Dis-incentivizing sustainable intensification? The case of Zambia's fertilizer subsidy program

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Abstract:

Poor and declining soil fertility remains a major constraint on increased cereal production in sub-Saharan Africa. Input subsidy programs (ISPs) for inorganic fertilizer are a popular and expensive tool used by African governments to increase cereal yields; however, far fewer resources are devoted to promoting other soil fertility management (SFM) practices that can improve soil quality, increase cereal yield response to inorganic fertilizer, and support sustainable agricultural intensification. This article uses nationally-representative household panel survey data from Zambia to estimate the effects of the country's ISP on smallholder farm households' adoption of several SFM practices: fallowing, intercropping, crop rotation, and the use of animal manure. The results suggest that Zambia's ISP induces reductions in fallowing and intercropping of maize with other crops. We also find some evidence that the program incentivizes an increase in continuous maize cultivation on the same plot in consecutive seasons but little evidence of effects on animal manure use. The changes in SFM practices induced by the ISP are likely to be detrimental to soil fertility, maize yield response to fertilizer, and returns to government expenditures on the ISP over the medium- to long-term. Overall, Zambia's ISP may have dis-incentivized sustainable intensification rather than promoted it.

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Abstract

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1. Introduction

Do fertilizer subsidy programs promote or discourage sustainable forms of agricultural intensification? With cereal demand in sub-Saharan Africa (SSA) projected to triple by 2050, there is a growing recognition that cereal yields must increase in order to meet this rising demand (van Ittersum et al. 2016). At the same time, there is an emerging consensus that increasing inorganic fertilizer use alone will be insufficient to sustainably intensify cereal production in the region (Montpellier Panel 2013, 2014; Jayne and Rashid 2013). A major reason for this is that poor and declining soil quality constrains crop yield response to inorganic fertilizer in many parts of SSA (Matson et al. 1997; Antle and Diagana 2003; Marenya and Barrett 2009; Tittonell and Giller 2013; Burke et al. 2016; FAO 2015). Moreover, the production and improper use of inorganic fertilizer can have detrimental environmental impacts (Wu and Babcock 1998; Pingali 2012; Petersen and Snapp 2015).

While the goal of sustainable agricultural intensification – i.e., raising crop yields while maintaining or improving the natural resource base including soil quality – is gaining traction in the region (Godfray et al. 2010; Montpellier Panel 2013; Pretty and Bharucha 2014; Petersen and Snapp 2015), many governments' attempts to catalyze an "African green revolution" have focused predominately on raising inorganic fertilizer use. In fact, collectively, African governments spend more than US$1 billion per year, and a large share of their agricultural and national budgets, on input subsidy programs (ISPs) for inorganic fertilizer and, in some cases, improved seed, mainly for maize and rice (Jayne and Rashid 2013; Jayne, Mason, Burke, and Ariga 2016). Far fewer resources are devoted to promoting other soil fertility management (SFM) practices that can improve soil quality and increase crop yield response to inorganic fertilizer. In the context of maize production systems in eastern and southern Africa, where inorganic fertilizer and maize seed subsidies have been particularly popular, such SFM practices include maize-legume intercropping and rotation, application of organic fertilizer (e.g., animal manure or compost), fallowing, crop residue retention, liming, minimum tillage, and agroforestry with nitrogen-fixing trees, *inter alia* (Place et al. 2003). Improving soil health and yield response to inorganic fertilizer is important not only for achieving sustainable intensification goals but also for improving the returns to government expenditures on ISPs in SSA (Jayne and Rashid 2013; Jayne et al. 2016). Despite heavy spending on the programs, ISP impacts on crop yields in the region have been smaller than anticipated (ibid.), and low cereal yield response to inorganic fertilizer has contributed to low economic returns to ISPs (Jayne et al. 2015). For example, Zambia's ISP benefit-cost ratio (BCR) is 0.92 while Malawi's is 1.08 (ibid.).

Given African governments' heavy emphasis on promoting increased inorganic fertilizer use and cereal production through ISPs, an important policy question and the focus of this article is whether these subsidies incentivize or dis-incentivize farmers' use of SFM practices other than inorganic fertilizer, and relatedly, if they promote or discourage sustainable agricultural intensification. By reducing the price of inorganic fertilizer, fertilizer subsidies may free up farmer resources to invest in other SFM practices. If this were the case, the ISPs could improve farmers' soil quality and cereal yield response to inorganic fertilizer, and increase the returns to government expenditures on ISPs while promoting sustainable intensification. On the other hand, the very cereal-centric input subsidy programs that have been common in SSA may encourage cereal monocropping within a given year, continuous cultivation of cereals on the same plot over time, and reduced fallows. Moreover, increased inorganic fertilizer utilization as a result of the subsidy program likely entails an increase in labor use (e.g., for inorganic fertilizer application and harvesting of additional cereal output), which, in the presence of labor market failures, could mean less labor is available to implement complementary SFM practices, potentially resulting in the use of inorganic fertilizer alone. If repeated over many years, this could increase soil acidity, especially in the case of nitrogenous fertilizers (Bouman et al. 1995; Lungu and Dynoodt 2008; Schroder et al. 2011). Over time, these unsustainable forms of intensification are likely to reduce soil quality and cereal yield response to inorganic fertilizer (Tittonell and Giller 2013), as well as diminish the returns to government expenditures on ISPs. Whether subsidies for inorganic fertilizer encourage ("crowd in") or discourage ("crowd out") other SFM practices is ultimately an empirical question, but to date, there is little empirical evidence available on this relationship.

