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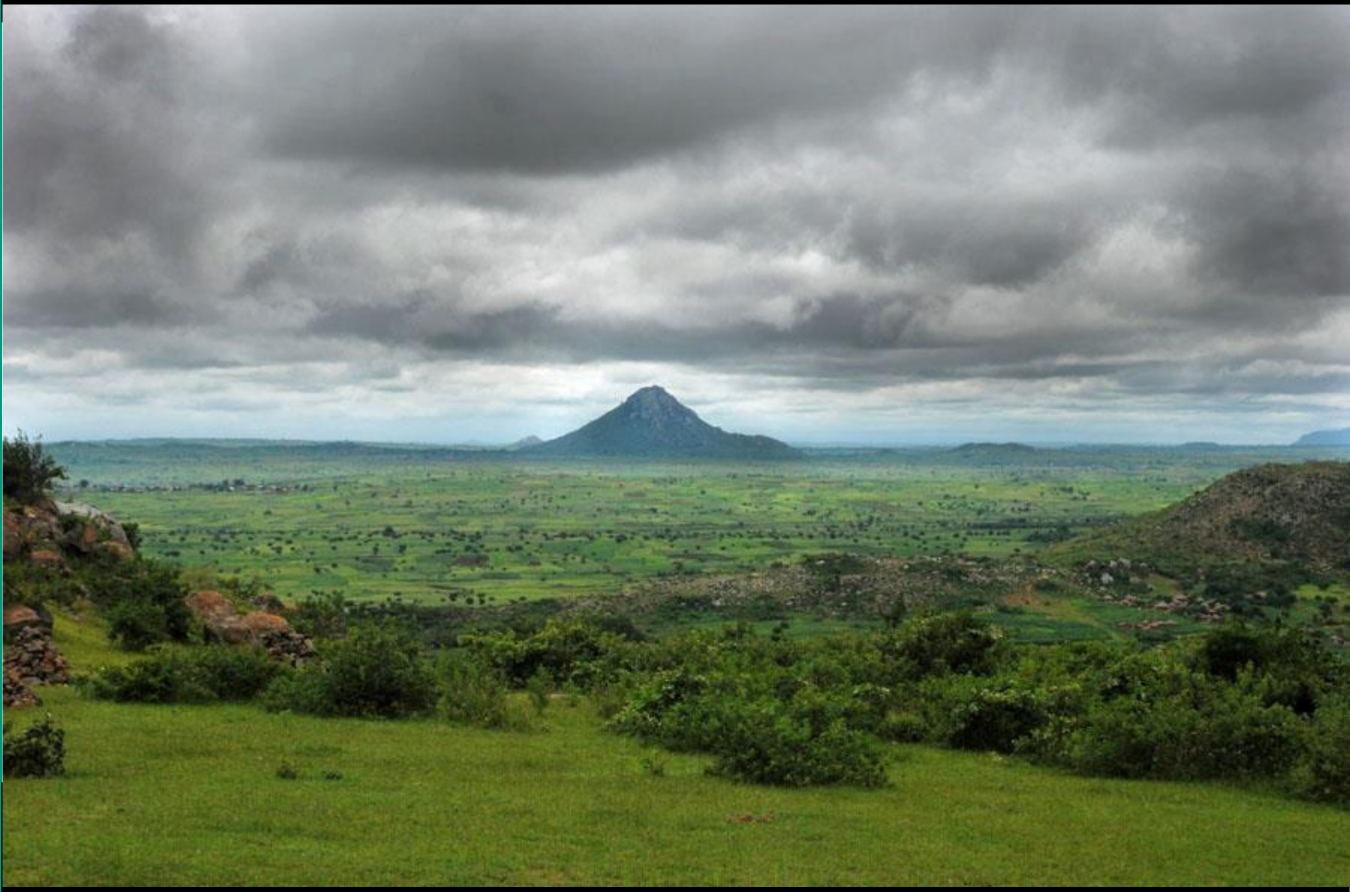

Norwegian University of Life Sciences
Centre for Land Tenure Studies

Centre for Land Tenure Studies Working Paper 11/17

Adoption of Soil Fertility Management Technologies in Malawi:

Impact of Drought Exposure

By

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Abstract

Soil fertility management (SFM) technologies may potentially protect against climate risks, reduce nutrient depletion and enhance food security. In this paper, we study impact of drought exposure on adoption and adoption intensity of SFM technologies, specifically, focusing on maize-legume intercropping and organic manure. The paper uses four-round panel data collected from six districts in Malawi over a period of nine years and we use correlated random effects models with a control function approach for data analysis. Results show an increase in adoption rates from 33% in 2006 to 76% in 2015 for maize-legume intercropping and from 30% (2006) to 53% (2015)

for organic manure. Regression results reveal that exposure to early and late dry spells increases the likelihood of adoption and adoption intensity of maize-legume intercropping with late droughts also having a positive impact on adoption and adoption intensity of organic manure. We also find positive effects of fertilizer use intensity and fertilizer price on adoption and adoption intensity of both intercropping and organic manure.

Key words: Soil fertility management, maize-legume intercropping, organic manure, adoption, drought impacts, Malawi.

JEL codes: Q54; Q56; Q12; Q16.

1.0. Introduction

In Malawi, a country heavily dependent on rain-fed agriculture, the twin problems of drought and low levels of nitrogen use are major causes of low crop productivity resulting in persistent food insecurity (Weber *et al.*, 2012). Efforts to enhance crop productivity through increased nutrient application, nutrient maintenance, and drought resilience are thus important to achieve sustainable food security. Such efforts require complementary investments in organic and inorganic integrated soil fertility management (ISFM) technologies and high yielding and drought tolerant crop varieties. ISFM technologies increase nutrient intake, protect the soils, minimize nutrient depletion through enhanced soil organic matter and biological activity and eventually increase crop yields and yield stability (Weidmann & Kilcher, 2011; Vanlauwe et al., 2011). ISFM ensures nutrient balance and efficient management of soil fertility through combinations of inorganic fertilizer, organic manure, soil and water conservation technologies, and crop diversification that include maize-legume intercropping.

In this paper, we use a four-wave panel dataset for central and southern Malawi to examine adoption and adoption intensity of two ISFM technologies – organic manure and maize-legume intercropping – and how drought exposure influences farmer uptake. Organic manure and maize-legume intercropping are popular technologies among smallholder farmers in Malawi and our dataset allows us to gain an improved understanding of their adoption pattern over a close to 10-year period. In this period the sample farmers have been exposed to several climate shocks in the form of late and early droughts and have also had varying access to input subsidies that indirectly may have affected the adoption of these technologies. We assess how adoption of organic manure and maize-legume intercropping is influenced by exposure to early and late droughts (one-year lagged variables). We also examine how adoption and adoption intensity is affected by changes in the prices and use of inorganic fertilizer and one-year lagged prices of maize and legume grain. The paper also examines the correlations between these technologies and distance to markets and population density.

