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Do changes in maize prices and input prices affect smallholder farmers' soil fertility management decisions? panel survey evidence from Kenya

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ABSTRACT

Soil fertility management (SFM) practices such as maize-legume intercropping and organic fertiliser, particularly when used jointly with inorganic fertiliser, have the potential to increase yields and yield response to inorganic fertiliser, improve soil health, and contribute to sustainable intensification (SI). However, relatively little is known about the drivers of adoption of these practices, especially for joint use. Moreover, it has been suggested that African farmers will respond to an increase in the maize price they expect to receive at the next harvest by increasing investment in their soils or altering use of SFM practices in response to input price changes. Yet previous studies largely ignore the role of prices. Using nationwide household panel survey data from Kenya, we estimate the effects of changes in crop and input prices on household use of individual SFM practices and combinations thereof. We find that Kenyan smallholders' SFM adoption decisions are largely insensitive to changes in expected maize prices. However, when inorganic fertiliser prices rise, farmers are more likely to use organic fertiliser and use less inorganic fertiliser per acre. These results suggest that price policies alone are unlikely to be effective ways to promote SI of maize production in Kenya.

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Soil fertility management; sustainable intensification; maize; smallholder farmers; Kenya; sub-Saharan Africa

1. Introduction

Many nations in sub-Saharan Africa (SSA), including Kenya, are experiencing challenges associated with soil nutrient losses and stagnant agricultural output growth (Jayne et al. 1993; Eicher 2009; Montpellier Panel 2013; NAAIAP 2014). In much of SSA, countries are net importers of food due to many factors, one of which is low agricultural productivity (Drechsel et al. 2001; van Ittersum et al. 2016). And while a number of factors undergird the production shortfall, soil fertility depletion has been identified as one of the major drivers (Sanchez and Logan 1992; Sanchez et al. 1997; Drechsel et al. 2001). Moreover, 3.3% of agricultural gross domestic product in SSA is lost each year due to soil degradation (Drechsel and Gyiele 1999; Montpellier Panel 2013). Soil fertility depletion has many drivers, including continuous cropping (Brams 1971; Vanlauwe and Giller 2006), lack of nutrient recycling (Bationo et al. 1995; Lal 1995; Marenya and Barrett 2009), and low use of organic and inorganic fertilisers (Oluoch-Kosura, Marenya, and Nzuma 2002).

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Sustainable intensification (SI) has been offered as a potential solution to the issues of declining soil fertility and low agricultural productivity in SSA (Royal Society 2009; Godfray et al. 2010; Pretty et al. 2011; Montpellier Panel 2013). SI is defined as a "process or system where yields are increased without adverse environmental impact and without the cultivation of more land" (Pretty and Bharucha 2014, p. 1578, and referencing Royal Society 2009).[1] It does not involve extensification or cultivation of newly cleared or fallowed land. SI is a guiding framework to inform which agricultural practices or combinations of technologies are sustainable (Garnett and Godfray 2012). SI of maize production is of specific interest in eastern and southern Africa, where maize is the leading staple food and is widely grown by smallholder farmers. The use of soil fertility management (SFM) practices on maize plots, such as organic and inorganic fertilisers, intercropping or rotating the maize with legumes, and crop residue retention and incorporation, among others, have the potential to contribute to SI in maize-based systems, particularly when inorganic fertiliser and other SFM practices are combined on the same plot (Bultena and Hoiberg 1983; Snapp et al. 2010; Montpellier Panel 2013; Mcdonahe, Lu, and Semalulu 2014). (Throughout this study, we use organic fertiliser to refer to animal manure and compost.) Understanding what factors encourage versus inhibit take-up of these practices by smallholder farmers in SSA is therefore of high policy relevance and importance.

Of particular interest in this study is the role of farmers' expectations about maize output prices in the SFM adoption process. Economic theory suggests that the maize price a farmer expects to receive at the next harvest is likely to be an important determinant of the farmer's adoption of SFM practices (and other input use and management decisions) on his/her maize plots.[2] Moreover, several recent reports posit that smallholders might respond to an increase in maize prices by investing in soil fertility-enhancing practices (e.g., Morris et al. 2007; Kassie et al. 2015; Montpellier Panel Report 2015). Yet there is very little empirical evidence to support or contradict this claim. In fact, while there is a growing literature on the drivers of adoption of SFM practices in SSA (e.g., Pretty et al. 2011; Kassie et al. 2013; Teklewold et al. 2013; Kamau et al. 2014; Manda et al. 2016; among others), very few studies (and none of the relevant studies we identified) include a farmer's expected maize price among the potential determinants of adoption of these practices.

Why might farmers be more willing or able to invest in sustainable intensification of their maize production in response to higher expected maize output prices (holding input prices and other output prices constant)? Farmers might do so because a higher maize price come harvest time could compensate for additional expenses incurred when implementing more sustainable practices (e.g., additional labour to collect and apply organic fertiliser rather than using inorganic fertiliser alone, or the cost of legume seed and more time-consuming crop management and harvesting when growing maize in an intercrop with legumes instead of as sole-cropped maize). Higher maize prices could potentially compensate for reduced maize revenue if the farmer switches from growing sole-cropped maize to intercropping maize with legumes. Higher expected maize prices might also give farmers an incentive to invest in livestock so that they can generate more manure for applying to their fields, or incentivize them to make soil fertility investments, the benefits of which may not manifest for several years. In general, an increase in the expected maize output price would likely increase farmers' expected profitability of adoption of SFM practices. On the other hand, if maize producers are maize net buyers (as many smallholders are), higher expected maize purchase prices during the next lean season might incentivize them to increase their maize output to reduce the amount of maize they have to purchase from the market. In addition, while not something we can rigorously analyze here due to lack of data, higher maize output prices obtained by farmers from sales in the *previous* season could give them additional cash that could be used to obtain the inputs (including additional labour) that are needed for SI of their maize production; this would be particularly important if there are liquidity or credit constraints to adoption. For net maize buyer households, however, higher maize purchase prices in the previous year might have reduced their cash on hand to invest in SI of their maize production in the subsequent year. Overall, whether and to what extent changes in expected maize prices affect farmers' SFM and SI adoption decisions is an empirical question.

Of secondary interest in this study is the role of input prices in the adoption process – specifically the prices of inorganic fertiliser and maize and legume seeds, agricultural wage rates, and land rental prices. While economic theory also suggests that input prices are likely to be important determinants of adoption of SFM practices, these prices, like maize prices, are infrequently included in the existing SFM determinants literature for SSA. Excluding expected output prices or input prices may lead to omitted variables bias and inaccurate estimates. A handful of SFM adoption-related studies do include one or more input prices. For example, Kamau et al. (2014) find that an increase in the inorganic fertiliser price is associated with reductions in the likelihood of inorganic fertiliser application and in the use of other soil amendments (as a broad group) among Kenyan smallholders. Holden and Lunduka (2012) similarly find that in Malawi, inorganic fertiliser use decreases as its price increases, but that organic fertiliser use increases with a rise in the inorganic fertiliser price. Most recently, Kopper and Jayne (2019), who study Kenyan smallholders' total area cultivated and nitrogen use decisions, find that households in different agro-ecological potential and market access regions behave differently in response to changes in input price ratios. For example, households in low agro-ecological potential zones cultivate less land and apply more fertiliser in response to higher land rental prices; area cultivated decisions by households in high potential zones are not influenced by changes in input prices, but such households use more fertiliser in response to higher land rental prices and lower fertiliser prices. Kopper and Jayne (2019) also generally find that farmers' area cultivated and fertiliser use decisions are not influenced by changes in lagged harvest-period wholesale maize prices. We move beyond this analysis by considering: (i) not only inorganic fertiliser use but also organic fertiliser use and maize-legume intercropping (individually and in combination); and (ii) alternative assumptions about how farmers form their maize price expectations (not just naïve expectations, as was assumed by Kopper and Jayne (2019)). Most other studies on SFM adoption in SSA omit expected output prices and input prices in their analyses. More research is therefore needed to understand how these prices affect households' adoption decisions.

In this paper we focus on the case of smallholder farm households in Kenya and use nationwide household panel survey data and econometric methods that control for time invariant heterogeneity to empirically estimate how changes in a household's expected maize output price and changes in various input prices affect their adoption of inorganic fertiliser, organic fertiliser, and maize-legume intercropping.[3] In addition to separately analyzing the determinants of households' use of each of these three practices, we also analyze their use of combinations of the practices. Joint use of inorganic fertiliser with at least one of the other practices is of particular importance for SI of maize production. There are eight possible combinations of the three practices (see the first four columns of Table 1). We follow Kim et al. (2019) and categorise the different combinations of SFM practices by the extent to which they can contribute to SI in maize-based systems; we refer to these as "SI categories". Per Kim et al., organic fertiliser and maize-legume intercropping are each considered a "Sustainable" practice and inorganic fertiliser is considered an "Intensification" practice. The combined use of at least one sustainable practice plus inorganic fertiliser on the same maize plot is considered to be a form of SI. A contribution of this paper is that we go beyond Kim et al. (2019) and distinguish between "Weak SI" and "Strong SI" combinations of SFM practices, where the former is inorganic fertiliser combined with *either* organic fertiliser *or* maize-legume intercropping, and the latter is the combination of *all three* practices. (See column 7 in Table 1.)

Organic fertiliser and maize-legume intercropping are classified as sustainable practices because they can be done individually over time with fewer negative effects on soil health relative to sole-cropped maize or maize plots without organic fertiliser (Dahmardeh et al. 2010). Indeed, when

Table 1. SFM practice combinations on maize plots, SI category designation, and prevalence in Kenya.