We add to this thin knowledge base and use data from smallholder farm households in Zambia to estimate the effects of receiving subsidized inorganic fertilizer on a household's decision to: (i) leave land fallow (where we consider fallowing in general, and then distinguish between natural and improved fallows); (ii) intercrop maize with other crops (in general and with legumes specifically); (iii) rotate maize with other crops; and (iv) apply animal manure. We give particular emphasis to SFM practices related to maize production because it is the dominant staple food in Zambia, it is produced by the vast majority of smallholders, and it is the main crop promoted by the country's ISP. Zambia is an important case study for this analysis for three reasons. First, the government has an extensive history of providing input subsidies for maize production. Second, low maize response to fertilizer, increasing soil acidity, and low levels of soil organic matter are major concerns in the country (Burke et al. 2016, 2017; Chapoto et al. 2016). And third, three of the four previous peer-reviewed journal articles related to the effects of ISPs on SFM have focused on Malawi, so insights from a different country are sorely needed.

This article makes several important contributions to the literature. First, it provides rigorous empirical evidence on the relationship between ISPs and the adoption of SFM practices, complementing the few previous peer-reviewed studies on the topic: Holden and Lunduka (2012), Kassie et al. (2015), and Koppmair et al. (2017), who all consider the case of Malawi; and Mason et al. (2013), who took a preliminary, cursory look at the impacts of Zambia's ISP on total hectares fallowed. More specifically, Holden and Lunduka (2012) analyze the effects of Malawi's ISP on the use of organic manure and find no statistically significant effect. Kassie et al. (2015) reach a similar conclusion for maize-legume intercropping and rotation, minimum tillage, and soil/water conservation, as do Koppmair et al. (2017) for maize-legume intercropping, manure use, ridges, terraces and stone bunds, and vegetative strips.[1] Second, unlike Holden and Lunduka (2012), Kassie et al. (2015), and Koppmair et al. (2017) who use data that are not nationally-representative, and unlike Kassie et al. (2015) who use cross-sectional data, we use nationally-representative household panel survey data. The panel nature of our data allows us to control for time invariant heterogeneity (which is not feasible with cross-sectional data) and should improve the internal validity of our results; additionally, the nationally-representative nature of our data should improve the external validity of our results.

Third, unlike three of the four aforementioned peer-reviewed studies (Holden and Lunduka is the exception here), we consider the effects of ISPs on SFM at both the extensive *and* intensive margins. Looking at one but not the other, as these previous studies have done, gives only a partial picture of the effects of ISPs on SFM. For example, by only considering

[1] This statement is based on the results from Koppmair et al.'s preferred model specification, which uses the Mundlak-Chamberlain device to control for time invariant unobserved heterogeneity.

the extensive margins (and using probit models), Kassie et al. (2015) and Koppmair et al. (2017) would miss instances where the ISP encourages farmers to reduce their area under the SFM practice, but not to abandon the practice altogether. In this article, we consider four different measures of adoption: probability of adoption, area under the practice (conditional and unconditional on adoption), and share of land under the practice. Finally, unlike Kassie et al. (2015) and Koppmair et al. (2017), we combine panel data methods and instrumental variables-related techniques to correct for the potential endogeneity of subsidized fertilizer to SFM adoption, which should further improve the internal validity of our results.[2]

The remainder of this article is organized as follows. First, we provide background information on the history of Zambia's ISPs and the use of SFM practices by Zambian smallholders. Next, we outline the data and empirical strategies used in the analysis. Finally, we present our results, conclusions, and policy implications.

2. Background

2.1. Agricultural Input Subsidies in Zambia

Since gaining independence in 1964, ISPs have played a key role in agricultural policy in Zambia. From independence until the early 1990s, the government offered subsidized maize inputs to producers on credit, purchased maize from farmers at a pan-territorial and pan-seasonal price, and sold the maize to consumers at subsidized prices (Smale and Jayne 2003; Mason and Smale 2013). Because the government lost money at each stage, the costly system was shut down during structural adjustment in the 1990s. Soon after, however, another countrywide fertilizer credit program was established in 1997. Then in 2002, the Ministry of Agriculture and Co-operatives (MACO) replaced it with a large-scale, targeted input subsidy program, the Fertilizer Support Program (FSP).

FSP's stated goals were "improving household and national food security, incomes, [and] accessibility to agricultural inputs by small-scale farmers through a subsidy" (MACO 2008, p. 3). The program was to provide a uniform package of 400 kg of fertilizer and 20 kg of hybrid maize seed to selected beneficiary households.[3] The beneficiaries paid 25-50% of the market price for the inputs while the government covered the rest of the cost. In the 2009/2010 agricultural year, FSP was renamed the Farmer Input Support Program (FISP). The main substantive change accompanying the name change was that FISP aimed to serve twice as many households as FSP by reducing the package size by 50% – i.e., under FISP, each beneficiary household was to receive 200 kg of fertilizer and 10 kg of hybrid maize seed.[4] According to both FSP and FISP program designs, each participating household was to receive the same quantity of fertilizer and seed and should have received no more than one of these uniform packages; however, in practice, participating households received varying amounts (Mason et al. 2013).