Previous research examined the determinants of farmers' investment decisions in maize-legume intercropping and organic manure in Malawi. Findings suggest that adoption of organic manure increases with inorganic fertilizer use and fertilizer price (Holden & Lunduka, 2012), tenure security (Kassie *et al.*, 2015), knowledge of manure making (Kilcher, 2007; Mustafa-Msukwa *et al.*, 2011) and household labor availability (Chatsika, 2016; Mustafa-Msukwa *et al.*, 2011; Snapp *et al.*, 2002). The probability of adopting maize-legume intercropping has been shown to be limited by the yield advantage of maize over legumes, pest susceptibility, and a lack of appropriate legume genotypes (Kerr *et al.*, 2007; Ortega *et al.*, 2016). Other factors shown to influence maize-legume intercropping are market access, output prices, availability and cost of improved legume seeds, farm size and exposure to weather shocks (Asfaw *et al.,* 2014; Kassie *et al.,* 2015; Kerr *et al.*, 2007; Kilcher, 2007; Ortega *et al.*, 2016).

Our paper builds on these studies by testing a number of hypotheses. First, the paper tests the hypothesis that exposure to drought shocks increases the likelihood of adopting maize-legume intercropping and organic manure. The paper makes a new contribution on this hypothesis by providing new evidence on how early and late dry spells affect adoption of maize-legume intercropping and organic manure. It is reported that sustainable conservation agriculture practices can minimize drought sensitivity of crop yields (Kilcher, 2007; Makate *et al.,* 2017a; Makate *et al.,* 2017b; Muzari *et al.,* 2012). However, whether farmers respond to previous exposure to droughts by adopting maize-legume intercropping and organic manure, and how early and late dry spells affect adoption, remains largely unexplored in the literature. Given that the government of Malawi has intensified promotion of these technologies as part of a climate-smart agriculture (CSA) campaign (Government of Malawi, 2011), this analysis reveals farmers' responses to drought shocks during the nine year period our data covers. An increase in adoption over the years in response to drought shocks would suggest that farmers have experienced the advantages of these technologies under drought growth conditions.

Second, we test the hypothesis that an increase in inorganic fertilizer price is associated with higher likelihood of adopting organic manure and maize-legume intercropping and we also test how fertilizer use intensity affects adoption of these technologies. We build on the findings of Holden and Lunduka (2012) to get robust evidence on impact of inorganic fertilizer price and fertilizer use intensity on adoption of organic manure. Holden and Lunduka reported positive impact of inorganic fertilizer price and fertilizer use intensity on uptake of organic manure. We extend the empirical analysis by including maize-legume intercropping technology. This hypothesis is of policy relevance in Malawi given the ongoing Farm Input Subsidy Program (FISP) that significantly affects inorganic fertilizer price as well as use intensity of inorganic fertilizer.

Third, we hypothesize that output prices for maize and legumes are incentives for higher adoption of organic manure and maize-legume intercropping. We extend this hypothesis by including how market access affects adoption of these technologies. Our paper uses panel data methods to assess the robustness of the evidence of previous studies (Kassie *et al.*, 2015; Kerr *et al.*, 2007; Kilcher, 2007; Ortega *et al.*, 2016; Snapp *et al.*, 2003) on impacts of output prices and market access on adoption of legume intensification and organic matter-based technologies.

Fourth, the paper tests the hypothesis that an increase in population density drives adoption of potentially land-saving technologies such as maize-legume intercropping. The evidence on how population growth affects adoption of maize-legume intercropping and organic manure is very important in Malawi given the country has one of the highest population densities in sub-Saharan Africa (SSA) (Holden & Lunduka, 2012). While researchers argue that population growth in Malawi pushes farmers to adopt maize-legume intercropping intensification and organic matter-based technologies (Snapp *et al.*, 2002), to our knowledge this has not been examined econometrically.

2.0. Maize-Legume Intercropping and Organic Manure in Malawi

Smallholder farming in Malawi is characterized by low crop yields, which is largely attributed to low soil fertility due to limited access to mineral fertilizer and soil nutrient depletion (Heerink, 2005; Holden & Lunduka, 2012; Kamanga *et al.*, 2010). Nutrient depletion is a net loss of soil nutrients from the production system caused by higher levels of nutrient outputs than inputs (Drechsel *et al.*, 2001). The problem is worsened by population pressure which has reduced natural methods of nutrient replenishment like fallows, crop rotations, animal manure and slash and burn (Mekuria & Siziba, 2003). A suggested long-term solution is the integrated nutrient management system which manipulates all outputs and inputs cautiously (Stoorvogel *et al.*, 1993). This ensures efficient management of soil fertility through combinations of inorganic fertilizer, organic manure, cover crops, and other conservation technologies.

High levels of fertilizer use have multiple benefits such as replenishing lost nutrients and enhancing land use intensification. This then contributes to better plant growth and soil cover, thereby reducing erosion while reducing area expansion and minimizing land pressure (Holden & Lunduka, 2012). At the same time, organic manure contributes to increases in nutrient and water retention capacity. At low organic matter, there is high and rapid leaching of nutrients beyond the potential root zone of most crops. Thus, application of organic manure increases both nutrient and water use efficiency and therefore enhances crop response to application of inorganic fertilizers (Heerink, 2005).

Maize-legume intercropping and related legume-intensification practices also improve sustainable crop productivity in maize-based cropping systems (Snapp *et al.*, 2002). Empirical evidence has shown that these systems increase soil productivity through biological nitrogen fixation and conservation of soil nutrients (Government of Malawi, 2012; Snapp *et al.*, 1998). Apart from the agronomic benefits, intercropping provides environmental benefits through reduced soil erosion, improved water infiltration and carbon sequestration, and through increased crop and food diversity by providing high protein grain and leaves. All these benefits are achieved at a low cost and low risk for the poor farmer (Government of Malawi, 2012; Kamanga *et al.*, 2010; Kerr *et al.*, 2007; Woomer *et al.*, 2004). In Malawi, the most common legumes that have been intercropped with maize are beans in the Central Region and pigeon peas in the Southern Region (Waddington, 1990; Waldman *et al.*, 2017).