(1) Case	(2) Inorganic fertiliser?	(3) Organic fertiliser?	(4) Maize-legume intercrop?	(5) Number of maize plots	(6) Percent of maize plots	(7) SI category	(8) Percent of maize plots by SI category (including the "None" category)	(9) Percent of maize plots by SI category (excluding the "None" category)
1	No	No	No	37	2.2%	None	2.2%	N/A
2	Yes	No	No	226	13.6%	Intensification	13.6%	13.9%
3	No	Yes	No	52	3.1%	Sustainable	15.5%	15.8%
4	No	No	Yes	83	5.0%			
5	No	Yes	Yes	123	7.4%			
6	Yes	Yes	No	109	6.5%	Weak SI	50.5%	51.7%
7	Yes	No	Yes	733	44.0%			
8	Yes	Yes	Yes	304	18.2%	Strong SI	18.2%	18.7%
Total number of maize plots with:								
Maize-legume intercropping				1,243	74.6%			
Inorganic fertiliser				1,372	82.3%			
Organic fertiliser				588	35.3%			

Source: Authors' calculations. See text for details on data sources.
Notes: Figures are based on all maize plots cultivated by balanced panel maize-growing households in the 2007 and 2010 waves of the TAPRA household panel survey. N=1,667 maize plots, of which 862 are for 2007 and 805 are for 2010.

applied appropriately, these practices can contribute to increased soil fertility (Snaginga and Woomer 2009). On the other hand, the application of inorganic fertiliser alone over time without any sustainable practice can result in soil acidification (and is thus referred to as Intensification in our categorisation, and not a form of SI). Soil acidification is particularly common with the application of DAP and CAN fertilisers due to their high content of ammonia. However, when inorganic fertiliser is combined with a sustainable practice, soil health may be maintained or even improve (Dutta et al. 2003; Kaur, Kapoor, and Gupta 2005; Chand, Anwar, and Patra 2006; Chen 2006; Snaginga and Woomer 2009).[4]

Kenya is a relevant case study because, like in much of the region, maize is the main staple food crop and many households are affected by soil degradation. To our knowledge, this is the first study to empirically test whether farmers respond to increases in their expected output maize price by adopting more sustainable forms of maize intensification. The study also adds to the thin literature on the role of changes in input prices in African farmers' use of SFM practices.

The remainder of the paper is organised as follows. In section 2, we provide additional information on the SFM practices analyzed in the paper and their contributions to soil fertility. The data are discussed in section 3, the methods are described in section 4, the results are presented in section 5, and conclusions and policy implications are drawn in section 6.

2. SFM practices analyzed

Intercropping maize with legumes can benefit the soil and the household in several ways. First, the legumes fix nitrogen, which adds to the soil's pool of nitrogen. This pool of nitrogen provides the maize with a supply of the element; the other main external source of nitrogen is the application of chemical fertiliser. Intercropping maize and legumes reduces the maize's requirements for nitrogen fertilisers (Zentner et al. 2001, 2004). Maize-legume intercropping has also been found to decrease disease, insects (Caswell and Raheja 1972; Power 1988; Skovgård and Päts 1997), and weeds (Steiner 1982) relative to sole-cropped maize. The legumes can produce a large quantity of plant material, which increases soil fertility and soil organic matter (SOM), especially when it is integrated into the soil after harvest (Liebman and Dyck 1993; Snapp et al. 2010, Berazneva et al. 2019). In addition, the legumes themselves can provide additional nutrients and calories to the farm household (Kassie et al. 2013).

The application of organic fertiliser in the form of animal manure or compost also increases SOM (Vanlauwe 2004). Organic fertiliser can be a complement to inorganic fertiliser, increasing its effectiveness (Shapiro and Sanders 1998; Juma et al. 1999; Place et al. 2002); however, some households use organic fertiliser as a substitute for inorganic fertiliser. Manure also increases the levels of nitrogen, phosphorous, and potassium in the soil, all of which are important to the development of plants (Gutser et al. 2005). Inorganic fertiliser adds these elements to the soil for plant use as well (Sanchez et al. 1997; Marenya and Barrett 2007). However, inorganic fertiliser application alone can damage soils in the following ways when not used appropriately: water pollution, destruction of micro-organisms, damage to plant tissues, and soil acidification (Lungu and Dynoodt 2008; Schröder et al. 2011; Savci 2012). High soil acidity reduces crop response to inorganic fertilisers (Wong et al. 1995). Soil acidification is of particular concern in Kenya due to the continuous use of inorganic fertiliser. In fact, a recent report suggests that nearly every county in Kenya has soil acidity challenges, with average pH levels below the ideal level for maize production (NAAIAP 2014). One soil additive that can reduce soil acidity is lime (Haynes 1984); however, no households in our sample report using lime. In addition to lime, the application of cattle manure can also counter soil acidification (Whalen et al. 2000).

The potential of organic fertiliser and maize-legume intercropping to help build SOM is important in the Kenyan context because SOM levels are low in much of country. In fact, average SOM levels are below the ideal level for maize in all counties in the country (NAAIAP 2014).

3. Data

The data come primarily from the Tegemeo Institute of Agricultural Policy and Development's Tegemeo Agricultural Policy Research and Analysis (TAPRA) household panel surveys. The TAPRA data are a five-wave panel; however, our analysis uses only the final two waves (2007 and 2010) because some important variables for the analysis were not collected in earlier waves of the survey.

The TAPRA surveys aimed to provide nationwide data on agricultural household activities, including plot level management practices, harvest data, agricultural input and output prices, household assets, and other household information. Of the original 1,540 households, 1,500 were in districts that were targeted for re-interview after the 2000 wave. Of these 1,500 households, 1,308 are present in the fourth (2007) wave and 1,275 in the final (2010) wave.

The starting point for our analytical sample is the 1,275 panel household observations for both the 2007 and 2010 TAPRA surveys (2,550 household-year observations). Almost all of these households cultivate maize; however, there are 35 households (21 in 2007 and 14 in 2010) that do not. We have removed these households from our analytical sample. Further narrowing of the analytical sample is done by restricting the definition of a maize plot, as our focus here is on farmers' use of SFM practices on their maize plots. We follow Sheahan et al. (2013) and define a maize plot as one that: (1) has maize cultivated on it; (2) has no more than six distinct crops grown on the plot; and (3) where maize is not intercropped with a cash crop (the assumption here being that the cash crop, not the maize, is the main crop on the plot). This narrows our analytical sample down to 1,296 households-year observations with 648 in 2007 and 648 in 2010 for the balanced panel. These households cultivate a total of 1,667 maize plots (as defined above), with 862 in 2007 and 805 in 2010.

In addition to the TAPRA data, we use ten-square kilometre (km) resolution rainfall data from the CGIAR Climate Research Unit (CRU), merged in at the village level (Hijmans et al. 2005). We also include as control variables in an auxiliary regression (discussed below) variables related to the quantity of maize purchased by and the maize price paid to farmers by the National Cereals and Produce Board (NCPB), Kenya's maize marketing board. These data are at the division level and were obtained from the NCPB.

Regarding data on the SFM practices analyzed here, the TAPRA survey includes animal manure and compost as individual practices; however, we group these together as organic fertiliser. Of the 588 total maize plots in our analytical sample with organic fertiliser applied, 563 had manure

Table 2. SI categories, rankings, and prevalence among maize-growing households in Kenya.

SI category	SI ranking	Number of household-year observations	Percent of household-year observations (all SI categories)	Percent of household-year observations (excluding the "None" SI category)
None	0	19	1.5%	N/A
Intensification	1	149	11.5%	11.7%
Sustainable	2	170	13.1%	13.3%
Weak SI	3	695	53.6%	54.4%
Strong SI	4	263	20.3%	20.6%
Total number of household-year observations using:				
Maize-legume intercropping		1,077	83.1%	N/A
Inorganic fertiliser		1,101	85.0%	N/A
Organic fertiliser		528	40.7%	N/A

Source: Authors' calculations. See text for details on data sources.
Notes: Figures are based on the balanced panel of households with maize plots in the 2007 and 2010 waves of the TAPRA household panel survey. N=1,296 maize-growing household-year observations (648 in 2007 and 648 in 2010).

and 28 had compost (three plots had both manure and compost applied). At the household level, 508 (39.2%) of the 1,296 total households used manure on maize, and 24 (1.9%) used compost. Overall, organic fertiliser is applied on 35.3% of the maize plots (Table 1) and used by 40.7% of the households in the analytical sample (Table 2). For the practice of maize-legume intercropping, the legume crops that are intercropped with maize by sample farmers are: common beans, cowpeas, pigeon peas, groundnuts, green grams, and soybeans. A breakdown of their individual prevalence as an intercropped legume with maize is shown in table A1 in the Supplemental Online Appendix. Overall, 74.6% of maize plots in the analytical sample are maize-legume intercrops (Table 1), while 83.1% of households use the practice (Table 2). Inorganic fertiliser is applied to 82.3% of maize plots (Table 1) and used by 85.0% of the households in the sample (Table 2).[5]

Table 1 also shows the prevalence of the various "SI categories" at the maize plot level (None, Intensification, Sustainable, Weak SI, and Strong SI). Weak SI is the most common category in our sample, with 50.5% of all maize plots falling in this category. Strong SI is the second most common category at 18.2% of all maize plots, followed by Sustainable at 15.5% and Intensification at 13.6%.

The analysis in this paper is conducted at the household level, not the plot level, due to a lack of adequate plot-level control variables. One of the models we seek to estimate is a multinomial logit model of the household's SI category; we use the plot-level SI category information to construct a household-level SI category variable. We determine a household's SI category based on the proportion of maize area it devotes to each SI category; the household-level SI category is then the SI category that accounts for the highest share of total maize area. Of the households in our analytical sample, 74.4% have only one maize plot. For households with multiple maize plots, in the case of a tie between two SI categories as having the largest proportion of a household's maize area, we follow Kim et al. (2019) and assign the household to the SI category with the higher "SI ranking". See Table 2 for the prevalence of the various SI categories at the household level as well as the SI rankings, which are based on Kim et al. (2019); this is the only way in which the SI rankings are used in this paper. Kim et al. (2019) base the SI rankings on the degree to which each SI category is likely to contribute to SI in maize-based systems. Finally, due to the low percentage of households in the "None" SI category (1.5%), we exclude these households from the analysis. Of the remaining households in the analytical sample, 11.7% are in the Intensification category, 13.3% in Sustainable, 54.4% in Weak SI, and 20.6% in Strong SI (Table 2).