[2] An additional contribution of the longer version of this paper but which is excluded here due to space constraints is that, unlike the previous peer-reviewed studies, we develop and ground our empirical model in a rigorous non-separable agricultural household model that illustrates the potential links between inorganic fertilizer subsidies and a household's choice of SFM regime.

[3] The agricultural year in Zambia is from October through September.

[4] Zambia began piloting a flexible electronic voucher-based version of FISP in 2015/16. Under this program, farmers can redeem a subsidized prepaid Visa card for the farm inputs or equipment of their choice, rather than being constrained to only maize seed and fertilizer.

In this paper we focus on FSP in the initial years of its implementation. To be eligible for FSP, a household was to meet the following requirements: be a small-scale farmer (i.e., cultivate less than five hectares of land) and be actively involved in farming; have the capacity to grow at least one hectare of maize; have the ability to pay the farmers' share of the input costs; be a member of a cooperative; have not defaulted from the fertilizer credit program implemented prior to FSP; and not be a current beneficiary of the Food Security Pack Program.[5] Farmers had to apply for FSP through their cooperative, then the District Agricultural Committee approved the list of farmers they received from the cooperatives. Next, approved farmer beneficiaries paid for the subsidized inputs through their cooperative, which deposited the money in a specified account with MACO. Lastly, beneficiary farmers collected their inputs from their cooperative (MACO 2002).[6]

The panel data used in this study cover the 2002/2003 and 2006/2007 agricultural years. In those years, subsidized fertilizer was provided to beneficiaries at roughly 50% and 60%, respectively, of the estimated district-level market price. In 2002/2003, 120,000 farmers were to receive 48,000 MT of FSP fertilizer. Ultimately, 8.4% of smallholder farmers in the country received FSP fertilizer that year, with each participating household receiving an average of 307 kg and a median of 200 kg. The program grew by 2006/2007, when 210,000 farmers were to receive 84,000 MT of FSP fertilizer. FSP ultimately reached 11.6% of smallholder farmers that year, with each participating household receiving an average of 356 kg and a median of 300 kg of fertilizer. FSP accounted for 10.4% and 25.5% of total agricultural sector spending in Zambia in 2002 and 2006, respectively (Mason et al. 2013).

2.2. Descriptive Statistics on the Use of SFM Practices and Receipt of FSP Fertilizer

To what extent did Zambian smallholders use SFM practices other than inorganic fertilizer during the period of analysis? Table 1 summarizes the prevalence of use of seven practices: (i) fallowing in general (natural or improved); (ii) improved fallowing; (iii) natural fallowing; (iv) maize-legume intercropping; (v) maize monocropping (i.e., planting maize in monoculture, rather than in an intercrop, in a given agricultural year); (vi) "continuous maize" (i.e., planting maize on the same plot in two consecutive agricultural years and thus *not* rotating the maize plot with another crop); and (vii) animal manure. For each practice, we report the proportion of smallholder farm households using it, the mean hectares under the practice at the household level, and the share of the household's land dedicated to the practice. For the fallow variables, the share is defined as the area of land left to the specified type of fallow divided by the household's total landholding size. For the other SFM practices, the share variable is defined as the area devoted to the practice divided by the total land area cultivated by the household.

As shown in Table 1, 38.0%, 1.1%, and 37.0% of Zambian smallholder households practiced general, improved, and natural fallowing, respectively. The vast majority of households (77.8%) had a least one monocropped maize field and only 3.1% practiced maize-legume intercropping. Continuous maize cultivation is common (practiced by 46.2% of households), and application of animal manure is quite rare (practiced by 6.8% of households).

To what extent does the use of these practices differ between FSP fertilizer recipient and non-recipient households? The main patterns based on bivariate mean comparisons are as follows.

[5] The Food Security Pack Program is a very small, grant-based ISP targeted at poor households.
[6] For further information on Zambia's ISPs, see Mason et al. (2013).

Households that receive FSP are less likely than non-recipients to leave land fallow (by 6 percentage points) and leave a smaller proportion of their land fallow (by 4 percentage points) ($p<0.01$). These results are driven by natural fallowing, which is by far the more common type of fallowing. There are no statistically significant differences for improved fallowing or maize-legume intercropping. Maize monocropping within a given year, continuous maize cultivation over time, and the application of animal manure are all more prevalent among FSP recipients compared to non-recipients (by 21, 6, and 5 percentage points, respectively). While not evidence of any causal effects of FSP fertilizer receipt on these practices, the results in Table 1 do suggest that these relationships warrant further investigation.

