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Maize marketing boards and sustainable intensification: Panel survey evidence from Kenya

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1. Introduction:

Many nations in sub-Saharan Africa (SSA), including Kenya, are experiencing challenges associated with soil nutrient losses and stalling agricultural output growth (Eicher 2009; Jayne et al. 1993; Montpellier Panel 2013; NAAIAP 2014). In much of SSA, countries are net importers of food due to many factors, including low productivity (Drechsel et al. 2001; van lttersum 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 (Drechsel et al. 2001; Sanchez et al. 1997; Sanchez and Logan 1992;). Moreover, 3.3% of agricultural gross domestic product (GDP) in SSA is lost annually due to soil and nutrient loss (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 from crop residues being left on the soil (Bationo et al. 1995; Lal 1995; Marenya and Barrett 2009), and low use of organic and inorganic inputs (Oluoch-Kosura, Marenya, and Nzuma, 2001).

Sustainable intensification (SI) has been proposed as a potential solution to the issues of declining soil fertility and low agricultural productivity in Africa (Haggblade and Hazell 2010; Montpellier Panel 2013; Pretty, Toulmin, Williams 2011). 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; Royal Society 2009).[1] It does not involve extensification or cultivation of newly cleared or fallowed land. SI is a guiding framework with which to think about what practices or combinations of technologies are sustainable (Garnett and Godfray 2012). SI of maize production is of particular interest in eastern and southern Africa (ESA), where maize in the main staple food and is grown widely by smallholder farmers. The use of soil fertility management (SFM) practices on maize plots, such as organic and inorganic fertilizers, intercropping or rotating the maize with legumes, and crop residue retention and incorporation, among others, has the potential to contribute to SI in maize-based systems, particularly when inorganic fertilizer and other SFM practices are combined on the same plot (Montpellier Panel 2013; Snapp et al. 2010).

Key policy issues and research questions, then, are: (1) what are the drivers of smallholder farmers' adoption of SFM practices and the degree of SI in maize-based systems? (2) How are current government policies and programs affecting incentives for smallholders to adopt these technologies? And (3), what policies and programs can be designed to encourage take-up of these technologies? This study contributes to the relatively thin literature on the second question, and also contributes to the large and growing literature on the first question.

In ESA, the two agricultural sector programs that often dominate governments' agricultural sector expenditures are input subsidies and output price support programs (Akroyd, and Smith 2007; Jayne et al. 2010; Jayne and Rashid 2013; Jayne, Mason, and Burke 2015; Mason, Jayne, & Myers 2015), the latter of which are typically implemented by grain marketing boards or the agencies responsible for countries' strategic grain reserves. Both types of programs are commonly used by ESA governments (e.g., Ethiopia, Kenya, Malawi, Tanzania, Zambia, and Zimbabwe) to incentivize the cultivation of specific crops or the use of certain inputs and soil amendments. While several recent studies have analyzed how *input subsidies* have affected farmers' decisions to adopt SFM practices (Holden and Lunduka 2011; Kassie et al. 2015; Koppmair, Kassie, and Qaim 2016; Levine, Mason, and Morgan 2016; Vondolia, Eggert, Stage

[1] Similar definitions have been used by Snapp et al. 2016 and others. Snapp et al. 2016 also integrate social and human condition dimensions into their definition of SI.

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2012), very little is known about how *output price supports* affect SFM adoption and SI of maize production.

To begin to fill this knowledge gap, this study analyzes the effects of the maize price support program implemented by Kenya's maize marketing board, the National Cereals and Produce Board (NCPB), on smallholder farm household's adoption of SFM practices and the degree of SI of their maize production. During the period of analysis, the NCPB purchased maize at a pan-territorial price that exceeded the market price in many areas, and it mainly bought from large-scale farmers and traders. Very few Kenyan smallholders sold maize to the NCPB; however, previous research on the NCPB and other maize price support programs in the region suggests that these programs raise smallholder farmers' maize price expectations (even if they do not sell directly to the marketing board). This, in turn, affects their crop production patterns (Jayne, Myers, Nyoro 2008; Mason, Jayne, and Myers 2015; Mather and Jayne 2011). We hypothesize that maize price support programs such as Kenya's influence households' SFM adoption decisions and SI through a similar mechanism.