Presently there are many public and private sector efforts in Malawi to promote adoption of both organic and inorganic technologies. The Government of Malawi (GoM) has been promoting the use of inorganic fertilizer through the Farm Input Subsidy Program (FISP). The GoM has also through its Agricultural Sector Wide Approach (ASWAp) promoted sustainable land management (SLM) practices that build soil fertility, prevent soil erosion, and conserve rain water, notably organic manure and maize-legume intercropping (Government of Malawi, 2011). There is some evidence of steady progress in adoption over time for the case of organic manure. Holden and Lunduka (2012) for instance reported an increase from 32% in 2006 to 48% in 2009 organic manure adoption.

3.0. Materials and Methods

3.1. Data

We use four waves of panel data collected through household surveys conducted between 2006 and 2015 in central and southern Malawi. The first round in 2006 drew a random sample of 450 households using a simple random sampling technique following the second integrated household survey of 2004 (IHS2) (Lunduka, 2009). Of these 450 households, 378 were resurveyed in 2009, 350 in 2012 and 353 in 2015, resulting in four rounds of unbalanced panel data. The data show an increase in adoption from 30% in 2006 to 53% in 2015 for organic manure and from 33% to 76% for maize-legume intercropping (Table 1). On intensity the data show a decrease for organic manure use between 2006 (2182 kg/ha) and 2015 (1456 kg/ha), but there is an increase in the share of farmed area allocated to maize-legume intercropping from 27% (2006) to 37% (2015).

Table 1: Adoption of organic manure and maize-legume intercropping

Technology	2006	2009	2012	2015	Total
Applied manure (1=yes)	0.30	0.43	0.49	0.53	0.43
Manure quantity (Kg/ha) for adopters	2182	1616	1526	1456	1724
Maize-legume intercropping (1=yes)	0.33	0.45	0.53	0.76	0.51
Farm size share of maize-legume intercropping (adopters)	0.27	0.25	0.34	0.37	0.30

Summary statistics of independent variables by year

Error! Reference source not found. presents summary statistics (means and proportions) for the explanatory variables used in this paper for each panel round. The data show considerable variation over time in output and input prices. For example, the one-year lag of maize grain real price was higher in 2009 than in 2006, was lower in 2012 than in 2009, and increased between 2012 and 2015. Some of the observed price variations could be explained by policy and weather changes. The FISP, for example, increases availability of cheap fertilizer on the market thereby reducing the average fertilizer price; when FISP is scaled back, this trend reverses. On the other hand, the combined effect of availability of fertilizer and good rains enhances output supply, which also affects output price. We expect these factors affect farmers' investment decisions in organic manure and maize-legume intercropping.

Table 2 also shows that fertilizer application intensity has generally been decreasing over time. Although our data show that the quantity of inorganic fertilizer applied per hectare of land increased between 2006 and 2009, since then it has been decreasing. This trend could reflect the scale of FISP, which has been scaled back in recent years. In 2006, the program supplied 166000 metric tons (MT) of fertilizer, 195000 MT in 2009, 140000 MT in 2012 and 150000 MT in 2015.

Table 2: Summary statistics of independent variables by year

Variable	2006	2009	2012	2015	Total
1 year lag longest early dry spell (days)	7.90	6.46	5.71	4.93	6.35
1 year lag longest late dry spell (days)	12.61	11.42	10.62	6.22	10.38
Fertilizer price (MK/kg)	60.35	76.72	116.79	126.69	92.99
Fertilizer quantity (Kg/ha)	150.32	223.53	186.76	149.53	176.51
Annual average maize price - 1 year lag (MK/Kg)	38.07	53.24	26.98	45.48	40.99
Annual average legume price - 1 year lag (MK/Kg)	103.65	70.87	120.90	139.98	107.92
Distance to agricultural markets (Km)	4.41	4.30	4.19	4.20	4.28
Population density (household size/ha)	4.68	4.62	4.62	4.61	4.64
Southern region (1=yes)	0.57	0.58	0.59	0.58	0.58
Maize seed subsidy (1=yes)	0.35	0.33	0.56	0.64	0.46
Fertilizer subsidy (1=yes)	0.35	0.54	0.73	0.54	0.53
Tropical livestock unit	1.08	1.49	1.11	0.50	1.05
Asset value (MK)	3364	4123	2438	5918	3931
Farm size (ha)	1.22	1.18	1.20	1.23	1.21
Plot distance (Km)	0.96	3.00	3.78	3.22	2.63
Household head sex (1=male)	0.25	0.24	0.26	0.34	0.27
Household size	5.28	5.30	5.29	5.61	5.36
Off-farm labor (# of adults)	0.14	0.21	0.35	0.25	0.23
Male labor (adult equivalent/ha)	3.64	3.76	3.54	4.12	3.76
Female labor (adult equivalent/ha)	3.51	3.56	3.20	3.76	3.51

[a]Values in Malawi Kwacha (MK) are deflated with consumer price indices (CPI) using 2010 prices

The data suggest there has not been a significant change in owned farm size from 2006 to 2015, but household size increased from 5.3 to 5.6. These changes present potential driving forces for adoption of organic manure and maize-legume intercropping technologies.

3.2. Theoretical framework

This section develops and discusses a theoretical model of household agricultural production decisions. We assume farmers make production and consumption decisions in a time-recursive state-contingent way within production years. Input decisions are made before the weather conditions are revealed and determine production outcomes that form the basis for consumption decisions within that year and next year's input decisions. Production decisions are made as a first step to maximize weighted probability utility of returns in different states of nature (Holden &

Quiggin, 2017). Given low crop productivity due to low soil fertility and erratic rains, and assuming risk averseness, farmers choose a mix of soil nutrient enhancing and climate-resilient input technologies to enhance production. Such inputs include inorganic fertilizer (F), organic manure (M), maize-legume intercropping (I), and other inputs (X). Let the production function be specified as:

$$Y = Y[N(F, M, I), X, \varepsilon] \tag{1}$$

where N represents soil nutrients from inorganic fertilizer, organic manure, and maize-legume intercropping, while ε is climate risk which is not known to the farmer at planting time and has a distribution function of G(.) (Ding *et al.*, 2009; Koundouri *et al.*, 2006). The production function is assumed continuous and twice differentiable (Holden & Lunduka, 2012; Koundouri *et al.*, 2006; Riley, 2012) such that:

$$\frac{\partial Y}{\partial N} > 0, \frac{\partial^2 Y}{\partial N^2} < 0;\ \frac{\partial N}{\partial F} > 0, \frac{\partial N}{\partial M} > 0, \frac{\partial N}{\partial I} > 0; \frac{\partial^2 N}{\partial F^2} < 0, \frac{\partial^2 N}{\partial M^2} < 0, \frac{\partial^2 N}{\partial I^2} < 0, \frac{\partial^2 N}{\partial F \partial M} < 0, \frac{\partial^2 N}{\partial F \partial I} < 0 \tag{2}$$

Equation (2) suggests diminishing marginal output returns from nutrient increases and diminishing marginal nutrient returns from increased amounts of inputs.