4. Empirical strategy

Building on Kamau, Smale, and Mutua (2014), we consider a household's demand for SFM practices (***SFM****) to be a function of the household's landholding size (*A*), labour endowment (*L*), off-farm income (O), agricultural input prices ($\boldsymbol{w}$), expected crop output prices ($\boldsymbol{P^e}$), household ($\boldsymbol{Z_h}$)and market ($\boldsymbol{Z_m}$) characteristics, and agro-ecological conditions ($\boldsymbol{S}$):

$$\boldsymbol{SFM}^* = \boldsymbol{SFM}^* \, (A, \; L, O, \boldsymbol{w}, \; \boldsymbol{P^e}, \; \boldsymbol{Z_h}, \; \boldsymbol{Z_m}, \; \boldsymbol{S}) \tag{1}$$

Empirical models corresponding to equation 1 are what we seek to estimate. However, because expected crop prices are not observable, we need to make some additional assumptions about farmers' price expectations in order to specify our empirical models. In this study, the main expected crop price of interest is that for maize. We consider four alternative maize price expectations assumptions. The first is a quasi-rational expectations-like approach (Nerlove and Fornari 1998), following Mason et al. (2015) and Mather and Jayne (2011). In this approach, a farmer's expected maize price is modelled as the *predicted* price they will receive at harvest time as a function of information plausibly known by the farmer at the time that SFM decisions are made. This approach is described in detail in section 4.1. The three other alternative assumptions made with regard to a household's expected maize price are: (i) naïve expectations (i.e., that farmers assume that the maize output price at the upcoming harvest will be the same as the price during the last harvest); (ii) perfect foresight (i.e., that a farmer's expected maize output price is equal to the maize output price that ultimately prevails at harvest time); and (iii) that the maize price that ultimately matters is the expected maize purchase price during the lean season. The latter may be particularly salient given that many Kenyan smallholder households are net buyers of maize. For example, Kirimi et al. (2011) estimate that in 2007 (the first year in our period of analysis), 42.8% of Kenyan smallholder households were maize net buyers, 43.2% were maize net sellers, and 14.0% were autarkic with respect to maize. Expected output prices for other crops are not of central interest here and so, for tractability, we assume naïve expectations for these prices.

4.1 Estimating a household's expected maize output price using a quasi-rational expectations-like approach

4.1.1 Model specification

To implement this approach, we first estimate the following regression using observations for households that sold maize:

$$P^m_{i,t} = \beta_0 + \boldsymbol{w_{v,\,t}\beta}_1 + \beta_2 P^m_{r,t-1} + \boldsymbol{NCPB_{d,\,t-1}\beta}_3 + \boldsymbol{Z_{h,i,\,t}\beta}_4 + \boldsymbol{Z_{m,v,\,t}\beta}_5 + \boldsymbol{S}_{\,v,t}\boldsymbol{\beta}_6 + c_i + \varepsilon_{i,\,t} \tag{2}$$

where P^m_{it} is household i's observed maize sale price at harvest time in agricultural year t; the β's are parameters to be estimated; c_i is time-constant unobserved heterogeneity; and $\varepsilon_{i,t}$ is the time-varying error term for the household. d indexes the division, r indexes the region, and v indexes the village. All right hand side variables in equation 2 (excluding the error terms) are assumed to be known by the household at the time SFM decisions are made and may affect the maize price they expect to receive at the upcoming harvest. $\boldsymbol{w}$ is a vector of input prices in agricultural year t. $P^m_{r,t-1}$ is the average wholesale maize price in the household's region during the last plentiful season, which we define as the three months after the last main season harvest. (This is also the price we use as a proxy for a farmer's expected maize price when we assume naïve expectations; farm-level maize output prices are not available for the previous harvest.) $\boldsymbol{Z_h}$ and $\boldsymbol{Z_m}$ are vectors of household characteristics and non-price market factors, respectively. See Table 3 for details on the specific variables included in $\boldsymbol{w}$ and the two $\boldsymbol{Z}$ vectors, as well as summary statistics for all variables included in equation 2. $\boldsymbol{S_{v,t}}$ captures lagged rainfall conditions (6-year moving averages in the household's village) to proxy for the household's anticipated weather conditions in season t; it also includes a vector of agro-ecological zone indicator variables and a variable controlling for rainfall stress. Rainfall stress is defined as the fraction of 20-day periods in the main season with less than 40 mm of rainfall. The vector $\boldsymbol{NCPB}_{d,\,t-1}$ contains the lagged (previous harvest) division-level quantity of maize purchased by the NCPB and the lagged NCPB pan-territorial maize purchase price

Table 3. Summary statistics of variables included in the maize price regression.

Variables	Mean	Std. Dev
Dependent variable		
Maize price received by household (real 2010 Ksh/kg)	19.323	3.843
Explanatory variables		
Maize seed price (real 2010 Ksh/kg, village median)	71.032	36.299
Inorganic fertiliser price (real 2010 Ksh/kg, village median for DAP)	56.730	4.235
Farm wage (real 2010 Ksh/hour, village median)	20.631	5.768
Land rental price (real 2010 Ksh/acre/year, village median)	4,553.334	1,657.405
Plentiful season avg. wholesale price of maize (t-1, real 2010 Ksh/kg)	28.333	4.511
Farmgate NCPB maize price (t-1, real 2010 Ksh/kg)	15.395	6.03
NCPB purchases of maize at division level (MT, t-1)	39.700	106.019
=1 if female headed	0.189	
Age of the HH head (years)	57.728	13.516
=1 if lower primary was the HH head's highest level of education	0.075	
=1 if upper primary was the HH head's highest level of education	0.407	
=1 if secondary was the HH head's highest level of education	0.267	
=1 if post-secondary was the HH head's highest level of education	0.096	
Number of prime age adults (age 15–59)	3.401	1.856
Total landholdings owned as of prior survey (acres)	10.624	22.523
Value of productive assets as of prior survey (1000 s of real 2010 Ksh)	0.343	3.314
Tropical Livestock Units owned as of one year ago	5.082	7.515
=1 if the household had a car, truck, or motorcycle in the prior survey	0.060	
=1 if the HH had a cart in the prior survey	0.076	
=1 if the HH had a bike in the prior survey	0.558	
=1 if the HH had stores in the prior survey	0.522	
Km to the nearest market place for farm produce	4.787	4.288
Km to the nearest motorable road	0.541	1.117
Km to the nearest fertiliser seller	3.763	3.279
Km to the nearest place to get extension advice	5.318	5.608
Average rainfall in prior six main cropping seasons (mm)	605.441	157.808
Average rainfall stress in prior six main cropping seasons	0.247	0.182
=1 if year is 2010	0.410	

Source: Authors' calculations. See text for details on data sources.

Notes: N=615 (sample households that sold maize). Tropical Livestock Units are defined as: cattle = 0.7, sheep & goats = 0.1, pigs = 0.2, chickens = 0.01, rabbits = 0.01. Agro-ecological zone dummies are omitted from this table but are included in the regression. In cases where values as of the previous survey are used, it is because the survey instrument captured values as of the time of interview for those questions, which would have been after SFM decisions were made. We use values as of the previous survey wave to ensure that these values are pre-determined at the time that SFM decisions were made.

adjusted for transportation costs from the household's village to the nearest NCPB depot. We include these NCPB variables in the model because prior studies have shown that maize marketing boards' administratively determined prices or maize marketing activities can affect maize market prices and/or smallholder farmers' maize price expectations (Jayne, Myers and Nyoro 2008; Mather and Jayne 2011; Mason and Myers 2013; Mason et al. 2015).

Equation 3 is a simplified version of equation 2 to facilitate the following discussion.

$$p^{m}_{i,t} = \Omega_{\boldsymbol{g},\boldsymbol{t}-1}\boldsymbol{\beta} + c_i + \varepsilon_{i,\,t} \qquad (3)$$

In equation 3, $\boldsymbol{\beta}$ is the vector of parameters to be estimated and $\Omega_{\boldsymbol{g},\boldsymbol{t}-1}$ is a composite vector of all of the explanatory variables in equation 2, where g is the level at which the data are defined (i.e., d, v, r, and i) and the *t-1* subscript here should be interpreted as signifying that all variables are realised at or before the time SFM decisions are made.

4.1.2 Estimation

To estimate equation 3 while controlling for potential correlation between c_i and the observed covariates, we use Mundlak-Chamberlain correlated random effects pooled ordinary least squares (CRE-POLS). The data used to estimate equation 3 are from sample households that sold maize because it is only for these households that we observe the maize price received at harvest time. Note, however, that all of the right hand side variables are observed for all households in our sample, not just those that ultimately sold maize; we leverage this as described below – with an appropriate test for selection bias – to obtain a predicted maize sale price for all households in the sample.

In order to obtain consistent estimates via the CRE approach, we must make the assumption of strict exogeneity of the covariates in the maize price regression ($\Omega_{g,t-1}$)conditional on the unobserved heterogeneity (c_i). In addition, we must assume that $c_i = \psi + \bar{\Omega}_g \xi + a_i$ and $c_i|\Omega_g \sim Normal(\psi + \bar{\Omega}_g \xi, \sigma_a^2)$, where $\bar{\Omega}_g$ is the average of the Ω_g variables for each household across the two survey years and σ_a^2 is the variance of a_i. Under these assumptions, we can control for c_i by including the means of the explanatory variables as additional regressors in equation 3 (Mundlak 1978; Chamberlain 1984; Wooldridge 2010). The main benefit of using CRE over fixed effects (FE) is that CRE allows us to use all observations of maize sales, whereas FE would only use observations for households that sold maize in both of our panel survey years (2007 and 2010).

Once equation 3 is estimated, we can use it to generate a predicted maize price $\widehat{p_{i,t}^{md}}$ for *all* households in the analytical sample, not just those that sold maize:

$$\widehat{p_{i,t}^{m}} = \Omega_{g,t-1}\hat{\beta} + \widehat{c_i} \text{ (computed for all households in the sample)} \quad (4)$$

This is possible because the values of the observed explanatory variables on the right hand side of equations 2 through 4 are known for both maize sellers and non-sellers. This predicted price, which we refer to as the household's "quasi-rational expectations maize price" for shorthand, in then used in the main SFM adoption regressions (described below).