We test this hypothesis using administrative data from the NCPB, nationwide household panel survey data from Kenya, panel data methods to control for time invariant heterogeneity, and a three-step analysis (summarized in figure 1). In the first step, we test whether the NCPB's maize purchase price or quantities purchased affect households' expected maize price. Then in the second step we test if the expected maize price is a significant determinant of households' SFM and SI decisions. Finally, the results from steps 1 and 2 are combined to obtain estimates of the effects of the NCPB variables on these outcomes.

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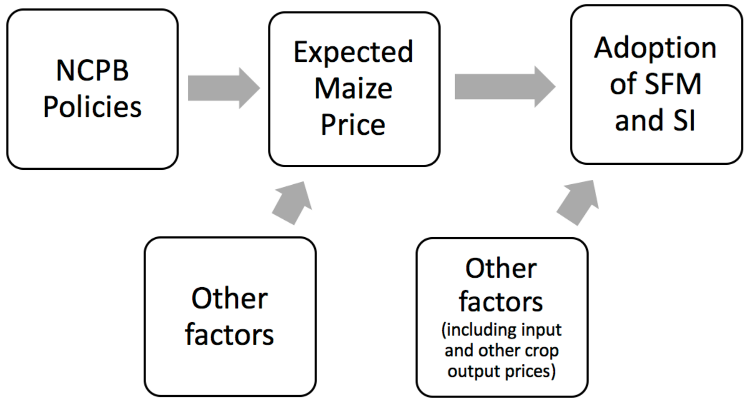
In addition to being the first detailed analysis (to our knowledge) of the effects of crop output price support programs in SSA on SFM and SI, this paper also contributes to the literature by examining how other crop prices and input prices affect households' SFM and SI adoption decisions. While there is a growing body of literature on the determinants of these decisions (Manda et al. 2016; Murendo et al. 2016; Teklewold et al. 2013; Teklewold, Kassie, and Shiferaw 2013; Kamau, Smale, and Mutua 2014; among many others), very few studies have considered the roles of input and output prices in the adoption process despite them being important potential determinants per economic theory.

The remainder of the paper is organized as follows. In section 2, we provide additional information on the operations of the NCPB. Section 3 summarizes sustainable intensification benefits to soil fertility and the household along with background on the SFM practices of interest and their benefits in a maize cropping system. Section 4 summarizes several studies on the drivers of adoption of SFM practices and on the effects of the NCPB on maize prices and smallholder behavior in Kenya. The conceptual framework is outlined in section 5, the empirical strategy is described in section 6, the data used in this study is examined in section 7, the results are presented in section 8, and conclusions and policy implications are drawn in section 9.

Figure 1: Simple conceptual model linking NCPB policies and SFM/SI adoption decisions

Source: Authors' creation



2. The National Cereals and Produce Board

Despite being scaled back in many African countries during structural adjustment in the 1980s and 1990s, crop marketing boards became popular again in the 2000s and continue to play an important role in the commodity markets of several countries in the region. Kenya's NCPB is a key example. The NCPB has three main roles. Its first role and core business is as a grain trader. In this role, the NCPB competes with nongovernmental players to buy and sell maize, wheat, beans, rice, millet and sorghum (NCPB n.d.). Maize is the primary focus of its operations due to it being the main staple food crop in Kenya. It purchases maize at pan-territorial prices, which are announced annually during the main season harvest. See Table 1 for the annual quantities of maize bought and sold by the NCPB, and the pan-territorial price at which it bought maize from 1990 to 2014, the most recent year for which data are available. As shown in table 1, the share of total national maize production purchased by the NCPB in a given year ranged from less than 1% to nearly 32% during this period. Although NCPB's maize market share has been lower in recent years, it was as high as 11-14% during the period of analysis for this paper, which covers the 2006/07 and 2009/10 agricultural years. It is important to note that in any given year the NCPB can sell more than it buys due to imports and having stocks on hand from previous years.

