-391.841		
	AIC	-394.871		
	McFadden R^2	0.403		

* p<0.05; ** p<0.01; *** p<0.001

Site variables are a means to condition for local effects and are all strongly significant. These are measured relative to the site with the lowest average HLC, in this case Madaka in the DRC. At a country level sites within DRC have mostly lower marginal estimates and there are variances within countries. Bushumba in DRC and Suna West in Kenya, have the highest predicted probabilities of 13.8% to 18% compared to Madaka respectively. This means these sites are much more likely to have higher HLC's compared to Madaka. Against the reference of no dry spells it seems that those who experience more frequent long dry spells are more likely to grow more legumes, possibly as a way to mitigate some of the risks in weather variance.

Given the structural change expected within agriculture, for farms consolidating to grow bigger an increase of 1% in area leads to a -1.5% predicted probability on household legume cultivation. This may indicate that as farms increase in farm size they are likely to grow crops for more accessible markets, rather than legumes. The relationship between size and intensity is shown in Figure 4. These are presented as predicted probabilities across the range of farm sizes observed in the survey. These show a downward effect and indicate that as the farm grows in size, the probability of household legume cultivation decreases.

Figure 4. Predicted probabilities of farm area variable



Livestock density is a positive predictor, which would infer the importance of legumes as an animal input to support livestock feed. Effectively a 1% increase in animal density tends to lead to a 3.4% increase in the planting of legumes.

Age is positively associated, though extremely marginal in terms of explaining HLC. This would infer that as farmers become older there is a slightly higher predicted probability that they will adopt more legumes within the farm. Gender is also a positive predictor, indicating that female farmers are 2.3% more likely to adopt legumes than males. Gender also has mixed effects in past literature on adoption of specific varieties, but is related to social and institutional conditions within the region of study. There is also a desire for the fertility building functions of legumes, as a 1% increase in farmers rating this as a preferred function of legumes would affect the predicated probability of legume uptake by 6.9%. Hence legumes are strongly seen, by farmers who adopt more of them within the farm, as a means to provide support for soil functions both directly, and indirectly, through the provision of feed.

The association between income and household legume cultivation is slightly positive but the effect is small. However, a stronger negative effect emerges from adoption of commercial objectives. Specifically, a 1% increase in preference for a commercialisation objective for the farm leads to a -2.4% change in household legume cultivation. This may be related to the effect of selling to market which is insignificant. This may imply that farmers are ranking the nutrition and supporting functions of legumes above those of commercial selling, but also, given the diversity of sites covered, may simply indicate no access to nearby markets for selling.

The use of official information sources shows mostly negative, or insignificant, relationships with HLC. Where significant, the use of newspapers and extension information leads to less intensive use of legumes. Conversely the targeted approach of past projects has a positive effect. A farmer who has engaged in past legume programmes is 0.7% more likely to intensify legume cultivation on the farm, compared to a farmer who has not engaged in these programmes. A test of the conditional mean of household legume cultivation for those in and out of past projects showed a significant positive difference ($z = 11.17$, $p > z\ 0.001$). This tends to indicate that the most effective legume information emerges from focused projects on legumes, which may mostly emerge from external funding. These interventions are more targeted than other information sources, both in terms of the advice given, but also the facilitation and support for growing these crops.

4.0 Discussion

Within the scientific community, legumes have been seen as a high priority intervention for Sub-Saharan Africa (Kerr *et al*., 2007). The long-term sustainability of these interventions must be disputed given only slight increases in legume area observed over the last 20 years (Vanlauwe *et al*., 2019). Nevertheless, as legumes provide support for some of the continent's biggest farming challenges, namely poor soil quality, limited access to chemical inputs and poor nutrition, legumes need to be an attractive option for the cropping portfolio of smallholder farmers in the coming decades. This is more pertinent as farms in SSA are under pressure to change (Abraham and Pingali, 2020).

Intensity of legume cultivation varies both across and within the study sites here. Whilst local site conditions can explain variances in uptake, more subtle differences emerge that are a confluence of other enablers and constraints. Hence, this calls for a range of targeted institutional improvements to support increased uptake, including more knowledge provision and the development of markets for legumes.

A number of studies have argued that legumes provide a way to support incomes (Rao and Mathuva, 2000; Franke *et al*., 2014), and that increased incomes allows access to higher yielding seed (Farrow *et al*., 2019). The association between income and intensity of legume cultivation was found to be slightly positive but the effect is small. However, preferences for commercialisation objectives for the smallholder were found to be negatively related to legume cultivation. Most development literature supports enabling market access and value chain development as key to supporting income growth, however a number recognise the lack of formal markets for legume products to achieve that goal (Zeller *et al*., 1998; Ojiewo *et al*., 2015; Trieneken, 2011; Foyer *et al*., 2016). Where legumes seem to differ from other sustainable interventions may be in their cultural and historic standing, but this is complicated by the multiplicity of markets for the products of legumes for food and feed. Hence it would seem a key barrier is on evolving markets for generating value added from legumes (Mabhaudhi et al., 2017; Rubyogo et al., 2019; Dawson *et al*., 2019).