The farmer's objective is to maximize expected utility E[U(.)] under the expected utility theory (EUT) through farm profits which are subject to input and output prices. The EUT can be extended to a more general rank-dependent expected utility (RDEU) to allow probability weighting (Quiggin, 1991) and loss aversion. Assume P_y is output price, P_f is fertilizer price, P_x is the price of other inputs, P_m is the price of organic manure and P_I is the price of maize-legume intercropping. P_m and P_I are measured as the cost of labor invested in organic manure and the opportunity cost of labor, respectively. Given that smallholder farmers are price takers, and prices are assumed non-random, the only source of uncertainty in the model is weather risk. Farmers will solve the following RDEU V[U(π)] function:

$$\max_{F,X,M,I} V(U[\pi]) = \max_{F,X,M,I} \int (U\left[P_y Y(N[F,M,I],X,\varepsilon)\right] - P_f F - P_m M - P_I I - P_x X) dG(\varepsilon) \quad (3)$$

where U(·) is the von Neumann-Morgenstern utility function. Solving this problem yields input demand functions for fertilizer, organic manure, maize-legume intercropping and other inputs that depend on input and output prices and the opportunity cost of labor. Taking first order conditions determines the optimal choices of the inputs and is independent of household preferences and characteristics.

$$\frac{\partial U}{\partial F} = V\left[P_y \frac{\partial Y}{\partial N}\frac{\partial N}{\partial F} U'\right] - V\left[P_f U'\right] = 0 \leftrightarrow V\left[P_f\right] = V\left[P_y \frac{\partial Y}{\partial N}\frac{\partial N}{\partial F}\right] \quad (4)$$

and

$$\frac{P_f}{P_y} = V\left[P_y \frac{\partial Y}{\partial N}\frac{\partial N}{\partial F}\right] + \frac{COV[U'; \frac{\partial Y \partial N}{\partial N \partial F}]}{V[U']} \quad (5)$$

where $U' = \frac{\partial U(\pi)}{\partial \pi}$ is the change in utility due to change in income. The FOCs for organic manure and maize-legume intercropping are derived in the same way but are not shown to save space. The first term on the right-hand side of equation (5) represents the expected marginal product from adoption of inorganic fertilizer while the second term is a measure of deviations from a risk-neutral position. For risk-neutral farmers, the second term is equal to zero such that the adoption decision will be influenced only by the expected marginal product of the technology. On the other hand, for risk averse farmers, the second term is not zero and is negatively proportional to the marginal risk premium with respect to the input of interest (Koundouri *et al.*, 2006). In this case, adoption will not only be influenced by the cost and benefit of the technology but also production risks and other factors that may influence the cost and performance of the technology (Ogada *et al.*, 2010).

Given that the choice variables of fertilizer, manure and intercropping are all sources of nutrients, the demand functions for these inputs are not independent of each other. Thus, the demand for one input will be determined not only by its marginal productivity but also by changes in the prices and use of other inputs. We can therefore derive comparative statistics to determine the complementarity or substitution effect of these inputs. Our main interest here is to examine how changes in fertilizer price affect demand for manure and intercropping. This is of particular interest in Malawi given its large-scale farm input subsidy program (FISP) which affects the price and use of fertilizer. We derive the comparative statistics by differentiating the manure and intercropping versions of the FOCs in equation (4) with respect to fertilizer price (P_f) (Riley, 2012, p. 577).

$$\frac{\partial P_m}{\partial P_f} = P_y \frac{\partial^2 Y}{\partial N^2} \frac{\partial^2 N}{\partial F \partial M} \frac{\partial F}{\partial P_f} + \frac{\partial^2 Y}{\partial N^2} \frac{\partial^2 N}{\partial M^2} \frac{\partial M}{\partial P_f} = 0 \iff \frac{\partial M}{\partial P_f} = -\frac{P_y \frac{\partial^2 Y \, \partial^2 N \, \partial F}{\underbrace{\partial N^2}_{<0} \underbrace{\partial F \partial M}_{<0} \underbrace{\partial P_f}_{<0}}}{\frac{\partial^2 Y \, \partial^2 N}{\underbrace{\partial N^2}_{<0} \underbrace{\partial M^2}_{<0}}} > 0 \tag{6}$$

$$\frac{\partial P_I}{\partial P_f} = P_y \frac{\partial^2 Y}{\partial N^2} \frac{\partial^2 N}{\partial F \partial I} \frac{\partial F}{\partial P_f} + \frac{\partial^2 Y}{\partial N^2} \frac{\partial^2 N}{\partial I^2} \frac{\partial I}{\partial P_f} = 0 \iff \frac{\partial I}{\partial P_f} = -\frac{P_y \frac{\partial^2 Y \, \partial^2 N \, \partial F}{\underbrace{\partial N^2}_{<0} \underbrace{\partial F \partial I}_{<0} \underbrace{\partial P_f}_{<0}}}{\frac{\partial^2 Y \, \partial^2 N}{\underbrace{\partial N^2}_{<0} \underbrace{\partial I^2}_{<0}}} > 0 \tag{7}$$

Equations (6) and (7) indicate positive effects of inorganic fertilizer price increase on organic manure and maize-legume intercropping, which suggests an inverse relationship between inorganic fertilizer and organic manure and maize-legume intercropping, i.e., a substitution effect. Thus, while an increase in price of inorganic fertilizer will reduce demand for inorganic fertilizer following the laws of demand (Nicholson & Snyder, 2011), the effect will be positive on demand for organic manure and maize-legume intercropping following the substitution effect. An implication of this may be that access to subsidized fertilizers through FISP may have reduced the demand for organic manure and intercropping. However, this relationship could be more complicated as shown by Holden and Lunduka (2012). Organic manure and inorganic fertilizers could be complements, as organic manure may improve the soil structure by adding soil organic matter and therefore increase the returns to inorganic fertilizer.

Given this production framework, farmers' decisions to use maize-legume intercropping and organic manure depends on the marginal productivity of the technology and the use and price of inorganic fertilizer. This implies that factors that influence the cost and performance of these technologies and use and access to inorganic fertilizer are all important adoption determinants. It is important therefore to control for factors such as access to fertilizer and seed subsidies, household endowments (e.g. labor, farm size, livestock and physical assets), weather expectations and population density. We model the adoption decision using the correlated random effects (CRE) models as also used by Holden and Lunduka (2012) in Malawi and Arslan *et al.* (2014) in Zambia.