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Table 1: NCPB maize purchases, sales, and prices, 1990-2014

Year	Quantity of maize purchased by the NCPB in Kenya (MT)	Estimated total national maize production (MT)	NCPB maize purchases as a percentage of total national maize production [(A)/(B)]*100	Quantity of maize sold by the NCPB (MT)	NCPB maize pan-territorial purchase price (nominal Ksh/kg)	NCPB maize sale price (nominal Ksh/kg)
	(A)	(B)	(C)	(D)	(E)	(F)
1990	502,243	2,289,600	21.9%	413,843	250	321
1991	301,848	2,400,000	12.6%	811,094	300	358
1992	346,468	2,430,000	14.3%	411,450	420	472
1993	663,192	2,089,000	31.7%	498,723	775	763
1994	246,225	3,060,000	8.0%	221,936	920	1,280
1995	363,482	2,698,863	13.5%	56,275	600	887
1996	113,612	2,160,000	5.3%	96,546	1,127	1,100
1997	119,688	2,214,000	5.4%	53,690	1,162	1,319
1998	83,476	2,464,101	3.4%	15,905	1,009	1,209
2000	80,436	2,322,140	3.5%	169,616	1,200	1,436
2001	155,857	2,160,000	7.2%	154,460	1,250	1,300
2002	279,409	2,790,000	10.0%	13,499	1,000	1,250
2003	279,548	2,408,596	11.6%	121,439	947	1,165
2004	119,702	2,710,848	4.4%	190,941	1,100	1,325
2005	101,583	2,607,139	3.9%	28,317	1,300	1,680
2006	310,942	2,905,559	10.7%	142,584	1,400	1,900
2007	133,935	3,247,200	4.1%	371,802	1,300	1,850
2008	403,100	2,928,793	13.8%	96,657	1,300	1,550
2009	32,584	2,367,237	1.4%	284,632	1,434	1,504
2010	351,930	2,439,000	14.4%	282,694	1,400	1,798
2011	231,714	3,464,541	6.7%	86	1,612	2,298
2012	21,745	3,376,862	0.6%	18,359	2,000	2,492
2013	58,243	3,749,880	1.6%	8,192	3,128	2,750
2014	60,232	3,592,688	1.7%	28,087	2,456	2,158

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Note: Year is calendar year, although the agricultural year falls in two calendar years in some districts. NCPB prices similarly span two calendar years and purchases are made throughout the 12 months. Production quantities, NCPB purchases, and sales are on a calendar year basis. Data from 2015 onward not available.
Sources: NCPB except for maize production statistics, which come from the FAO Stat database, available at http://www.fao.org/faostat/en/#data/QC.

The purpose of the NCPB's involvement in grain trading and its second role of serving as Kenya's Strategic Grain Reserve (SGR) is to address the food price dilemma (Timmer, Falcon, and Pearson 1983). By purchasing maize at above-market prices in normal and bumper harvest years, the Kenyan government through the NCPB seeks to maintain incentives for farmers to continue cultivating maize. On the other hand, the NCPB sells its stocks of grain at subsidized rates to millers, with the goal of keeping food prices down for consumers (Food Security Report n.d.). As Kenya's SGR, the NCPB holds up to 720,000 metric tons (MT) of maize on behalf of the government.[2] The government releases these stores when the price of maize rises above a government-set threshold. At 720,000 MTs, the SGR represents up to 40% of the NCPB's 1,800,000 MT storage capacity.[3]

The NCPB's third role is to assist with famine relief. In this capacity, the board distributes relief stores of maize to famine areas when there is a lack of food. The determination to release these stores is made by the government.

The NCPB currently operates six regional offices and 98 silos and depots, down slightly from 110 depots in 2010 (NCPB n.d.; Nyameino 2010). See Figure 2 for a map of the NCPB's major depots and regional offices. Maize bought by the NCPB during our period of analysis was purchased primarily from large-scale farmers and from traders who compile smallholders' harvests into larger lots for sale to the NCPB. Very few smallholders sold directly to the NCPB during our study period (e.g., only 1.5% in 2007 and 0.6% in 2010). However, the NCPB has more recently shifted to purchasing maize from any farmer regardless of size and it no longer purchases from traders. Parties wishing to sell maize to the NCPB deliver it to an NCPB depot. The NCPB does not pay sellers immediately and payments may be delayed up to several months. This is in contrast to when a farmer sells maize to a trader and payment is typically made immediately in cash and transportation costs are minimal (Nyoro, Kiiru, and Jayne 1999). Once it has purchased the grain, the NCPB uses it for one of its three main roles: grain trading, SGR, or famine relief.

Our main interest with regard to the NCPB in this study is how the NCPB's maize purchase activities (quantities and prices) affect smallholder SFM and SI adoption. In addition to the aforementioned three main roles, beginning in 2002 the NCPB began selling agricultural inputs, such as fertilizer and certified seeds, to farmers at subsidized prices.[4] We discuss these subsidies and how we control for their effects on farmer behavior in the empirical strategy section.