Table 1. Comparisons of mean values of SFM outcome variables between FSP fertilizer recipient & non-recipient households, 2002/2003 and 2006/2007 agricultural years

	Obs. [a]	Mean	Received FSP fertilizer? Yes (Mean)	No (Mean)	Difference in means	Sig.	p-value [b]
General fallowing							
=1 if adopted	9245	0.380	0.326	0.386	-0.060	***	0.001
Area (ha, if >0)	3591	1.227	1.690	1.184	0.507	***	0.003
Area (ha)	9245	0.466	0.551	0.457	0.094		0.140
Share	9245	0.149	0.113	0.153	-0.040	***	0.000
Improved fallowing							
=1 if adopted	9245	0.011	0.010	0.011	-0.001		0.818
Area (ha, if >0)	95	0.947	0.954	0.946	0.008		0.982
Area (ha)	9245	0.010	0.010	0.011	-0.001		0.868
Share	9245	0.004	0.003	0.004	-0.001		0.664
Natural fallowing							
=1 if adopted	9245	0.370	0.316	0.376	-0.060	***	0.001
Area (ha, if >0)	3507	1.231	1.714	1.187	0.527	***	0.003
Area (ha)	9245	0.456	0.541	0.446	0.095		0.137
Share	9245	0.146	0.110	0.149	-0.039	***	0.000
Maize-legume intercropping							
=1 if adopted	9391	0.031	0.029	0.032	-0.002		0.745
Area (ha, if >0)	308	0.979	1.033	0.970	0.063		0.791
Area (ha)	9391	0.031	0.030	0.031	0.000		0.968
Share	9391	0.012	0.012	0.012	0.000		0.936
Maize monocropping							
=1 if adopted	9391	0.778	0.967	0.757	0.210	***	0.000
Area (ha, if >0)	7285	0.978	1.568	0.896	0.671	***	0.000
Area (ha)	9391	0.761	1.516	0.679	0.837	***	0.000
Share	9391	0.402	0.528	0.388	0.140	***	0.000
Continuous maize							
=1 if adopted	9239	0.462	0.512	0.456	0.056	***	0.005
Area (ha, if >0)	4263	0.969	1.521	0.901	0.620	***	0.000
Area (ha)	9239	0.447	0.778	0.411	0.367	***	0.000
Share	9239	0.297	0.318	0.295	0.024		0.158
Animal manure							
=1 if adopted	9097	0.068	0.113	0.063	0.050	***	0.000
Area (ha, if >0)	690	1.402	1.758	1.330	0.429	***	0.002
Area (ha)	9097	0.095	0.198	0.083	0.115	***	0.000
Share	9097	0.041	0.063	0.038	0.024	***	0.003

Note: ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. [a] The difference in the number of observations across SFM practices is due to missing data. [b] p-value is for a t-test of H_0: mean values are equal for FSP fertilizer recipient and non-recipient HHs versus H_1: the means are different.

3. Data

Our primary data source is the Zambia Supplemental Survey (SS), a three-wave nationally representative survey of smallholder farm households conducted in May-June 2001, 2004, and 2008 and covering the 1999/2000, 2002/2003, and 2006/2007 agricultural years, respectively.[7, 8] The Zambia Central Statistical Office (CSO) and MACO implemented the SS in collaboration with the Food Security Research Project. The SS captures detailed information on household demographics, on- and off-farm activities, asset holdings, household participation in FSP, and farmer use of SFM practices. A total of 6,922 households were interviewed in the 2001 wave of the survey. We do not use this first wave of data because not all of the SFM practices we seek to analyze were covered in it. The 2004 wave of the SS successfully re-interviewed 5,358 (77.4%) of the first wave households. The 2008 wave of the SS successfully re-interviewed 4,286 (80.0%) of the second wave households. There are thus 4,286 households in the balanced panel.

Given that a sizable percentage of households were not successfully re-interviewed in the second and third waves of the survey, attrition bias is a potential concern. We use the regression-based test described in Wooldridge (2010) to determine if there are systematic differences in the SFM dependent variables between attritors and non-attritors after controlling for observed covariates. To conduct this test, we add an indicator variable to our main empirical specifications that is equal to one for 2004 SS households that were re-interviewed in the 2008 SS (i.e., non-attritors) and equal to zero for 2004 SS households that were not re-interviewed in the 2008 SS (i.e., attritors). We then run an OLS regression using all of the households interviewed in 2004. The attrition bias test is then a *t*-test of the re-interview variable. The null hypothesis is that there is no attrition bias, and the alternative hypothesis is that there is attrition bias. We fail to reject the null hypothesis of no attrition bias in all cases ($p>0.10$).

All econometric models are estimated using the balanced panel of households that were interviewed in both the 2004 and 2008 waves of the survey and for which complete data are available on all explanatory variables (8,188 total observations and 4,094 households). In some cases, the sample size is slightly smaller due to missing data on the dependent variable.

We draw on other data sources for several of the control variables. Namely, lagged producer prices for maize, sweet potato, mixed beans, and groundnuts are from the 2001/2002 and 2005/2006 CSO/MACO Post-Harvest Surveys. Rainfall data are from Tropical Applications of Meteorology using SATellite data (TAMSAT) (Tarnavsky et al. 2014; Maidment et al. 2014; Grimes et al. 1999; Milford and Dugdale 1990) and are merged with the SS data at the standard enumeration area (SEA) level.[9] Additional geo-referenced variables merged with the SS at the SEA level are: (i) a slope variable from the Shuttle Radar Topography Mission and processed by the CGIAR's Consortium for Spatial Information (Jarvis et al. 2008); (ii) soil nutrient availability and soil nutrient retention capacity variables from the Harmonized World Soil Database v1.2 (FAO 2012); and (iii) soil type from the Zambia Agriculture Research Institute. Finally, our instrumental variable is based on constituency-level data from the Electoral Commission of Zambia.

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[7] In Zambia, smallholder households are defined as those cultivating less than 20 hectares of land.
[8] The 1999/2000 survey covered all 70 rural districts in the country and used a stratified three-stage sampling design to select the households surveyed. See Megill (2005) for a detailed description of the sampling design.
[9] An SEA contains approximately 150-200 households.