3.3. Model specification and estimation strategy

The correlated random effects (CRE) model is specified as follows:

$$C_{it} = \beta_0 + \beta_1 D_{it} + \beta_2 P^{y}_{dt} + \beta_3 P^{f}_{it} + \beta_4 F_{it} + \beta_5 W_{dt} + \beta_6 Pd_{ivt} + \beta_7 R_{it} + \beta_8 H_{it} + \beta_9 \overline{H}_i + \beta_{10} T_t + \beta_{11} S_{it} + \alpha_i + \varepsilon_{it} \tag{8}$$

C_{it} is the dependent variable and takes different values for adoption and intensity of adoption. In adoption estimation, C_{it} is a dummy, equal to one if household *i* used organic manure (maize-legume intercropping) in year t, and equal to zero otherwise. For intensity of organic manure use, C_{it} is measured as quantity of organic manure applied in kilograms per hectare (kg/ha) and is log transformed. For maize-legume intercropping adoption intensity, C_{it} is defined as the share of total cultivated land under intercropping.

$D_{it}$is average distance to the market in km (a proxy for market access); P_{dt}^{y} is a vector of annual average real output prices[1] (maize and legume grain) in district d at time *t* while $P_{it}^{\mathrm{f}}$is fertilizer[2] real price. We include both commercial and subsidized fertilizer prices. F_{it} is (log of) fertilizer (including both commercial and subsidy) used (kg/ha) by household *i* at time *t*; W is a vector of previous (one-year lagged dry spells (e.g. length of longest early and late dry spells measured in days); Pd_{ivt} is (log of) population density in household i's village *v* while R_{it} is a dummy variable for the southern region. H_{it} and $\overline{H}_i$ is a vector of household and time-averages of household endowments, respectively. These variables include (log of) farm size (ha), distance to the farm (km), (log of) male and female labor endowment (adult equivalent/ha), (log of) livestock endowment (livestock tropical unit), and (log of) asset value in Malawi Kwacha (MK). T_t are year dummies (2006 is the reference) which control for price variation across years, while S_{it} indicates that a seed subsidy coupon was received. α_{i} captures individual time-invariant household fixed effects, while $\varepsilon_{\mathrm{it}}$ is the error term. By using CRE method, we are able to control for unobserved heterogeneity across households that is time invariant.

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1 Data on annual average output prices is from the Ministry of Agriculture, Irrigation and Water Development.

[2] Fertilizer price is at household level while output price is at district level. We use household level price for fertilizer to capture variations in final price paid by the farmer considering farmers access commercial and subsidized fertilizer.

3.4. Attrition, sample selection, and endogeneity

A common problem in longitudinal data is attrition, which is the loss of sample members between the first and subsequent waves of data collection (Fitzgerald *et al.*, 1998; Wooldridge, 2010). We first conduct a simple probit test to assess whether attrition is random and therefore ignorable. Separate tests are conducted for organic manure and maize-legume intercropping outcome variables. We find a chi-square of 111.27 and 110.77 in organic manure and maize-legume intercropping outcome variables, respectively, with a very high p-value (0.0000) in both cases. We therefore reject the null hypothesis that attrition is random.

Fortunately, as noted by Fitzgerald *et al.* (1998), unbiased estimation is possible even when attrition is high, provided that the proper adjustments are made. In this study, attrition bias is addressed in the following ways: First, we control for time-constant unobservable factors that affect attrition by using the CRE models – an alternative to household fixed-effects. Second, Fitzgerald *et al.* (1998) and Wooldridge (2010) proposes controlling for attrition bias due to observables using an inverse probability weights (IPW) approach. IPW is however not available in non-linear models used in this paper such as CRE models. We therefore estimated the linear models with household fixed effects (HHFE) with and without IPW as suggested by Ricker-Gilbert and Jayne (2017). If coefficient estimates with and without IPW are systematically different then there is reason for concern that estimates suffer from attrition bias. Fortunately, as shown in

Appendix A, IPW makes a very small difference to the coefficients of interest, which suggests that attrition bias is unlikely to be an issue.

Attrition is not the only problem faced in the empirical modeling. The models could also suffer from sample selection bias due to farmers having non-random access to the Farm Input Subsidy Program and endogeneity bias of fertilizer use as it is a choice variable. To control for sample selection and endogeneity bias, we use a two-step control function (CF) approach (Petrin & Train, 2010; Wooldridge, 2011). The first step involves estimating two separate selection equations. We estimate a probit selection model for receipt of the seed subsidy including as explanatory variables the exogenous variables defined in equation (8) plus several identifying instruments: age and age squared of household head and a binary variable for whether the household resides in the wife's home village. The residual ($\bar{\lambda}_{it}$) from this regression is then computed. We also estimate a Tobit selection model of fertilizer use intensity with the same set of explanatory variables as in the seed subsidy model plus number of children (for household dependants) and physical asset endowments (wealth level) and obtain the residual ($\bar{\mu}_{it}$). The set of instruments controls for endogeneity related to the fertilizer subsidy access variable in the fertilizer demand equation, an approach adopted from Holden and Lunduka (2012).

Selection of the identifying instruments is based on previous studies, theory and FISP targeting criteria which seek to reach village-resident households who are resource poor and headed by a child, orphan, or female. Holden and Lunduka (2012) used age and age squared of household head on the assumption that access to FISP could be influenced by one's position in the village. In rural Malawi, social position is often a function of age, but this position may diminish as one grows older and less involved in village affairs. While FISP was meant to target resource poor households, Holden and Lunduka (2013) found targeting errors where in essence it is the powerful that benefit more from the program and this includes the wealthier. We therefore include wealth level on the assumption that such households should access more of inorganic fertilizer. However, despite the program targeting errors, we hypothesize that household residence in wife's village and household dependants would increase access. However, these variables are expected to not directly affect adoption of organic manure and maize-legume intercropping. The residuals from these regressions are included in the second step as additional regressors, while the instruments are excluded.

4.0. Results and Discussions

Table 3 presents results for adoption and adoption intensity of organic manure and maize-legume intercropping. The first two columns are for adoption and adoption intensity of organic manure while adoption and adoption intensity of maize-legume intercropping are respectively, in the third and fourth columns. Fertilizer demand and access to seed subsidy endogeneity is controlled for by including residuals from first-stage regressions, as described earlier. Results from reduced form equations are presented in Appendix B where we used several instruments. The instruments are jointly significant in the fertilizer demand and seed subsidy equations. The error component from the inorganic fertilizer use intensity model is significant in structural models in Table 3 for adoption and adoption intensity for both organic manure and maize-legume intercropping, but the residual from seed subsidy is insignificant (

Appendix A). We therefore re-estimated the maize-legume intercropping models presented in Table 3 excluding seed subsidy residual (Mason & Ricker-Gilbert, 2013). Significance of residuals suggests endogeneity of fertilizer use intensity.