4.1.3 Incidental truncation

A challenge that we face in estimating equation 3 is that only 47.5% of households in our sample sold maize. Our approach leads to the possibility that the estimates of the parameters in equation 3 and used in equation 4 could be biased if the households that sold maize are non-randomly different in unobserved, time-varying ways from those that did not sell maize. We test for such selection bias due to incidental truncation following Procedure 17.3 in Wooldridge (2010, p. 572). Incidental truncation here refers to the fact that we only observe the maize price received for maize sellers. Because we have data on the quantity of maize sold by sellers (as opposed to only knowing whether or not they sold maize), this procedure entails estimating a Tobit selection equation (rather than a probit selection equation as in a Heckman selection model). More specifically, to implement Wooldridge's Procedure 17.3, we first estimate a CRE-Tobit regression in which the dependent variable is the kg of maize sold by the household (which is a positive value for sellers and zero for non-sellers) and the explanatory variables are the same as in the main maize price regression (equation 3). The Tobit residuals (call them $\widehat{u_{i,t}}$) are then included as an additional regressor in the maize price regression as shown in equation 5.[6] A t-test of the residuals tests the null hypothesis of no selection bias against the alternative of selection bias. Standard errors as bootstrapped to account for the two-stage estimation.

$$p_{i,t}^{m} = \Omega_{g,t-1}\beta + \alpha \widehat{u_{i,t}} + c_i + \varepsilon_{i,t} \quad (5)$$

The benefit of using a Tobit selection equation (Wooldridge 2010 – Procedure 17.3) instead of a probit selection equation is that we achieve identification in equation (5) without the need for an exclusion restriction. This is because there is variation in the kg of maize sold that is separate from variation in the observed covariates ($\Omega_{g,t-1}$). If we were to use a Heckman selection model and did not have a valid exclusion restriction, identification would hinge (tenuously) on the nonlinearity of the inverse Mills ratio (Wooldridge 2010). For further details on Procedure 17.3, see Wooldridge (2010, pp. 571-572).

4.2 Estimating the effects of expected maize prices, input prices, and other factors on SFM adoption

4.2.1 Model specifications

To estimate the effects of a maize grower's (estimated or proxied) expected maize price, input prices, and other factors on their SFM adoption decisions, we bring equation 1 to the data and specify the following general empirical model:

$$SFM_{i,t} = \gamma_1 \widehat{P_{i,t}^{m,e}} + \gamma_2 P_{i,t-1}^{o} + \gamma_3 A_{i,t} + \gamma_4 L_{i,t} + \gamma_5 O_{i,t} + \boldsymbol{w_{v,t}}\boldsymbol{\gamma_6} + \boldsymbol{Z_{h,i,t}}\boldsymbol{\gamma_7} + \boldsymbol{Z_{m,v,\,t}}\,\boldsymbol{\gamma_8} + \boldsymbol{S_{v,t}}\boldsymbol{\gamma_9} + c_i + \varepsilon_{i,\,t} \quad (6)$$

$$SFM_{i,t} = \boldsymbol{D_g}\boldsymbol{\gamma} + c_i + \varepsilon_{i,t} \quad (7)$$

Equation 7 is a more compact representation of equation 6, and $\boldsymbol{D_g}$ and $\boldsymbol{\gamma}$ capture, respectively, all the explanatory variables and parameters in equation 6. *SFM* represents the dependent variable of interest, which is either: (i) a binary variable equal to one if a given SFM practice was used by household *i* in the main season of agricultural year *t* (and equal to zero otherwise); (ii) the household's SI category in that agricultural year; or (iii) the household's intensity of inorganic fertiliser use on maize (in kg/acre). (The particular estimators used in each case are discussed below.) A household's proxied or estimated expected maize price is denoted by $\widehat{P_{i,t}^{m,e}}$. When we assume quasi-rational expectations, $\widehat{p_{i,t}^{m}}$ is used (obtained via the method described in sub-section 4.1). Note that standard errors are bootstrapped in this case to account for the fact that $\widehat{p_{i,t}^{m}}$ is a generated regressor (i.e., it is not an observed value, but a value that is estimated via the approach described in section 4.1). When we assume naïve expectations, we use the lagged regional wholesale maize price during the plentiful season. When we assume perfect foresight, we use the maize price received by sellers for households that ultimately sold maize at the next harvest, and the district median price received by sellers for households that did not ultimately sell maize at the next harvest. The fourth proxy used for $\widehat{P_{i,t}^{m,e}}$ is the district median maize purchase price during the most recent lean season.

$P_{i,t-1}^{o}$ denotes the lagged bean price. We chose the bean price because it is by far the most commonly used legume in maize-legume intercrops in Kenya (see table A1 in the Supplemental Online Appendix). A_t is the household's landholding size. $L_{i,t}$ is the household's labour endowment. $O_{i,t,}$ is an indicator variable for whether the household had off-farm income in the previous survey. $\boldsymbol{w_{v,t}}$ is a vector of input prices (for inorganic fertiliser, maize seed, bean seed, agricultural labour, and land rental). In addition to estimating models like equation (6) where prices enter in levels, we estimate a second set of models in which we instead use price ratios, with all input prices and the lagged bean price being relative to the proxied/estimated expected maize price. This is done because farmers might consider input:output price ratios (and bean:maize output price ratios) more than price levels when making input use and management practice decisions.

$\boldsymbol{Z_{h,i,t}}$ is a vector of household characteristics including the sex, age, and education of the household head and the household's productive assets. In addition, $\boldsymbol{Z_{h,i,t}}$ captures the proportion of the household's maize land under various tenure arrangements with the base being rented-in land, and other tenure types being family-owned land, land owned without a deed, and land owned with a deed. $\boldsymbol{Z_{m,v,\,t}}$ is a vector of non-price market characteristics, such as distances to the nearest market, nearest extension service, road, and NCPB depot, among others. $\boldsymbol{Z_{m,v,\,t}}$ also includes the mean tropical livestock units (TLUs) owned by households in household *i*'s village in the prior season; this variable is used as a proxy for the availability of animal manure in the village. $\boldsymbol{S_{v,t}}$ is as defined in section 4.1.1. See Table 4 for a full listing and summary statistics for the explanatory and dependent variables used in the SFM regressions.

Table 4. Summary statistics for variables used in the SFM adoption regressions.

Dependent variables	Mean	Std. Dev.
= 1 if the HH used inorganic fertiliser on any maize plot	0.850	
= 1 if the HH used organic fertiliser on any maize plot	0.407	
= 1 if the HH intercropped maize and legumes	0.831	
HH's intensity of inorganic fertiliser use on maize (kg/acre)	62.778	56.467
= 1 if the HH is in the "None" category (not used in regressions)	0.015	
= 1 if the HH is in the "Intensification" category	0.115	
= 1 if the HH is in the "Sustainable" category	0.131	
= 1 if the HH is in the "Weak SI" category	0.536	
= 1 if the HH is in the "Strong SI" category	0.203	
Explanatory variables	**Mean**	**Std. Dev.**
Maize output prices (only one used per model specification)		
Quasi-rational expectations: Predicted maize output price (real 2010 Ksh/kg)	19.370	2.121
Naïve expectations: Plentiful season average wholesale price of maize (t-1, real 2010 Ksh/kg)	27.954	4.781
Perfect foresight: Maize producer price received among sellers, and district median price among non-sellers (real 2010 Ksh/kg)	19.973	3.019
Lean season maize purchase price (real 2010 Ksh/kg, district median)	26.854	13.231
Bean output price (real 2010 Ksh/kg, village median)	34.595	17.402
Maize seed price (real 2010 Ksh/kg, village median)	68.064	37.121
Bean seed price (real 2010 Ksh/kg, village median)	10.787	8.240
Inorganic fertiliser price (real 2010 Ksh/kg, village median for DAP)	57.459	5.243
Farm wage (real 2010 Ksh/hour, village median)	20.629	5.536
Land rental price (real 2010 Ksh/acre/year, village median)	4,357.388	1,732.422
Total landholdings owned as of previous survey (acres)	7.831	16.369
Number of prime age adults (age 15–59)	3.200	1.839
=1 if the HH had off farm income in the previous survey	0.848	
=1 if female headed	0.218	
Age of the HH head (years)	58.710	13.261
=1 if lower primary was the HH head's highest level of education	0.087	
=1 if upper primary was the HH head's highest level of education	0.426	
=1 if secondary was the HH head's highest level of education	0.231	
=1 if post-secondary was the HH head's highest level of education	0.080	
Value of productive assets as of previous survey (1000 s of real 2010 Ksh)	0.228	2.326
TLUs owned as of one year ago	4.116	8.424
HH's proportion of maize land that is family owned	0.020	0.134
HH's proportion of maize land that is owned with a deed	0.526	0.486
HH's proportion of maize land that is owned without a deed	0.338	0.459
Km to the nearest NCPB depot	19.646	14.551
Km to the nearest fertiliser seller	3.410	3.239
Km to the nearest market place for farm produce	4.296	4.184
Km to the nearest motorable road	0.446	0.892
Km to the nearest place to get extension advice	5.132	4.967
Village-level proportion of HHs that received credit	0.537	0.264
Village-level average TLUs per acre in prior survey	0.613	0.340
Average rainfall in prior six main cropping seasons (mm)	572.539	181.159
Average rainfall stress in prior six main cropping seasons	0.283	0.204
=1 if year is 2010	0.500	

Source: Authors' calculations. See text for details on data sources.

Notes: N=1,296. Tropical Livestock Units (TLUs) are defined as: cattle = 0.7, sheep & goats = 0.1, pigs = 0.2, chickens = 0.01, rabbits = 0.01. Agro-ecological zone dummies are omitted from this table but are included all regressions. In cases where values as of the previous survey are used, it is because the survey instrument captured values as of the time of interview for those questions, which would have been after SFM decisions were made. We use values as of the previous survey wave to ensure that these values are pre-determined at the time that SFM decisions were made.