4. Empirical strategy

We first consider a household's probability of adopting a given SFM practice and specify an unobserved effects probit model (Wooldridge 2010). In this model, the dependent variable, SFM_{it}, is equal to one if household i adopts a specified SFM practice in agricultural year t (t = 2002/2003, 2006/2007), and zero otherwise:

$$
\begin{aligned}
&P\left(SFM_{it}=1 \mid FSP_{it}, \boldsymbol{p}_{it}, \boldsymbol{w}_{it}, \boldsymbol{A}_{it}, \boldsymbol{x}, \boldsymbol{z}_{it}^{q}, \boldsymbol{z}_{it}^{c}, d_t, c_i\right)= \\
&\Phi\left(\beta_0+\beta_1 FSP_{it}+\boldsymbol{p}_{it}\boldsymbol{\beta}_2+\boldsymbol{w}_{it}\boldsymbol{\beta}_3+\boldsymbol{A}_{it}\boldsymbol{\beta}_4+\boldsymbol{x}_{it}\boldsymbol{\beta}_5+\boldsymbol{z}_{it}^{q}\boldsymbol{\beta}_6+\boldsymbol{z}_{it}^{c}\boldsymbol{\beta}_7+d_t+c_i\right)
\end{aligned} \quad (1)
$$

Separate equations are estimated for each SFM practice: (i) fallowing (general, natural, and improved), (ii) maize-legume intercropping, (iii) maize monocropping, (iv) continuous maize, and (v) applying animal manure. The legumes commonly grown in Zambia and captured in our analysis are groundnuts, soybeans, mixed beans, bambara nuts, cowpeas, and velvet beans. Time-constant unobserved household-level heterogeneity is denoted by c_i; d_t is an agricultural year fixed effect; and the β's are parameters to be estimated.

The explanatory variables, which are derived from a non-separable agricultural household model, are defined as follows. FSP, the key explanatory variable of interest, is the kilograms of FSP fertilizer acquired by the household. As discussed above, the quantity of FSP fertilizer acquired by beneficiaries varies considerably, so this specification is preferred to using a dummy variable for receipt of FSP fertilizer. A variable for the subsidy rate does not appear in our empirical model because it is pan-territorial and thus perfectly collinear with the year fixed effect.

$\boldsymbol{p}$ and $\boldsymbol{w}$ are vectors of expected output prices and variable input prices, respectively. For the former, we use producer prices from the previous year as a proxy for expected prices and include the district median producer price of maize, and provincial median producer prices of sweet potato, mixed beans, and groundnuts.[10] For variable input prices, we include the district median farmgate market price of inorganic fertilizer and an agricultural wage rate (the district median wage paid to weed 0.25 ha of cropland). Spatially-varying prices for other inputs are not available. $\boldsymbol{A}$ includes the household's landholding size in hectares and its square, and the percentage of total landholding that is owned by the household (as a proxy for land tenure security).

$\boldsymbol{x}$ is a vector of variables related to soil and land quality. Specifically, we include SEA-level variables for soil type, nutrient availability, nutrient retention capacity, and slope. We do not have household-specific data on soil quality but our use of panel data methods (discussed below) should control for average soil quality on the household's farm to the extent that it changes very little between the two survey waves.

$\boldsymbol{z}^{q}$ is a vector of quasi-fixed factors and exogenous variables affecting production. These include: the number of cattle owned; the number of other livestock owned expressed in Tropical Livestock Units (TLU); indicator variables for whether the household owns a cell phone and a radio (both could be used to access production and market price information); distances from the center of the household's SEA to the nearest town, feeder road, and tarmac

[10] These four crops are among the most commonly sold by Zambian smallholders.

road; and the distance from the homestead to the nearest location where the household can get vehicular transport. We also include three SEA-level rainfall variables for the growing season months of November to March for the 16 years prior to agricultural year *t*: mean growing season rainfall (mm), mean moisture stress (measured as the number of 20 day periods with less than 40 mm of rain), and the coefficient of variation (CV) of growing season rainfall. Lastly, we include agro-ecological zone dummies.

z^c is a vector of household characteristics affecting consumption including the age, education, and gender of the household head, as well as the number of household members in four age categories: under 5, 5-14, 15-59, and 60 and above. In addition to the aforementioned variables in z^q and z^c, we also include provincial dummies (there were nine provinces in Zambia during the study period) as well as province-agricultural year interaction terms.

Equation (1) is estimated via Mundlak-Chamberlain device correlated random effects (CRE) probit. Let $\boldsymbol{X}_{it}$ denote the vector of observed, time-varying explanatory variables. The CRE approach assumes that the unobserved heterogeneity is a function of the household-level time averages of $\boldsymbol{X}_{it}$, which we denote as $\bar{\boldsymbol{X}}_i$. That is, $c_i = \psi + \bar{\boldsymbol{X}}_i \xi + a_i$ where $a_i \mid \boldsymbol{X}_i \sim Normal(0, \sigma_a^2)$ (Mundlak 1978; Chamberlain 1984). Under these assumptions and strict exogeneity of the explanatory variables conditional on c_i, we can control for c_i in a probit model by including $\bar{\boldsymbol{X}}_i$ as additional regressors. (See Wooldridge 2010 for a detailed discussion of CRE probit.) Additionally, the CRE approach allows c_i and the observed covariates to be correlated.