The first hypothesis the paper tests is that exposure to drought shocks increases the likelihood of adopting maize-legume intercropping and organic manure. The results in Table 3 show that we cannot reject this hypothesis and show a positive and significant relationship between previous exposure to late dry spells and adoption and adoption intensity of organic manure. For maize-legume intercropping, adoption and adoption intensity are positively correlated with both early and late dry spells. These results suggest that farmers are aware of climatic shocks and their negative consequences and one of the ways they try to adapt, i.e. hedge against production losses, is by adopting these technologies. Research indicates that occurrence of climatic shocks creates fear and worry among smallholder farmers of a reoccurrence and leads to increased investments in adaptive mechanisms that hedge against resulting losses (Van Den Berg *et al.*, 2009). Increased adoption of these technologies over time in response to drought exposure could be evidence that farmers are able to observe the impact of these technologies on yield and yield stability under drought growth conditions.

Our results also show that late droughts stimulate adoption of both maize-legume intercropping and organic manure, while exposure to early droughts appears to only stimulate more adoption of maize-legume intercropping. Crop production, maize in particular, which dominates in Malawi, is susceptible to early and late droughts and farmers are willing to invest in technologies that minimize the impacts. While irrigation technology is an option, the high investment and maintenance costs in SSA (Inocencio, 2007; Woodhouse *et al.*, 2017) limit most smallholder farmers from adoption of this technology. Organic manure and maize-legume intercropping offer farmers an option to hedge against late droughts in particular by conserving soil moisture through organic matter and soil cover. Furthermore, some legumes (e.g. pigeon peas) are late drought tolerant hence more likely to be intercropped with maize in areas where late droughts are frequent. The positive significance of early droughts on maize-legume intercropping could be related to farmers' need for short duration crops that fit into a short season when an early drought occurs. Maize-legume intercropping allows farmers to plant short duration legumes in maize plots such as beans and soybeans.

The second hypothesis we test is that an increase in inorganic fertilizer price is associated with higher likelihood of adopting organic manure and maize-legume intercropping. This was extended to test how fertilizer use intensity affects adoption of these technologies. The results indicate that we cannot reject these hypotheses as we found that fertilizer price is positive and significant in both organic manure and maize-legume intercropping models. Similarly, adoption intensity of organic manure is positively related with both (log of) commercial and (log of) subsidized inorganic fertilizer use intensity. A 1% increase in commercial fertilizer use intensity is associated with a 1.77% increase in organic manure use intensity. These findings concur with Holden and Lunduka (2012) who reported a 0.6-1.9% effect on organic manure of a 1% increase in fertilizer use intensity. The positive relationship between inorganic fertilizer use and organic manure use intensity suggests the two inputs are complements. The consistency of our findings with Holden and Lunduka (2012) provides additional evidence that inorganic fertilizer crowds in organic manure. There is also a positive and significant relationship between inorganic fertilizer use intensity and both adoption and adoption intensity of maize-legume intercropping. A 1% increase in fertilizer use intensity increases farmland share under intercropping by 0.11%.

On fertilizer price, an increase in fertilizer price of MK1000/Kg is associated with a 19% increase in quantity of organic manure use (Kg/ha) and 1% increase in farm size allocation to maize maize-legume intercropping. Results for the fertilizer demand equation (Appendix B) suggest that an increase in the fertilizer price of MK1000/Kg reduces fertilizer demand by 9%. As an increase in fertilizer price reduces demand for fertilizer, farmers make a systematic tradeoff by investing more in organic manure and maize-legume intercropping. In our theoretical framework, farmers' decisions to adopt organic manure is not only influenced by its marginal productivity but also the price of inorganic fertilizer. Considering that organic manure is labor intensive as reported by Mustafa-Msukwa *et al.* (2011) and there is a complementarity relationship between inorganic fertilizer and organic manure, an increase in fertilizer price will lead farmers to transfer resources between the two inputs to balance soil nutrient requirements while minimizing costs. Consequently, use intensity of these inputs will increase or decrease correspondingly.

Third, we hypothesized that output prices for maize and legumes are incentives for higher adoption of organic manure and maize-legume intercropping. This hypothesis was also extended by including how market access affects adoption of these technologies. Findings imply that we cannot reject the hypothesis and show a positive and significant correlation between one-year lag of legume prices and adoption of organic manure as well as adoption and adoption intensity of maize-legume intercropping. But there is a negative correlation between adoption intensity of organic manure and lagged maize prices. On the second part, the results reject the hypothesis on the impact of market access on adoption of organic manure but does not reject the hypothesis with respect to maize-legume intercropping.

Overall, these results suggest that farmers are somewhat price and market responsive. However, while legume price presents an incentive potential for farmers to adopt soil fertility management technologies, maize price appears to demotivate farmers from adopting organic manure. We hypothesized in our theoretical framework that adoption of organic manure and maize-legume intercropping would be affected by their marginal productivity which is a function of output and input prices. Relative to the opportunity cost for labor, a higher and significant output price signifies higher expected profits and increases the probability of adopting the technologies. With greater profits, farmers are more able to afford the new technologies.

The fourth hypothesis is that an increase in population density drives adoption of potentially land-saving technologies such as maize-legume intercropping. Our results do not allow us to reject the hypothesis as higher population density is associated with higher adoption and adoption intensity of organic manure and adoption intensity of maize-legume intercropping. These results provide more empirical evidence to support the claim by Snapp *et al.* (2002) that population growth has potential to drive smallholder farmers to adopt maize-legume intensification and organic matter-based technologies. Related to this we find that adoption and adoption intensity of maize-legume intercropping is higher in Malawi’s Southern Region than in the Central Region. This is as expected because maize-legume intercropping is a land-saving technology. Compared to the Central Region, the Southern Region has small land holdings and high population density. The high importance of tobacco production in the Central Region is another plausible explanation. Tobacco fields account for a large share of farmed area in the Central Region, such that land available for maize-legume intercropping is very limited.

A final result worth noting in Table 3 (not one of our hypotheses) is for the sex of household head dummy variable, which has a positive and significant association with adoption and adoption intensity of maize-legume intercropping. This finding suggests that this technology is more commonly and intensively adopted by female-headed households. While this would make sense because female-headed households are more land and labor constrained in Malawi (FAO, 2011), we see that this result holds even after controlling for labor endowment and farm size.