4.2.2 Estimation

For models in which a binary variable for a given SFM practice is the dependent variable, estimation is via CRE-logit, practice by practice. For models in which the outcome variable is the household's SI category (SFM practice combinations), estimation is via CRE-multinomial logit. And for the model in which the household's intensity of inorganic fertiliser use on maize is the dependent variable, estimation is via CRE-Tobit. (See Supplemental Online Appendix B for additional estimation details.) In each case, we report average partial effects (APEs) instead of coefficients to facilitate interpretation. We rely on the CRE approach for identification in the SFM adoption models. This approach (if its assumptions hold) controls for correlation between the explanatory variables and time-constant unobserved heterogeneity and is compatible with nonlinear in parameters models like logit, Tobit, and multinomial logit. However, if the explanatory variables are correlated with the idiosyncratic error term ($\varepsilon_{i,\,t}$), then our results cannot be interpreted as causal effects. We thus refer to our results as correlations or associations below. Finally, in addition to the two sets of models described above (price levels vs. price ratios with the expected maize price in the denominator), we also estimate as robustness checks a parsimonious specification of each model in which only the price-related variables and a year dummy are included.

5. Results

We begin by discussing the results of the regressions used to estimate a household's quasi-rational expectations maize price. We then discuss the results of the SFM practice and SI adoption decision regressions, with a focus on the results for the estimated/proxied expected maize price and other price-related explanatory variables.

5.1 Quasi-rational expected maize price regression results

These results are reported in Table 5. There are three specifications: column A is the main specification as described in sections 4.1.1-4.1.2; column B is a robustness check that excludes household characteristics; and column C is the main specification plus the Tobit residuals to test and control for possible selection bias due to incidental truncation as discussed in section 4.1.3. The results in all three columns are quite similar. The Tobit residuals are not statistically significant in column C (p=0.799), indicating that we fail to reject the null hypothesis of no selection bias. Given these results, we use the parameter estimates from the main specification (column A) when computing each household's estimated quasi-rational expectations maize output price (following the approach described in section 4.1.2).

One finding of interest in Table 5 is that a one Kenyan Shilling (Ksh) increase in the lagged NCPB maize price is associated with a 0.12 Ksh average increase in the maize price the household receives at harvest (column A), *ceteris paribus*. This positive association is consistent with *a priori* expectations and with previous findings in the literature on the NCPB (e.g., Jayne, Myers, and Nyoro (2008) and Mather and Jayne (2011)).

The extent to which the other statistically significant determinants of a household's maize price at harvest conform to *a priori* expectations is more variable (see Table 5). Households in areas with higher average rainfall over the last six main cropping seasons generally receive a lower maize price at the next harvest, which may be due to higher maize supplies in such areas. But areas with more rainfall stress periods over the last six main cropping seasons also get lower maize prices, on average, at the next harvest; more research is needed to understand this result. Households with more land receive a lower maize price, on average; while we initially expected this effect to be positive, the negative effect of landholding on the maize price received may be explained by maize production levels in general being higher in areas where households have larger landholdings, which would be expected to put downward pressure on maize prices. Finally, while one might expect households with a bicycle to be able to fetch a higher price for their maize, we find statistically weak evidence of the opposite. If our other distance variables do not adequately capture market access, the negative coefficient on bike ownership in column A might simply reflect that such households are in more remote areas and need a bike to reach markets.

Table 5. Maize price regression results (CRE-POLS results).

Dependent variable: Maize price received at harvest (real 2010 Ksh/Kg)	(A)			(B)			(C)		
	Coef	Sig	*p*-val	Coef	Sig	*p*-val	Coef	Sig	*p*-val
Maize seed price (real 2010 Ksh/kg, village median)	−0.018	*	0.084	−0.016		0.124	−0.014		0.128
Inorganic fertiliser price (real 2010 Ksh/kg, village median)	0.007		0.905	0.011		0.855	0.004		0.941
Farm wage (real 2010 Ksh/hour, village median)	0.034		0.716	0.016		0.855	0.055		0.562
Land rental price (real 2010 Ksh/acre/year, village median)	−0.000		0.407	−0.000		0.397	−0.000		0.513
Plentiful season avg. wholesale price of maize (t-1, real 2010 Ksh/kg)	0.016		0.876	0.018		0.855	−0.035		0.720
Farmgate NCPB maize price (t-1, real 2010 Ksh/kg)	0.124	**	0.038	0.120	**	0.045	0.165	***	0.003
NCPB purchases of maize at division level (MT, t-1)	−0.002		0.492	−0.003		0.291	−0.002		0.577
=1 if female headed	−2.562		0.176	-		-	−2.867		0.204
Age of the HH head (years)	−0.044		0.508	-		-	−0.046		0.586
=1 if lower primary was the highest level of education of the HH head	−1.153		0.418	-		-	−1.342		0.368
=1 if upper primary was the highest level of education of the HH head	0.458		0.670	-		-	0.282		0.805
=1 if secondary was the highest level of education of the HH head	−1.764		0.262	-		-	−1.700		0.313
=1 if post-secondary was the highest level of education of the HH head	0.764		0.670	-		-	0.462		0.814
Number of prime age adults (age 15–59)	0.108		0.547	-		-	0.133		0.403
Total landholdings owned as of previous survey (acres)	−0.076	**	0.042	-		-	−0.074	*	0.058
Value of productive assets as of previous survey (1000 s of real 2010 Ksh)	−0.738		0.391	-		-	−0.661		0.703
TLUs owned as of one year ago	0.013		0.694	-		-	0.013		0.738
=1 if the household had a car, truck, or motorcycle in the prior survey	−1.243		0.451	-		-	−1.218		0.504
=1 if the HH had a cart in the prior survey	−0.255		0.834	-		-	−0.207		0.866
=1 if the HH had a bike in the prior survey	−1.158	*	0.075	-		-	−0.992		0.132
=1 if the HH had stores in the prior survey	0.008		0.988	-		-	0.063		0.919
Km to the nearest market place for farm produce	0.010		0.853	−0.002		0.970	0.016		0.793
Km to the nearest motorable road	−0.149		0.370	−0.104		0.558	−0.125		0.500
Km to the nearest fertiliser seller	0.067		0.412	0.065		0.385	0.055		0.486
Km to the nearest place to get extension advice	−0.003		0.953	0.012		0.818	0.009		0.892
Average rainfall in prior six main cropping seasons (mm)	−0.016	**	0.036	−0.018	**	0.015	−0.017	**	0.030
Average rainfall stress in prior six main cropping seasons	−14.427	*	0.065	−12.582		0.115	−12.646	*	0.087
=1 if year is 2010	1.776	**	0.039	1.802	**	0.035	1.871	**	0.020
Tobit residuals for selection bias test	-		-	-		-	−0.000		0.799

Source: Authors' calculations. See text for details on data sources.
Notes: N=615. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. *P*-values based on standard errors clustered at the household level. Standard errors for column (C) bootstrapped (100 replications) to account for the generated regressor (Tobit residuals). Agro-ecological zones are included in the regressions, however not included in this table.

5.2 Associations between changes in a household's expected maize price and other prices, and their SFM/SI adoption decisions

5.2.1 CRE-logit results (inorganic fertiliser, organic fertiliser, and maize-legume intercropping)

The main results of interest from the CRE-logit models for the factors associated with the yes/no decisions to use inorganic fertiliser, organic fertiliser, and maize-legume intercropping on maize plots are reported in Tables 6 and 7 (price levels and price ratios, respectively, both with the full set of controls) and tables A2 and A3 in the Supplemental Online Appendix (parsimonious models for the price levels and price ratios specifications, respectively). (See tables A4 through A6 and A7 through A9, respectively, for the full regression results associated with the summary results reported in Tables 6 and 7.) Focusing first on the estimated effects of changes in a

Table 6. Main results from the CRE-logit models for households' use of inorganic fertiliser, organic fertiliser, and maize-legume intercropping (price levels with the full set of control variables).

Panel A: Inorganic fertiliser (=1 if used on any maize plot)	Maize output price specification											
	(1) Quasi-rational expectations producer price [a]			(2) Naïve expectations producer price			(3) Perfect foresight producer price			(4) Lean season purchase price		
Explanatory variables	APE	Sig	*p*-val	APE	Sig	*p*-val	APE	Sig	*p*-val	APE	Sig	*p*-val
Maize output price (real 2010 Ksh/kg)	−0.029		0.111	0.001		0.872	0.004		0.374	0.007		0.279
Bean output price (real 2010 Ksh/kg)	−0.002	**	0.043	−0.001		0.140	−0.001		0.103	−0.001		0.103
Maize seed price (real 2010 Ksh/kg)	−0.001		0.290	−0.000		0.780	−0.000		0.811	−0.000		0.850
Bean seed price (real 2010 Ksh/kg)	0.001		0.471	0.000		0.947	0.000		0.861	0.001		0.812
Inorganic fertiliser price (real 2010 Ksh/kg)	−0.003		0.295	−0.002		0.420	−0.002		0.363	−0.003		0.160
Farm wage (real 2010 Ksh/hour)	−0.004		0.374	−0.004		0.282	−0.004		0.323	−0.003		0.480
Land rental price (real 2010 Ksh/acre/year)	0.000		0.713	0.000		0.288	0.000		0.343	0.000		0.107
Other control variables, year dummy, and CRE time averages	Yes			Yes			Yes			Yes		

Panel B: Organic fertiliser (=1 if used on any maize plot)	Maize output price specification											
	(1) Quasi-rational expectations producer price [a]			(2) Naïve expectations producer price			(3) Perfect foresight producer price			(4) Lean season purchase price		
Explanatory variables	APE	Sig	*p*-val	APE	Sig	*p*-val	APE	Sig	*p*-val	APE	Sig	*p*-val
Maize output price (real 2010 Ksh/kg)	−0.003		0.894	0.008		0.191	−0.005		0.414	−0.005		0.540
Bean output price (real 2010 Ksh/kg)	−0.002		0.316	−0.001		0.313	−0.001		0.270	−0.002		0.236
Maize seed price (real 2010 Ksh/kg)	0.001	**	0.041	0.001		0.131	0.001		0.113	0.001	*	0.084
Bean seed price (real 2010 Ksh/kg)	0.005		0.274	0.004		0.280	0.005		0.112	0.004		0.218
Inorganic fertiliser price (real 2010 Ksh/kg)	0.006		0.106	0.007	*	0.056	0.006	*	0.077	0.006	*	0.097
Farm wage (real 2010 Ksh/hour)	0.010		0.166	0.007		0.235	0.010	*	0.079	0.009		0.121
Land rental price (real 2010 Ksh/acre/year)	−0.000	***	0.010	−0.000	**	0.043	−0.000	**	0.045	−0.000	**	0.038
Other control variables, year dummy, and CRE time averages	Yes			Yes			Yes			Yes		