In relation to this farm size was found to have a negative effect on household legume cultivation. The desire for farms to increase in size is generally led by a more commercial outlook and the negative relationship may also reflect the lack of markets for selling legumes compared to common staples (Atlin *et al*., 2019). This is also an artefact of where the farms are situated and the level by which markets exist for legumes, compared to common staple, crops. Hall *et al*., (2017) identifies three pathways for the commercialisation of smallholder farmers, one of which revolves around growing from small to medium scale commercial farming areas. To enable this requires increased access not just to land, but inputs and knowledge, as well as capital to support labour replacement. This is a major constraint for the majority of farmers but Poole *et al*. (2013) also suggest that the commercialisation narrative should not be assumed within a rural sector more concerned with food security. The farmers participating within this study tend to validate this view as they show a desire for self-sufficiency from legumes to support other functions on the farm.

The most effective legume information evolved from focused interventions. These emerge from externally funded projects focused wholly or in part on increasing intensity of legume cultivation. These interventions are more targeted but also offer the enabling conditions to increase legume cultivation, such as seeds and support for managing these crops. Accordingly, this may offer a bleak assessment for long-term adoption as once these projects finish there is little to suggest continuation of practice. Moreover, farmers have limited access to structures, such as advice and plant breeding services that support new varietal adoption of legumes within these countries (Atlin *et al*., 2019). This seems to infer local institutions promoting staple cash crops rather than legumes which need to be recognised for co-developing and implementing interventions (Bezner Kerr *et al*., 2007).

Supporting co-creation and embedding social norms around legumes may lead to support for long-term sustainability of projects. This would also make them an attractive and cost-effective intervention for future investment from donor governments experiencing pressures on overseas public expenditure[1]. Whilst there are economic drivers, such as the further development of legume-based value chains, most behavioural studies find a mix of economic and environmental goals within farmer practices (Wilson and Hart, 2000) and legumes may be grown as they appeal to the farmers, rather than any profit-seeking motive. Their function in spreading risk through diversity of cropping and also by breaking pest cycles adds to the attractiveness of legumes. Consequently, promoting a more ecological ethos may be a route to engagement of farmers for long-term sustainable development, especially as the benefits that legumes offer will support goals for individual farmers but also society as a whole.

Targeting on gender and age may have an effect on uptake but these have been mixed on the uptake of crops and crops mixtures and this may explain the very marginal effect of age on the decision to intensify legume cultivation (Saka *et al*., 2004; Katungi *et al*., 2017). Moreover, whilst we find a positive effect for gender, this too has had mixed effects in past studies. Ronner *et al*. (2018) found a positive gender effect for adoption of practices around

[1] see for example: https://foreignpolicy.com/2019/08/13/how-to-save-foreign-aid-in-the-age-of-populism-usaid-dfid/

climbing bean cultivation in Uganda. Muoni *et al*. (2019) also found a similar positive effect of gender in Kenya. However, Larochelle *et al*. (2016) could find no gender differences in uptake of improved bean varieties in Rwandan agriculture.

Climatic factors will become more acute in these regions (Cooper et al, 2008; Connolly-Boutin and Smit, 2016) and dry spells, as a proxy for these climatic effects, are a driver of intensity of cultivation. Stevenson *et al.* (2014) found that farmers perceive legumes as part of a potential risk mitigation portfolio when rainfall is erratic. In terms of biophysical constraints and drivers, livestock density has a positive effect which would infer the importance of legumes as low-cost feed to support livestock production (Atnaf *et al*., 2015; Tothill, 1986; Odendo *et al*., 2011). Similarly, those who experienced soil problems are more likely to intensify their legume cultivation, which agrees with several studies which identified this as a source of uptake (Snapp *et al*., 2002; Bezner Kerr, 2005).

5.0 Conclusions

Household legume cultivation is a useful metric for measuring progress towards ecological intensification in low income countries. By quantifying the level of legume cultivation intensity at a micro level, we can explore the extent to which this technology is adopted on-farm and the highly nuanced nature of the differences between farms adopting these technologies. It provides a basis for regional benchmarks but also allows, through its decomposition, understanding of the magnitude of institutional, climatic and personal drivers behind the choice to cultivate more legumes.

The opportunity to compose such an indicator comes from bespoke field data offering detail on leguminous crops, alongside other activities. Household surveys, such as those provided by the Living Standards Measurement Systems-Integrated Surveys on Agriculture (see for example Leigh Anderson *et al*., 2017) may go some way to replicating this study. Given their regional spread these surveys could provide benchmarks of HLC over time, as well as quantification of the success of particular interventions towards legumes. Due to financial constraints these surveys are somewhat limited in time frame and region, but also in the number of crops recorded (Dawson *et al*., 2018). Current limited data collection further complicates knowledge of progress towards ecological intensification overall. Overcoming these constraints may support a more balanced assessment of how we can reach ecological intensification for the continent (Smith *et al*., 2017; Jayne *et al*., 2019).

What emerges acutely from this, and related studies, is the lack of market opportunities for legume products with SSA but also that farmers with higher legume cultivation intensities are less driven by commercial growth. As a consequence these farmers mostly use legumes for providing home nutrition or supporting services around fertility and feed. Accordingly, the development of commercial opportunities for legume products, increasing market access and promotion of legume consumption within growing urban centres should be considered a prime aspect of any future legume strategy.

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Declaration of interest statement

The authors declare no conflicting interest that they have no affiliations with or involvement in any organization or entity with any financial or non-financial interest in the subject matter or materials discussed in this manuscript.

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