5.0. Conclusions and policy implications

Using four waves of panel data for nine years, this paper finds an increase in adoption from 33% in 2006 to 76% in 2015 for maize-legume intercropping and for organic manure increasing from 30% in 2006 and 53% in 2015. Our results demonstrate that adoption and adoption intensity of maize-legume intercropping are positively associated with exposure to early and late dry spells. Exposure to late dry spell in the previous year also appeared to stimulate adoption intensity of organic manure. The positive impact of dry spells on adoption of maize-legume intercropping and organic manure implies that farmers respond to occurrence and risks associated with dry spells and may perceive that maize-legume intercropping and organic manure help them to hedge against resulting production losses. We leave for future research to investigate how efficient these technologies are in achieving this. With the Government of Malawi taking an active role in promoting these technologies, there is need for collective and coordinated efforts to ensure that appropriate climate-smart agriculture technologies are available and disseminated to the farmers. While irrigation technology is an expensive option due to high investment and maintenance costs,

Table 3: Regression results on adoption of organic manure and maize-legume intercropping

Variable	Organic Manure		Maize-legume intercropping	
	Adoption (1=yes)	Log Manure (Kg/ha)	Adoption (1=yes)	Farm size share

Early dry spell (1-year lag)	-0.007	-0.135	0.039*	0.015**
	(0.018)	*(0.091)*	*(0.022)*	*(0.007)*
Late dry spell (1-year lag)	0.020**	0.132**	0.035***	0.015***
	(0.010)	*(0.053)*	*(0.011)*	*(0.004)*
Log-commercial fertilizer (Kg/ha)	0.348***	2.176***	0.391***	0.115***
	(0.120)	*(0.556)*	*(0.134)*	*(0.044)*
Log-subsidized fertilizer (Kg/ha)	0.032	0.147	-0.009	-0.001
	(0.034)	*(0.164)*	*(0.036)*	*(0.013)*
Price commercial fertilizer (Mk/Kg)	0.004***	0.021***	0.003**	0.001**
	(0.001)	*(0.006)*	*(0.001)*	*0.000*
Price subsidized fertilizer (Mk/Kg)	-0.002	-0.010	-0.002	-0.001
	(0.002)	*(0.011)*	*(0.002)*	*(0.001)*
1-year lag legume price (Mk/Kg)	0.003***	0.006	0.003**	0.001***
	(0.001)	*(0.005)*	*(0.001)*	*0.000*
1-year lag maize price (Mk/Kg)	-0.005	-0.121**	-0.014	-0.007
	(0.013)	*(0.061)*	*(0.016)*	*(0.005)*
Distance to market (km)	-0.039	-0.180	0.049*	0.023***
	(0.025)	*(0.117)*	*(0.028)*	*(0.009)*
Log-population density	1.524***	6.132**	0.368	0.434**
	(0.542)	*(2.794)*	*(0.622)*	*(0.211)*
Southern region dummy	-0.208	-0.408	1.246***	0.520***
	(0.161)	*(0.843)*	*(0.199)*	*(0.064)*
Household head sex (1=female)	-0.005	0.040	0.303**	0.103***
	(0.122)	*(0.564)*	*(0.147)*	*(0.038)*
Log-male labor (adult equivalent/ha)	0.083	0.722	-0.411*	-0.149*
	(0.186)	*(0.849)*	*(0.230)*	*(0.087)*
Log-female labor (adult equivalent/ha)	-0.040	0.376	0.146	0.068
	(0.193)	*(0.885)*	*(0.247)*	*(0.089)*
Log-farm size (ha)	0.099	-0.411	0.276	-0.048
	(0.218)	*(0.995)*	*(0.235)*	*(0.074)*
Seed subsidy dummy			-0.018	-0.012
			(0.118)	*(0.036)*
2009 year dummy	-0.093	-0.178	0.234	0.099
	(0.315)	*(1.454)*	*(0.386)*	*(0.127)*
2012 year dummy	-0.092	-1.302	0.269	0.047
	(0.292)	*(1.395)*	*(0.322)*	*(0.117)*
2015 year dummy	-0.249	-0.255	1.012**	0.278*
	(0.375)	*(1.822)*	*(0.463)*	*(0.161)*
Error from fertilizer equation	-0.332***	-2.054***	-0.374***	-0.111**
	(0.122)	*(0.566)*	*(0.132)*	*(0.043)*
Constant	-4.215***	-12.350**	-3.110***	-1.361***
	(1.070)	*(5.217)*	*(1.074)*	*(0.364)*
Prob > chi2	0.000	0.000	0.000	0.000
Rho	0.208	0.146	0.212	0.148

Number of observations	1490	1490	1475	1475

Significance levels: ∗10%, ∗∗5%, ∗∗∗1%. The household endowments and mean household endowments are left out of the table to shorten the size. The standard errors are bootstrapped with 400 replications, resampling households.

organic manure and maize-legume intercropping offer smallholder farmers lower-cost options to hedge against late droughts by conserving soil moisture.

Second, our findings show that subsidies for inorganic fertilizer do not necessarily crowd out organic manures or maize-legume intercropping. Although there is a significant positive effect of maize price on use of these technologies this is compensated by the positive and significant (complementary) relationship between inorganic fertilizer use and use of organic manure and maize-legume intercropping. It may be possible to further enhance such complementarities through extension efforts. Promotion of ISFM can facilitate further extraction of such synergistic effects. Vanlauwe et al. (2011) showed that Nitrogen use efficiency can be enhanced in maize-based systems by combining moderate amounts of organic manures with inorganic N fertilizers.

Third, the positive correlation between adoption of maize-legume intercropping and population density and residence in Southern Region (the region with highest population density) indicates that intensification takes place on small farms through adoption of land-saving technologies as population growth continues putting pressure on land. Maize-legume intercropping is a land-saving technology as it maximizes output per unit land. Promotion of legumes such as pigeon peas and soya beans can facilitate such intensification.

Acknowledgement

This is an output from the "Adoption of Conservation Agriculture Technologies in Malawi" project of the School of Economics and Business, Norwegian University of Life Sciences. It was funded by the CGIAR Independent Science and Partnership Council, the NORAD-funded NORHED "Climate-Smart Natural Resource Management and Policy (CLISNARP)" project and the NORAD-funded NOMA program. Thanks are due to Rodney Lunduka who was responsible for the first baseline survey in 2006 and jointly responsible for the second round (2009) survey with the second author. Julius Mangisoni facilitated the third round (2012) survey in collaboration with the second author. The authors take full responsibility for any remaining errors.