Panel C: Maize-legume intercropping (=1 if used on any maize plot)	Maize output price specification											
	(1) Quasi-rational expectations producer price [a]			(2) Naïve expectations producer price			(3) Perfect foresight producer price			(4) Lean season purchase price		
Explanatory variables	APE	Sig	*p*-val	APE	Sig	*p*-val	APE	Sig	*p*-val	APE	Sig	*p*-val
Maize output price (real 2010 Ksh/kg)	−0.016		0.344	0.002		0.758	0.008		0.129	−0.001		0.871
Bean output price (real 2010 Ksh/kg)	−0.001	*	0.068	−0.001		0.600	−0.001		0.388	−0.001		0.484
Maize seed price (real 2010 Ksh/kg)	0.000		0.733	0.000		0.421	0.001		0.265	0.001		0.362
Bean seed price (real 2010 Ksh/kg)	0.001		0.725	−0.000		0.985	−0.000		0.870	0.000		0.956
Inorganic fertiliser price (real 2010 Ksh/kg)	−0.000		0.899	−0.000		0.968	0.000		0.941	−0.000		0.922
Farm wage (real 2010 Ksh/hour)	−0.008	**	0.033	−0.007		0.108	−0.008	*	0.097	−0.007		0.116
Land rental price (real 2010 Ksh/acre/year)	0.000		0.866	0.000		0.701	0.000		0.680	0.000		0.689
Other control variables, year dummy, and CRE time averages	Yes			Yes			Yes			Yes		

Source: Authors' calculations. See text for details on data sources.

Notes: N=1,296. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. *p*-values based on standard errors clustered at the household level in all regressions. [a] Standard errors for column 1 are bootstrapped (100 replications) to account for the generated regressor (predicted maize producer price). See tables A4 through A6 in the Supplemental Online Appendix for the full results.

Table 7. Main results from the CRE-logit models for households' use of inorganic fertiliser, organic fertiliser, and maize-legume intercropping (prices ratios with the full set of control variables).

Panel A: Inorganic fertiliser (=1 if used on any maize plot)	Maize output price specification											
	(1) Quasi-rational expectations producer price [a]			(2) Naïve expectations producer price			(3) Perfect foresight producer price			(4) Lean season purchase price		
Explanatory variables	APE	Sig	*p*-val	APE	Sig	*p*-val	APE	Sig	*p*-val	APE	Sig	*p*-val
Bean output price:maize output price ratio	−0.020		0.247	−0.031		0.111	−0.022		0.118	−0.023	*	0.079
Maize seed price:maize output price ratio	−0.001		0.952	−0.006		0.759	−0.001		0.895	−0.003		0.654
Bean seed price:maize output price ratio	0.009		0.814	0.012		0.840	−0.003		0.933	−0.001		0.967
Inorganic fertiliser price:maize output price ratio	−0.004		0.931	−0.022		0.567	0.001		0.967	−0.054		0.183
Farm wage:maize output price ratio	−0.031		0.639	−0.134		0.265	−0.051		0.353	−0.034		0.450
Land rental price:maize output price ratio	0.000		0.403	0.001		0.202	0.000		0.354	0.000		0.263
Year dummy and CRE time averages	Yes			Yes			Yes			Yes		
Other control variables	Yes			Yes			Yes			Yes		
Panel B: Organic fertiliser (=1 if used on any maize plot)	Maize output price specification											
	(1) Quasi-rational expectations producer price [a]			(2) Naïve expectations producer price			(3) Perfect foresight producer price			(4) Lean season purchase price		
Explanatory variables	APE	Sig	*p*-val	APE	Sig	*p*-val	APE	Sig	*p*-val	APE	Sig	*p*-val
Bean output price:maize output price ratio	−0.031		0.187	−0.071	**	0.036	−0.028		0.231	−0.027		0.289
Maize seed price:maize output price ratio	0.014		0.261	0.025		0.246	0.016		0.199	0.018	*	0.071
Bean seed price:maize output price ratio	0.081	*	0.099	0.194	**	0.028	0.051		0.368	−0.010		0.836
Inorganic fertiliser price:maize output price ratio	0.105		0.114	0.006		0.913	0.050		0.243	0.071		0.364
Farm wage:maize output price ratio	0.152		0.143	0.132		0.437	0.078		0.352	0.078		0.262
Land rental price:maize output price ratio	−0.001	**	0.010	−0.001	**	0.035	−0.001	**	0.022	−0.001	**	0.028
Year dummy and CRE time averages	Yes			Yes			Yes			Yes		
Other control variables	Yes			Yes			Yes			Yes		
Panel C: Maize-legume intercropping (=1 if used on any maize plot)	Maize output price specification											
	(1) Quasi-rational expectations producer price [a]			(2) Naïve expectations producer price			(3) Perfect foresight producer price			(4) Lean season purchase price		
Explanatory variables	APE	Sig	*p*-val	APE	Sig	*p*-val	APE	Sig	*p*-val	APE	Sig	*p*-val
Bean output price:maize output price ratio	−0.003		0.898	−0.022		0.429	−0.015		0.436	−0.004		0.829
Maize seed price:maize output price ratio	0.007		0.515	0.019		0.304	0.002		0.824	0.013		0.121
Bean seed price:maize output price ratio	0.008		0.860	0.013		0.845	−0.010		0.815	0.015		0.673
Inorganic fertiliser price:maize output price ratio	0.023		0.696	0.007		0.903	0.002		0.954	0.074		0.177
Farm wage:maize output price ratio	−0.132		0.122	−0.235	*	0.073	−0.108		0.127	−0.066		0.279
Land rental price:maize output price ratio	0.000		0.808	0.000		0.367	0.000		0.561	−0.000		0.487
Year dummy and CRE time averages	Yes			Yes			Yes			Yes		
Other control variables	Yes			Yes			Yes			Yes		

Source: Authors' calculations. See text for details on data sources.

Notes: N=1,296. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. *p*-values based on standard errors clustered at the household level in all regressions. [a] Standard errors for column 1 are bootstrapped (100 replications) to account for the generated regressor (predicted maize producer price).

See tables A7-A9 in the Supplemental Online Appendix for the full results.

farmer's expected maize price on their decisions to use these practices (Table 6 and Table A2), the overwhelming weight of the evidence suggests no statistically significant associations. Regardless of the assumption made about how farmers form their maize price expectations (quasi-rational expectations, naïve expectations, or perfect foresight with respect to the maize producer price, or using the most recent lean season purchase price), none of the coefficients on the maize price variable is statistically significant at the 10% level or lower in the full models (Table 6). In the parsimonious versions of these models (table A2 in the Supplemental Online Appendix), we find very weak associations (statistically significant at only the 10% level) between changes in the expected maize price and farmers' use of these practices in three of the 12 regressions (two of four cases for the inorganic fertiliser logit and one of four cases for the maize-legume intercropping logit), but these effects do not hold up once we add other control variables to the models (i.e., in Table 6). Thus, based on the overall body of evidence, we conclude that changes in farmers' expected maize price levels have little bearing on their decisions of whether or not to use inorganic fertiliser, organic fertiliser, and maize-legume intercropping on their maize plots.

Changes in the levels of the lagged bean output price and in the levels of the various input prices also appear to have little effect on these decisions. None of the price variables is consistently statistically significant in the inorganic fertiliser and maize-legume intercropping logits (and this is the case in both the full and parsimonious specifications – see Table 6 and Table A2). Only in the case of the binary decision of whether or not to use organic fertiliser on maize do we find consistent evidence of statistically significant associations with any price. In both the full and parsimonious models (Table 6 and Table A2), an increase in the land rental price is associated with a decline in the probability of using organic fertiliser. This result holds across all expected maize price assumptions. It may be that with a rise in land rental prices, owner-cultivator farmers may consider renting out the plot in future years and thus be reluctant to make longer terms investments in the soil fertility of the plot via application of organic fertiliser. Similarly, in the face of higher land rental prices, renting farmers may be concerned about their ability to afford renting the plot again in the next year, and be likewise hesitant to make such longer-term soil fertility investments.

We also find that after controlling for the full set of explanatory variables, there is a positive association between the inorganic fertiliser price and farmers' use of organic fertiliser. More specifically, a 10 Ksh/kg increase in the inorganic fertiliser price is associated with a 6–7 percentage point increase in a household's probability of applying organic fertiliser on at least one of their maize plots (Table 6). Kenyan maize farmers may thus view inorganic and organic fertilisers as economic substitutes. This finding is similar to findings by Holden and Lunduka (2012) for Malawi. We discuss the implications of this result in the concluding section of the paper.

Turning to the price-related results from the models in which we use price ratios (with the maize output price in the denominator) instead of price levels, we find very little evidence that changes in input price:maize output price ratios or the bean output price:maize output price ratio are significantly associated with farmers' binary decisions to use inorganic fertiliser, organic fertiliser, and maize-legume intercropping (Table 7 and Table A3). The main exception is that we find consistent evidence (in both the full and parsimonious models and across almost all maize price expectation assumptions) that an increase in the land rental price:maize output price ratio is associated with reductions in the likelihood that a farmer applies organic fertiliser on one or more of their maize plots. This is consistent with land rental price-related results in the price level models discussed above and similar explanations of this finding apply.

5.2.2 CRE-Tobit results (intensity of inorganic fertiliser use on maize)

The main results of interest from the CRE-Tobit models for the factors associated with farmers' intensity of inorganic fertiliser use on maize are reported in Table 8 for models that included the full set of explanatory variables (with the price levels results in Panel A, and the price ratios results in Panel B). Similar results for the parsimonious specifications are reported in table A10 in the Supplemental Online Appendix, and the full regression results associated with Table 8 are reported in tables

Table 8. Main results from the CRE-Tobit models for households' intensity of fertiliser use on maize (kg/acre) (price levels and price ratios with the full set of control variables).