Obtaining unbiased or consistent estimates of the causal effect of FSP on SFM is a challenge because we do not observe the counterfactual, i.e., we cannot observe a farmer's SFM use when they both receive and do not receive FSP simultaneously. Randomization of treatment assignment is also not an option due to the targeting used in FSP. Non-random receipt of FSP fertilizer could lead to selection bias. There could also be unobserved factors that are correlated with FSP fertilizer receipt and affect the use of SFM practices that are not explicitly controlled for in equation (1). For example, more motivated farmers or those with better management ability might be able to access more FSP fertilizer and may also be more likely to use SFM practices. If FSP fertilizer receipt is mainly correlated with *time-constant* unobserved factors that also affect households' use of SFM practices, then the CRE approach should largely correct for the potential endogeneity of FSP to SFM adoption. However, if FSP fertilizer receipt is correlated with *time-varying* unobserved heterogeneity, then we need to take additional steps to address the endogeneity problem. To do so, we utilize the control function (CF) approach. The CF approach is preferable to a standard instrumental variables approach in this article because of our extensive use of nonlinear-in-parameters econometric models. The CF approach is more compatible with such models (Wooldridge 2010).

In the current application, the CF approach entails estimating a first stage CRE Tobit regression in which the dependent variable is the endogenous explanatory variable (FSP_{it}) and the explanatory variables are all of the exogenous regressors in equation (1) as well as an instrumental variable (IV). In the second step of the CF approach, the residuals from the first stage are included as an additional regressor in equation (1), which is estimated via CRE probit. Conditional on the validity of the IV, the inclusion of the CF residuals in the second step corrects the endogeneity problem. A *t*-test of the residuals tests the null hypothesis that FSP fertilizer is exogenous against the alternative that it is endogenous. Standard errors in the second step are bootstrapped to account for the multi-stage estimation (Wooldridge 2010).

We follow Mason and Jayne (2013) and use as an IV for FSP fertilizer a variable that is equal to zero for households in constituencies lost by the ruling party in the last presidential election, and equal to the percentage point margin of victory between the ruling party and lead opposition otherwise.[11] The first stage estimation results suggest that this IV is relevant and strong, as the partial F-statistic of 10.79 exceeds 10, the typical threshold for a sufficiently strong IV (Staiger and Stock 1997). More specifically, these results suggest that a one percentage point increase in the ruling party's margin of victory in a constituency raises the quantity of FSP fertilizer received by households in that constituency by approximately 4 kg, other factors constant. (See Mason et al. 2017 for a detailed discussion of the political economy of FSP.) Our argument for the validity of the IV is that, conditional on the rich set of observed covariates and our use of CRE to control for time constant unobserved heterogeneity, election results in the household's constituency should only affect adoption of SFM practices through their effect on FSP fertilizer distribution patterns, which are highly politicized. Moreover, the constituency-level election results reflect the voting decisions of thousands of households and are thus exogenous to an individual household.

For the other outcome variables analyzed – hectares under the practice and share of area under the practice – we estimate CRE truncated normal hurdle (TNH) and CRE fractional response probit (FRP) models, respectively, both with and without the CF approach. TNH models are two-part models in which the first part is a probit model for the decision to use a given SFM practice or not, and the second part is a truncated normal regression, in our case for the number of hectares on which to use the practice, conditional on adoption. We report average partial effect estimates (APEs) from both parts of the model, as well as the overall (unconditional) APEs. TNH models are more flexible than Tobit models because they allow different variables to affect the adoption and extent of adoption decisions, and allow a given variable to have potentially opposite effects on these two decisions (Cragg 1971, Wooldridge 2010). See Cragg (1971) and Wooldridge (2010) for detailed discussions of these models. FRP models are similar to binary response probit models except that they allow for proportion dependent variables such as our share of area variables. See Papke and Wooldridge (1996, 2008) for a detailed discussion of these models. As a benchmark, we estimate linear household fixed effects (FE) models for all outcome variables.

5. Results

In this section we discuss the key results from the econometric analysis. The full regression results are excluded due to space constraints but are available from the authors upon request. We focus our discussion on the FE models and the nonlinear CRE models without the CF approach because in the CF regressions, we fail to reject the null hypothesis that FSP fertilizer is statistically exogenous at the 5% level for all SFM practices. We report the APE of a 200-kg increase in FSP fertilizer on each of the SFM outcome variables. 200 kg was the median amount of FSP fertilizer acquired by households in our sample and was the quantity of subsidized fertilizer included in FISP from 2009/2010 through 2016/2017.

[11] The ruling party during both the 2002/2003 and 2006/2007 agricultural years was the Movement for Multi-Party Democracy. The most recent elections prior to these agricultural years were in 2001 and 2006.