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Appendix A: Household fixed effects models with and without IPW and control function (CF)

Variable	Log Manure (Kg/Ha)		Farm size share under intercropping		Intercropping with CF	
	FE with IPW	FE without IPW	FE with IPW	FE without IPW	Adoption	Intensity
Early dry spell (1-year lag)	-0.027	-0.024	0.015****	0.015****	0.042*	0.016**
	(0.041)	*(0.042)*	*(0.004)*	*(0.004)*	*(0.023)*	*(0.008)*
Late dry spell (1-year lag)	0.052**	0.052**	0.007****	0.007***	0.040**	0.016***
	(0.020)	*(0.020)*	*(0.002)*	*(0.002)*	*(0.017)*	*(0.006)*
Southern region dummy	6.515****	6.554*	0.087	0.094	1.232****	0.517****
	(1.107)	*(3.782)*	*(0.148)*	*(0.374)*	*(0.201)*	*(0.064)*
Log-population density	-15.623***	-15.763***	0.541	0.507	0.269	0.424*
	(5.787)	*(5.790)*	*(0.823)*	*(0.573)*	*(0.674)*	*(0.234)*
Distance to market (km)	-0.051	-0.054	0.030*	0.029**	0.048*	0.024***
	(0.101)	*(0.130)*	*(0.015)*	*(0.013)*	*(0.028)*	*(0.009)*
1-year lag maize price (Mk/Kg)	-0.035	-0.035	-0.005	-0.005*	-0.017	-0.007
	(0.026)	*(0.026)*	*(0.003)*	*(0.003)*	*(0.018)*	*(0.006)*
1-year lag legume price (Mk/Kg)	-0.001	-0.001	0.001***	0.001***	0.003**	0.001**
	(0.002)	*(0.002)*	*0.000*	*0.000*	*(0.001)*	*0.000*
Log-fertilizer (Kg/ha)	-0.009	-0.018	-0.002	-0.002	0.372***	0.110**
	(0.051)	*(0.053)*	*(0.005)*	*(0.005)*	*(0.143)*	*(0.048)*
Fertilizer price (Mk/Kg)	0.001	0.001	0.000	0.000	0.004*	0.001
	(0.001)	*(0.001)*	*0.000*	*0.000*	*(0.002)*	*(0.001)*
Fertilizer subsidy dummy	-0.083	-0.102	0.004	0.004	0.044	0.013
	(0.247)	*(0.241)*	*(0.031)*	*(0.030)*	*(0.170)*	*(0.052)*
Log-farm size (ha)	-0.25	-0.247	-0.058	-0.058	0.227	-0.055
	(0.350)	*(0.396)*	*(0.038)*	*(0.040)*	*(0.306)*	*(0.099)*
Household head sex (1=female)	0.052	0.05	0.044**	0.043*	0.305**	0.105***
	(0.237)	*(0.239)*	*(0.022)*	*(0.024)*	*(0.151)*	*(0.040)*
2009 year dummy	0.874*	0.892*	0.126*	0.123**	0.341	0.119
	(0.509)	*(0.538)*	*(0.064)*	*(0.059)*	*(0.471)*	*(0.165)*
2012 year dummy	0.163	0.188	0.059	0.063	0.191	0.054
	(0.422)	*(0.436)*	*(0.048)*	*(0.046)*	*(0.455)*	*(0.157)*
2015 year dummy	1.437***	1.468***	0.209****	0.210****	1.013**	0.300*
	(0.486)	*(0.462)*	*(0.050)*	*(0.047)*	*(0.455)*	*(0.153)*
Log-male labor (adult equivalent/ha)	0.899***	0.906**	-0.072	-0.070*	-0.413*	-0.151*
	(0.323)	*(0.386)*	*(0.049)*	*(0.039)*	*(0.227)*	*(0.087)*
Log-female labor (adult equivalent/ha)	-0.287	-0.289	0.048	0.045	0.161	0.074
	(0.338)	*(0.396)*	*(0.050)*	*(0.039)*	*(0.243)*	*(0.088)*
Seed subsidy dummy			0.000	0.001	0.071	-0.006
			(0.028)	*(0.029)*	*(0.423)*	*(0.144)*
Error from seed subsidy equation					-0.117	-0.013
					(0.391)	*(0.135)*
Error from fertilizer equation					-0.356**	-0.106**
					(0.141)	*(0.048)*

Constant	24.682** *(9.580)*	24.992** *(9.778)*	-0.888 *(1.344)*	-0.842 *(0.969)*	-2.882* *(1.627)*	-1.378** *(0.579)*
Prob > chi2		0.000		0.000	0.000	0.000
Rho	0.544	0.542	0.434	0.435	0.217	0.151
Observations	1504	1508	1481	1485	1482	1482

*10%, **5%, ***1%, ****0.1%. We report only adoption intensity results for linear FE models with and without IPW leaving out adoption results to save space. Standard errors are robust in FE models and bootstrapped with 400 replications in CF models. The household endowments (FE models) and mean household endowments (CF models) are left out to save space

Appendix B: First stage regression results with probit and tobit selection models

Variable	**Seed subsidy (1=yes)**	**Log of fertilizer (Kg/ha)**
Age of household head	*0.028** (0.011)*	*0.042** (0.020)*
Age squared	*-0.000*** 0.000*	*-0.001*** 0.000*
Household resides in wife's village	*0.204** (0.089)*	*0.063 (0.165)*
Number of children in a household		*-0.306*** (0.087)*
Log-asset value (MK)		*0.078*** (0.024)*
Distance to market (km)	0.012 *(0.017)*	0.000 *(0.035)*
1-year lag maize price (Mk/Kg)	0.033*** *(0.010)*	0.018 *(0.019)*
1-year lag legume price (Mk/Kg)	0.001 *-0.001*	-0.004** *-0.001*
Fertilizer price (Mk/Kg)	-0.006*** *(0.001)*	-0.009*** *(0.001)*
Early dry spell (1-year lag)	-0.013 *(0.016)*	0.008 *(0.030)*
Late dry spell (1-year lag)	-0.040*** *(0.009)*	-0.003 *(0.016)*
Southern region dummy	0.140 *(0.139)*	-0.090 *(0.278)*
Log-population density	-3.107 *(1.943)*	-1.750 *(3.699)*
Log-farm size (ha)	0.438** *(0.170)*	-0.009 *(0.310)*

Sex of household head (1=male)	0.085	0.050
	(0.108)	*(0.189)*
Log-male labor (adult equivalent/ha)	0.075	0.150
	(0.151)	*(0.285)*
Log-female labor (adult equivalent/ha)	-0.093	-0.261
	(0.148)	*(0.298)*
2009 year dummy	-0.637***	1.451***
	(0.202)	*(0.369)*
2012 year dummy	1.051***	1.451***
	(0.168)	*(0.316)*
2015 year dummy	0.784***	2.318***
	(0.188)	*(0.346)*
Constant	-0.152	-0.04
	(1.924)	*(3.678)*
Prob > chi2	0.000	0.000
Rho	0.077	0.128
Number of observations	1499	1499

The household and mean household endowments are left out of the table to shorten the size.