Panel A: Prices in levels	Maize output price specification											
	(1) Quasi-rational expectations producer price [a]			(2) Naïve expectations producer price			(3) Perfect foresight producer price			(4) Lean season purchase price		
Explanatory variables	APE	Sig	*p*-val	APE	Sig	*p*-val	APE	Sig	*p*-val	APE	Sig	*p*-val
Maize output price (real 2010 Ksh/kg)	−4.796	*	0.091	0.908		0.202	0.151		0.837	1.002		0.241
Bean output price (real 2010 Ksh/kg)	−0.251	**	0.048	−0.165		0.277	−0.199		0.187	−0.202		0.178
Maize seed price (real 2010 Ksh/kg)	−0.156	*	0.089	−0.087		0.300	−0.061		0.465	−0.062		0.449
Bean seed price (real 2010 Ksh/kg)	−0.035		0.903	−0.355		0.334	−0.204		0.558	−0.072		0.842
Inorganic fertiliser price (real 2010 Ksh/kg)	−1.096	**	0.014	−0.845	*	0.088	−0.987	**	0.040	−1.018	**	0.035
Farm wage (real 2010 Ksh/hour)	−0.349		0.494	−0.612		0.384	−0.361		0.592	−0.269		0.692
Land rental price (real 2010 Ksh/acre/year)	0.002		0.636	0.003		0.326	0.003		0.265	0.004		0.166
Year dummy and CRE time averages	Yes			Yes			Yes			Yes		
Other control variables	Yes			Yes			Yes			Yes		
Panel B: Price ratios	Maize output price specification											
	(1) Quasi-rational expectations producer price [a]			(2) Naïve expectations producer price			(3) Perfect foresight producer price			(4) Lean season purchase price		
Explanatory variables	APE	Sig	*p*-val	APE	Sig	*p*-val	APE	Sig	*p*-val	APE	Sig	*p*-val
Bean output price:maize output price ratio	−3.012		0.197	−2.701		0.482	−3.658		0.199	−2.624		0.429
Maize seed price:maize output price ratio	−0.771		0.535	−1.925		0.453	−1.358		0.304	−0.867		0.470
Bean seed price:maize output price ratio	−2.689		0.569	−14.779		0.130	−0.094		0.988	1.036		0.851
Inorganic fertiliser price:maize output price ratio	−8.557		0.229	−11.716		0.191	−6.335		0.299	−2.881		0.752
Farm wage:maize output price ratio	0.609		0.942	−15.825		0.417	−0.366		0.974	12.219		0.191
Land rental price:maize output price ratio	0.057		0.227	0.057		0.458	0.085	**	0.041	0.050		0.110
Year dummy and CRE time averages	Yes			Yes			Yes			Yes		
Other control variables	Yes			Yes			Yes			Yes		

Source: Authors' calculations. See text for details on data sources.

Notes: Dependent variable is inorganic fertiliser use on maize in kg/acre. N=1,296. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. [a] Standard errors for column 1 are bootstrapped (100 replications) to account for the generated regressor (predicted maize producer price). See tables A11 and A12 in the Supplemental Online Appendix for the full results for the Panel A and Panel B models, respectively.

A11 and A12 in the Online Appendix. The weight of the evidence again suggests that changes in maize and bean output prices, input prices, and the ratio of input prices or the bean output price to the maize output price play little role in a farmer's decision about how much inorganic fertiliser to apply to their maize. The key exception is that an increase in the price of inorganic fertiliser is associated with a reduction in the intensity of fertiliser use, holding other input price levels as well as maize and bean output price levels constant (Table 8). More specifically, a 1 Ksh/kg increase in the inorganic fertiliser price is associated with a roughly 1 kg/acre reduction in the inorganic fertiliser application rate. This result holds in both the full and parsimonious model specifications, and across all maize price expectation assumptions. Interestingly, however, when we include price ratios rather than price levels in the models, the inorganic fertiliser price:maize output price ratio is not statistically significant. Rather, it appears (based on our results) that Kenyan farmers' inorganic fertiliser application rate decisions are driven more by changes in inorganic fertiliser price *levels* than by changes in the ratio of the inorganic fertiliser price to their expected maize price.

5.2.3 CRE-multinomial logit results (SI category)

The final sets of regression results are from the CRE-multinomial logit (MNL) models for a maize-growing household's SI category decision, where the categories are Intensification, Sustainable, Weak SI, and Strong SI. (Recall that the None category is excluded because just 1.5% of household-year observations fall in this category.) The main results from the price levels and price ratios models including the full set of controls are reported in Tables 9 and 10, respectively. The corresponding parsimonious specification results as well as the full regression results associated with Tables 9 and 10 can be found in tables A13 to A16 in the Supplemental Online Appendix. These tables are structured differently than others given that the dependent variable has four different possible values. Also note that the APEs sum to zero across the four categories for a given explanatory variable because, for example, a positive effect on the probability of one SI category implies a negative effect of the same magnitude on the other three categories combined.

Consistent with the general finding from the CRE-logit and CRE-Tobit models that changes in a household's expected maize output price generally do not influence their inorganic fertiliser, organic fertiliser, or maize-legume intercropping-related adoption decisions, once we control for factors other than prices, we find no evidence of statistically significant expected maize price associations with a household's SI category decisions (Table 9). However, a few of the input price-related variables have fairly robust associations with such decisions – albeit not always in intuitive ways (which is often the case in the context of multiple market failures, per de Janvry et al. (1991)). One set of results that is fairly consistent across the price levels and price ratios models (when the full set of control variables is included) is that an increase in the farm wage or farm wage: maize output price ratio is associated with a shift from Weak SI (where inorganic fertiliser is combined with maize-legume intercropping or organic fertiliser on the same maize plot) to Intensification (where inorganic fertiliser is used without any sustainable practices). This is fairly intuitive given that Weak SI is expected to be more labour-intensive than Intensification. Somewhat puzzling, however, is that an increase in the farm wage:maize output price ratio (but not the farm wage in levels) is statistically weakly associated with a shift *toward* Strong SI (where inorganic fertiliser is used in conjunction with both maize-legume intercropping and organic fertiliser on the same plot) (Table 10). We would expect Strong SI to be even more labour-intensive than Weak SI, so it is not clear why an increase in the farm wage:maize price ratio would be associated with a shift away from Weak SI toward Strong SI. The parsimonious specification results also suggest a shift from Weak SI to Strong SI given an increase in the farm wage or farm wage:maize output price ratio (tables A13 and A14 in the Supplemental Online Appendix). Further research is needed to fully understand what is driving these results.

The other set of results that is fairly consistent across the price levels and price ratios MNL models (and in both the full and parsimonious specifications) is that an increase in the bean seed price or the bean seed price:maize output price ratio is associated with an increase in a maize-growing

Table 9. Main results for the CRE-multinomial logit models for households' SI category decisions (price levels with the full set of controls).

Dependent variable (SI category) Explanatory variables	Maize output price specification											
	(1) Quasi-rational expectations producer price [a]			(2) Naïve expectations producer price			(3) Perfect foresight producer price			(4) Lean season purchase price		
	APE	Sig	*p*-val	APE	Sig	*p*-val	APE	Sig	*p*-val	APE	Sig	*p*-val
Maize output price (real 2010 Ksh/kg)												
Intensification	−0.027		0.152	−0.006		0.284	−0.008		0.105	0.008		0.234
Sustainable	0.020		0.295	−0.002		0.750	−0.001		0.790	−0.006		0.304
Weak SI	0.042		0.153	0.006		0.404	0.005		0.455	−0.010		0.278
Strong SI	−0.034	*	0.099	0.001		0.862	0.004		0.433	0.008		0.252
Bean output price (real 2010 Ksh/kg)												
Intensification	0.000		0.627	0.001		0.462	0.001		0.309	0.001		0.467
Sustainable	0.001		0.263	0.001		0.309	0.001		0.305	0.001		0.202
Weak SI	0.000		0.769	0.000		0.976	−0.000		0.928	−0.000		0.928
Strong SI	−0.002	*	0.071	−0.002	*	0.084	−0.002	*	0.066	−0.002	*	0.068
Maize seed price (real 2010 Ksh/kg)												
Intensification	−0.000		0.630	0.000		0.697	0.000		0.940	0.000		0.781
Sustainable	−0.001		0.382	−0.001	*	0.051	−0.001	**	0.030	−0.001	**	0.014
Weak SI	0.001		0.293	0.000		0.794	0.000		0.628	0.000		0.616
Strong SI	−0.000		0.897	0.001		0.403	0.001		0.330	0.001		0.274
Bean seed price (real 2010 Ksh/kg)												
Intensification	−0.001		0.630	−0.002		0.546	−0.001		0.613	−0.001		0.686
Sustainable	0.005	**	0.020	0.006	**	0.011	0.006	**	0.014	0.005	**	0.023
Weak SI	−0.005		0.115	−0.005		0.168	−0.005		0.159	−0.005		0.149
Strong SI	0.001		0.641	0.000		0.991	0.000		0.992	0.001		0.814
Inorganic fertiliser price (real 2010 Ksh/kg)												
Intensification	−0.002		0.539	−0.003		0.441	−0.003		0.426	−0.001		0.669
Sustainable	0.002		0.530	0.002		0.520	0.002		0.470	0.004		0.199
Weak SI	0.004		0.467	0.004		0.391	0.004		0.399	0.002		0.633
Strong SI	−0.004		0.398	−0.003		0.342	−0.003		0.319	−0.005		0.177
Farm wage (real 2010 Ksh/hour)												
Intensification	0.010	**	0.042	0.012	**	0.017	0.011	**	0.021	0.010	**	0.027
Sustainable	−0.001		0.840	−0.001		0.778	−0.002		0.646	−0.004		0.339
Weak SI	−0.016	**	0.019	−0.017	***	0.009	−0.015	**	0.010	−0.014	**	0.019
Strong SI	0.006		0.278	0.007		0.163	0.007		0.132	0.008	*	0.079
Land rental price (real 2010 Ksh/acre/year)												
Intensification	−0.000		0.474	−0.000		0.564	−0.000		0.591	−0.000		0.787
Sustainable	0.000		0.813	0.000		0.946	0.000		0.958	−0.000		0.874
Weak SI	0.000		0.482	0.000		0.607	0.000		0.634	0.000		0.845
Strong SI	−0.000		0.704	−0.000		0.846	−0.000		0.868	0.000		0.890
Year dummy and CRE time averages	Yes			Yes			Yes			Yes		
Other control variables	Yes			Yes			Yes			Yes		

Source: Authors' calculations. See text for details on data sources.
Notes: N=1,277 (due to removing 19 observations that fell into the "None" SI category). ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. *p*-values based on standard errors clustered at the household level in all regressions [a] Standard errors for column 1 are bootstrapped (100 replications) to account for the generated regressor (predicted maize producer price). See table A15 in the Supplemental Online Appendix for the full regression results.

household's likelihood of being in the Sustainable category (i.e., using maize-legume intercropping and/or organic fertiliser, but without use of inorganic fertiliser on the same plot). The results in the parsimonious price levels model suggest that this shift toward Sustainable may be coming mainly from the Weak SI category (table A13). An increase in the price of bean seed may mean a household that is practising maize-legume intercropping (a Sustainable category practice on its own) is less able

Table 10. Main results for the CRE-multinomial logit models for households' SI category decisions (price ratios with the full set of controls).