5.1. Effects on fallowing

The results in Table 2 suggest statistically significant ($p<0.05$) crowding out effects of FSP fertilizer on farmers' use of fallowing in general and on natural fallowing in particular. This is the case regardless of the measure of general and natural fallowing used. An increase in the quantity of FSP fertilizer received is associated with reductions in general and natural fallowing at both the intensive and extensive margins. For example, a 200-kg increase in FSP fertilizer reduces the probability of general fallowing by approximately 3 percentage points. This increase is FSP fertilizer is associated with reductions in area fallowed of 0.13 hectares among those that practice fallowing, and 0.08 to 0.16 hectares overall; it is also associated with decreases in the share of total landholding fallowed of 1.7 percentage points (Table 2). While relatively small in magnitude, these results are robust to the estimator used and, when aggregated to the national level, could translate into substantial reductions in fallowing. The results for improved fallowing are more sensitive to the estimator used and we have less power to detect effects when they are present for this practice due to its low prevalence (it is used by 1.1% of smallholder households) but the results are indicative of potential negative FSP effects on improved fallowing.

Table 2. Effects of FSP fertilizer on adoption of fallowing practices

Dependent variable	Estimator	APE (200 kg of FSP)	Sig.	p-value
General fallowing				
=1 if adopted	FE	-0.0284	***	0.003
	CRE probit	-0.0331	**	0.013
Area (ha, if >0)	CRE truncreg	-0.131	***	0.007
Area (ha)	FE	-0.155	***	0.001
	CRE TNH	-0.0813	***	0.001
Share of area	FE	-0.0176	***	0.000
	CRE FRP	-0.0171	***	0.006
Natural fallowing				
=1 if adopted	FE	-0.0216	**	0.017
	CRE probit	-0.0264	**	0.034
Area (ha, if >0)	CRE truncreg	-0.137	***	0.005
Area (ha)	FE	-0.149	***	0.001
	CRE TNH	-0.0760	***	0.002
Share of area	FE	-0.0158	***	0.000
	CRE FRP	-0.0147	**	0.015
Improved fallowing				
=1 if adopted	FE	-0.00770	***	0.008
	CRE probit	-0.00882	***	0.006
Area (ha, if >0)	CRE truncreg	0.119		0.750
Area (ha)	FE	-0.00660	***	0.009
	CRE TNH	-0.00860		0.103
Share of area	FE	-0.00172	****	0.007
	CRE FRP	-0.00342		0.288

Note: ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. Truncreg = truncated normal regression.

5.2. Effects on maize-legume intercropping, maize monocropping, and continuous maize

We find no evidence of statistically significant FSP fertilizer effects of Zambian smallholders' use of maize-legume intercropping at the intensive or extensive margins (Table 3). While we cannot rule out low statistical power as the explanation for these findings (recall that only 3% of Zambian smallholders use maize-legume intercropping), our results are consistent with the findings of Kassie et al. (2015) and Koppmair et al. (2017) that Malawi's fertilizer subsidy program has no effect on maize-legume intercropping. However, we consistently find that an increase in FSP fertilizer *is* associated with increases in planting maize in monoculture within a given season. These results are robust to the estimator used and suggest increases in both the probability and extent of maize monocropping. For example, based on the CRE models, a 200-kg increase in FSP fertilizer raises the probability of a Zambian smallholder maize monocropping at least one field by 6.7 percentage points; increases the area monocropped (conditional on adoption) by 0.05 hectares and the overall (unconditional) area by 0.09 hectares; and raises the share of total cropped area that is maize monocropped by 2.4 percentage points, on average, *ceteris paribus* (Table 3). As was the case with fallowing, these results are fairly small in magnitude but could translate into substantial increases in maize monocropping at the national level. Among maize fields that are intercropped with one other crop in our data, the most common crop grown with maize is cassava, so the results may signal a shift away from maize-cassava intercropping. Maize-bean and maize-groundnut are the next two most common maize-related intercrops in the data, but the findings above suggest no FSP effects on these intercrops, on average.

While we find strong evidence that FSP incentivizes maize monocropping within a given agricultural season, we find only weak evidence that FSP induces Zambian smallholders to plant maize on the same plot in consecutive years (i.e., it discourages them from rotating their maize with other crops) (Table 3). The average area devoted to continuous maize (in absolute and relative terms) appears to be unaffected by FSP fertilizer. However, there is some evidence (based on both the FE and CRE probit results) that a 200-kg increase in FSP fertilizer acquired is associated with a 2 percentage point increase in the probability of planting continuous maize, on average and other factors constant.

Table 3. Effects of FSP fertilizer on maize-legume intercropping, maize monocropping, and continuous maize

Dependent variable	Estimator	APE (200 kg of FSP)	Sig.	p-value
Maize-legume intercropping				
=1 if adopted	FE	-0.00090		0.752
	CRE probit	-0.00234		0.604
Area (ha, if >0)	CRE truncreg	0.0564		0.686
Area (ha)	FE	-0.00206		0.798
	CRE TNH	-0.0005		0.938
Share of area	FE	-0.00048		0.781
	CRE FRP	-0.00036		0.852
Maize monocropping				
=1 if adopted	FE	0.00760	**	0.041
	CRE probit	0.0665	***	0.009
Area (ha, if >0)	CRE truncreg	0.0525	***	0.004
Area (ha)	FE	0.190	***	0.000
	CRE TNH	0.0886	***	0.000
Share of area	FE	0.0232	***	0.000
	CRE FRP	0.0239	***	0.000
Continuous maize				
=1 if adopted	FE	0.0150	*	0.095
	CRE probit	0.0173	*	0.070
Area (ha, if >0)	CRE truncreg	-0.00206		0.945
Area (ha)	FE	0.089	*	0.061
	CRE TNH	0.0172		0.345
Share of area	FE	0.00848		0.256
	CRE FRP	0.00764		0.273

Note: ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. Truncreg = truncated normal regression.