Dependent variable (SI category)	Maize output price specification											
	(1) Quasi-rational expectations producer price [a]			(2) Naïve expectations producer price			(3) Perfect foresight producer price			(4) Lean season purchase price		
Explanatory variables	APE	Sig	*p*-val	APE	Sig	*p*-val	APE	Sig	*p*-val	APE	Sig	*p*-val
Bean output price:maize output price ratio												
Intensification	0.015		0.417	0.024		0.364	0.023		0.236	0.010		0.566
Sustainable	0.014		0.440	0.028		0.324	0.019		0.293	0.028		0.120
Weak SI	−0.003		0.909	0.013		0.686	−0.011		0.660	−0.022		0.412
Strong SI	−0.026		0.240	−0.066	**	0.020	−0.031		0.104	−0.017		0.406
Maize seed price:maize output price ratio												
Intensification	0.001		0.934	0.011		0.581	−0.004		0.736	−0.007		0.475
Sustainable	−0.018	*	0.062	−0.035	**	0.040	−0.009		0.222	−0.010		0.141
Weak SI	0.010		0.559	0.006		0.807	0.012		0.437	0.015		0.234
Strong SI	0.007		0.516	0.018		0.408	0.001		0.928	0.002		0.788
Bean seed price:maize output price ratio												
Intensification	−0.029		0.576	−0.043		0.523	−0.012		0.807	−0.011		0.775
Sustainable	0.102	**	0.039	0.158	**	0.020	0.095	**	0.015	0.050		0.188
Weak SI	−0.080		0.219	−0.177	*	0.066	−0.069		0.271	−0.014		0.800
Strong SI	0.007		0.914	0.062		0.458	−0.014		0.765	−0.026		0.548
Inorganic fertiliser price:maize output price ratio												
Intensification	−0.022		0.723	−0.041		0.467	−0.038		0.338	−0.087		0.165
Sustainable	0.011		0.830	0.041		0.444	0.016		0.660	0.086	*	0.096
Weak SI	0.033		0.743	0.093		0.272	0.062		0.303	0.080		0.387
Strong SI	−0.022		0.772	−0.093		0.141	−0.041		0.318	−0.080		0.212
Farm wage:maize output price ratio												
Intensification	0.224	**	0.010	0.298	**	0.024	0.154	**	0.032	0.098		0.116
Sustainable	−0.042		0.543	0.011		0.924	−0.025		0.695	−0.047		0.435
Weak SI	−0.325	***	0.006	−0.449	**	0.010	−0.260	***	0.010	−0.185	**	0.032
Strong SI	0.143	*	0.083	0.139		0.299	0.131	*	0.086	0.134	*	0.059
Land rental price:maize output price ratio												
Intensification	−0.000		0.720	−0.000		0.444	0.000		0.791	0.000		0.917
Sustainable	0.000		0.843	−0.000		0.807	−0.000		0.637	−0.000		0.511
Weak SI	0.000		0.714	0.000		0.522	0.000		0.860	0.000		0.528
Strong SI	−0.000		0.794	0.000		0.895	−0.000		0.815	−0.000		0.599
Year dummy and CRE time averages	Yes			Yes			Yes			Yes		
Other control variables	Yes			Yes			Yes			Yes		

Source: Authors' calculations. See text for details on data sources.
Notes: N=1,277 (due to removing 19 observations that fell into the "None" SI category). ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. *p*-values based on standard errors clustered at the household level in all regressions [a] Standard errors for column 1 are bootstrapped (100 replications) to account for the generated regressor (predicted maize producer price). See table A16 in the Supplemental Online Appendix for the full regression results.

to afford inorganic fertiliser to use on its maize-legume intercropped plot(s) (i.e., which would constitute Weak SI).

The results for the other price variables are not robust to the use of price levels vs. price ratios and/or to the use of the full set of controls vs. the parsimonious specification, so we do not emphasise them here.

6. Conclusions and policy implications

Soil degradation is a serious concern in Kenya, as it is in many other countries in SSA. Adoption of SFM practices and SI can slow soil degradation and, over time, improve soil fertility. Given the prime importance of maize as a staple food consumed and a crop produced by smallholder farmers in Kenya, SI of maize production is particularly critical. In this study, we focused on three SFM practices that are commonly but not universally used in Kenya: inorganic fertiliser, organic fertiliser, and maize-legume intercropping. We also categorised households by their degree of SI of maize production based on which combination (if any) of these practices they used on their maize plots. Motivated by suggestions in the literature but a dearth of empirical evidence that smallholder farm households might adopt more sustainable forms of maize intensification if they expect to receive a higher maize price come harvest time, we sought to understand the role that changes in a household's expected maize price play in their SFM adoption and SI decisions. We also sought to measure how such households respond to changes in input prices (in levels and relative to their expected maize price), as economic theory suggests that expected maize prices, input prices, and input: maize output price ratios are likely to be important drivers of farmers' maize production-related technology adoption decisions.

Our six main findings and associated policy implications are as follows. First, the expected maize price does not appear to be an important determinant of Kenyan smallholder households' SI category or SFM practice adoption decisions on their maize plots. We find essentially no empirical evidence to support claims made in the literature that households are likely to respond to an increase in their expected maize price by adopting more SFM practices and sustainably intensifying their maize production. This finding is generally robust to different assumptions about how households form their maize price expectations and to whether we control for other price variables only or a more extensive set of control variables. An important policy implication of this finding is that maize price policies (including those implemented by the NCPB) are unlikely to have an appreciable effect on Kenyan smallholders' investments in their soils.

Second, relatively few input price level or input price:expected maize output price ratio variables are statistically significant in our analyses. The general lack of responsiveness to changes in maize output prices and input prices is not entirely unexpected given that in a context of multiple market failures such as our study context, households often have unexpected responses or no response to changes in market prices (de Janvry et al. 1991).

Third, one of the consistently statistically significant price effects found is this study is that an increase in the inorganic fertiliser price is associated with a reduction in a household's likelihood of using organic fertiliser on one or more of its maize plots. Similar to findings from Holden and Lunduka (2012) for Malawi, this suggests that the two inputs are viewed as economic substitutes by Kenyan maize farmers. However, from an agronomic and soil health perspective, it is desirable for the two types of fertiliser to be used as complements (Shapiro and Sanders 1998; Juma et al. 1999; Place et al. 2002). Greater extension emphasis and other information dissemination on the agronomic complementary between inorganic and organic fertilisers appears to be needed to promote SI of maize production in Kenya.[7] How best to do this is an important area for future research. Another implication of this finding (and the lack of an effect of inorganic fertiliser prices on households' joint use of organic and inorganic fertilisers) is that subsidies for inorganic fertiliser in Kenya are unlikely to incentivize SI and, at worst, may inadvertently incentivize unsustainable forms maize intensification, as has occurred in Zambia (Morgan et al. 2019).

Fourth, while an increase in inorganic fertiliser price levels is associated with a reduction in the intensity of inorganic fertiliser use on maize (in kg/acre), the inorganic fertiliser price:expected maize output price ratio is not significantly associated with this outcome variable. Given that the profitability of inorganic fertiliser use on maize is more likely to be linked to the inorganic fertiliser:maize price ratio and not the absolute level of inorganic fertiliser prices, it may be important for extension efforts and information campaigns to encourage farmers to consider changes in this price ratio when making inorganic fertiliser use decisions.

Fifth, an increase in the land rental price (as well as the land rental price:expected maize output price ratio) is associated with a reduction in the likelihood that farmers use organic fertiliser on their maize plots, perhaps because of concerns about making longer-term investments in their soil if the land is likely to be rented out to someone else in the future. Additional incentives may need to be provided to farmers to invest in the health of their soils in the face of rising land rental prices in land-scarce Kenya (Kopper and Jayne 2019).

Sixth and finally, an increase in the farm wage (or the farm wage:expected maize output price ratio) is associated with a shift away from Weak SI (which entails joint use of inorganic fertiliser with either maize-legume intercropping or organic fertiliser) and toward Intensification (i.e., use of inorganic fertiliser without complementary sustainable practices), likely because Weak SI is more labour-intensive than Intensification. In areas with rising farm wages, additional incentives may be needed for farmers to utilise labour-intensive practices that sustainably improve soil health.

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Notes

1. Similar definitions have been used by Snapp et al. (2017) and others. Snapp et al. (2017) also integrate social and human condition dimensions into their definition of SI.
2. Farmers do not know what maize prices will be at harvest time when they are making SFM adoption decisions, so it is their *expectation* of the maize price that is likely to affect behavior.
3. We do not analyze other SFM practices such as maize-legume rotations due to data constraints.
4. See Kim et al. (2019) for a detailed discussion of the rationale for the different SI category designations.
5. The two most commonly used inorganic fertilisers in our data are diammonium phosphate (DAP) and calcium ammonium nitrate (CAN). DAP is applied to 69.9% of maize plots, while CAN is applied to 32.3%; 38.4% of maize plots have both applied. DAP is commonly used as basal dressing and CAN as top dressing in Kenya, which is why there is significant overlap in their application.
6. Note that in Procedure 17.3, Tobit (regular) residuals are used, whereas in a control function approach, the Tobit generalised residuals would be used (Wooldridge 2010).
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