5.3. Effects on use of animal manure

We find essentially no evidence that FSP affects Zambian smallholder's use of animal manure (Table 4). While we again cannot rule out the possibility of type II error given the relatively low prevalence of animal manure use in Zambia (only 6.8% of smallholders use it), our results are consistent with findings by Holden and Lunduka (2012) and Koppmair et al. (2017) that an increase in subsidized fertilizer through Malawi's input subsidy program has no statistically significant effect on the use of organic manure.

Table 4. Effects of FSP fertilizer on use of animal manure

Dependent variable	Estimator	APE (200 kg of FSP)	Sig.	p-value
Animal manure				
=1 if adopted	FE	0.00008		0.988
	CRE probit	-0.00068		0.863
Area (ha, if >0)	CRE truncreg	-0.09672	*	0.066
Area (ha)	FE	-0.0412		0.135
	CRE TNH	-0.00872		0.225
Share of area	FE	-0.00448		0.286
	CRE FRP	-0.00276		0.183

Note: ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. Truncreg = truncated normal regression.

6. Conclusions & policy implications

African governments spend more than US$1 billion per year on ISPs, yet the returns to these programs have been disappointingly low in several countries due in large part to low crop yield response to inorganic fertilizer (Jayne and Rashid 2013; Jayne et al. 2016). There is an emerging consensus that, in many cases, other SFM practices should be used in conjunction with inorganic fertilizer to improve soil quality so that it is above the minimum thresholds necessary for inorganic fertilizer to be effective (Jayne and Rashid 2013; The Montpellier Panel 2014; FAO 2015). Among other impacts, SFM practices can build SOM, prevent erosion, increase soil nutrients, and reduce soil acidity, all of which are crucial for raising agricultural productivity and work synergistically with the inorganic fertilizer that ISPs promote and distribute (Weight and Kelly 1999). Moreover, achieving sustainable agricultural intensification goals in SSA will likely require increased use of SFM practices that are complementary to inorganic fertilizer.

In this article, we estimate the effects of receipt of subsidized inorganic fertilizer through Zambia's ISP on smallholder farmers' use of such SFM practices. The results suggest that the program induces a reduction in both the probability and extent of fallowing by Zambian smallholders. We also find strong evidence that the ISP incentivizes increases in maize monocropping, a known driver of soil degradation and decreased maize yields if practiced continually over multiple seasons (Bennett et al. 2012). In addition, there is some evidence that Zambian smallholders are more likely to plant maize on the same plot in consecutive seasons (i.e., they are *less* likely to rotate maize with other crops) in response to receiving more subsidized fertilizer. Similar to studies from Malawi (Holden and Lunduka 2012, Koppmair et al. 2017), an increase in subsidized fertilizer has no statistically significant effect on Zambian farmers' use of animal manure. Taken together, these results suggest that

Zambia's ISP did little to promote sustainable agricultural intensification and may have even incentivized behaviors that will be detrimental to soil quality over the medium to long term.

The implications of the results for farmer welfare in the short-run are not easy to draw due to smallholder households' multiple objectives, including, amongst others, increasing household income, maintaining the soil health in their fields over multiple seasons, and including necessary nutrients in the household diet. More research is needed to understand the impacts of reduced fallowing and decreased intercropping and rotating of maize fields in Zambia and whether the benefits to the farmer from the subsidized fertilizer and possible increased maize output in the short-run outweigh the potential costs of these practices.

The SFM practices that have the most impact on long-term sustainable production and to what extent they should be used are context specific, based on household and farm characteristics, households' needs, and economic conditions, *inter alia*. This, too, is an area in great need of further study. There is, however, strong international consensus that soils are degraded in many parts of Africa and that the general combination of inorganic fertilizer, organic inputs, and other soil and land management practices is a strategy that may sustainably increase yields and yield response to inorganic fertilizer across the region over many seasons (Jayne and Rashid 2013; The Montpellier Panel 2014; FAO 2015).

Where it can cost-effectively improve farmer welfare or raise the BCRs of ISPs, the following policies could be carefully explored and analyzed as potential means of using ISPs to encourage greater use of SFM practices that are complementary to inorganic fertilizer: incorporating SFM practices into ISPs via extension efforts (e.g., trainings and demo plots); requiring use of one or more of a menu of SFM practices as a precondition for receiving the subsidies; offering larger percentage subsidies or greater quantities of subsidized inputs to farmers that use SFM practices; and encouraging intercropping or rotation with legumes by including legume seed in all ISP packs (as the Malawian government has done) (Dorward and Chirwa 2011). Zambia's nationwide shift to a flexible e-voucher approach in the 2017/2018 agricultural season may also encourage take-up of complementary SFM practices, as farmers can redeem the e-voucher for legume seed, for example. Providing direct cash payments to farmers' for investing in soil conservation has also been proposed (Marenya et al. 2014). Supporting the development of markets and supplies chains for and increased production of organic fertilizer is another policy option worth exploring. In general, policies designed to crowd in complementary SFM practices could boost governments' returns on their inorganic fertilizer investments, promote sustainable forms of agricultural intensification, and aid in the transformation of low productivity farms into those that can be profitably farmed for many years to come.

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