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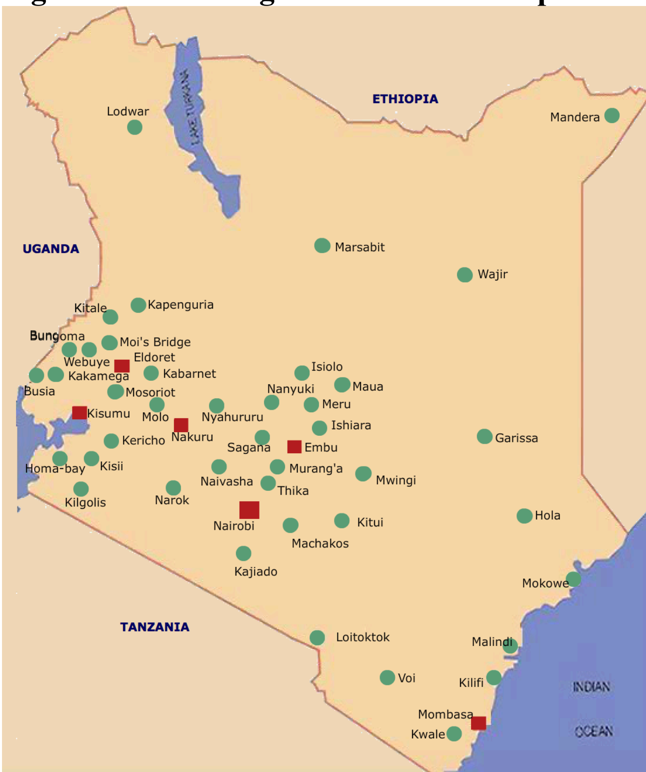
[2] The SGR storage capacity was recently raised from 360,000 MT to 720,000 MT (NCPB n.d.).

[3] This storage capacity is greater than the needs of the NCPB, so it offers storage services to third parties. Additional services offered by the NCPB include weighing, drying, cleaning, grading, aerating, and bagging of grain, pest control (fumigation, spraying, and rodent and termite control), clearing and forwarding, and aflatoxin testing, among others (NCPB n.d.).

[4] Households who wish to receive subsidized inputs are screened by a village level vetting committee (Ministry of Agriculture, Livestock, and Fisheries 2014).

Figure 2: NCPB regional offices and depots



Source: NCPB website: http://www.ncpb.co.ke/index.php?option=com_content&task=view&id=42&Itemid=70
Red squares are the regional offices, green dots are the depots

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3. SFM practices analyzed and their potential to contribute to SI in maize-based systems

This study analyzes three SFM practices that have the potential to contribute to SI of maize-based systems, particularly when they are used in combination with each other: maize-legume intercropping, organic fertilizer, and inorganic fertilizer. We discuss each of these in turn.

Intercropping maize with legumes can benefit the soil and the household in several ways. First, the legumes fix nitrogen into the soil, benefiting the maize, which would otherwise only have access to the nitrogen that was in the soil or nitrogen applied in the form of inorganic fertilizer. Intercropping maize and legumes reduces the maize's requirements for nitrogen fertilizers (Zentner et al. 2001; Zentner et al. 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 monocropped maize fields. 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). In addition, the legumes themselves can provide additional nutrients to the farm household (Kassie et al. 2013).

The application of organic fertilizer in the form of animal manure or compost also increases SOM (Vanlauwe 2004). Organic fertilizer is a complement to inorganic fertilizer, increasing its effectiveness (Juma et al. 1997). Manure also increases the levels of nitrogen, phosphorous, and potassium in the soil, all of which are important to the development of plants.

Inorganic fertilizer also adds these elements to the soil for plant use (Marenya and Barrett 2007; Sanchez et al.1997). However, inorganic fertilizer application alone can damage soils in the following ways when not used appropriately: water pollution, destruction of micro-organisms, damage to plant tissues, negative effects on legumes' ability to fix nitrogen, and perhaps most critically, the decomposition of SOM (Chen 2006). Of particular concern in Kenya is the acidification of soils over time due to the continuous use of inorganic fertilizer; high soil acidity reduces crop response to inorganic fertilizers (Wong et al. 1995). One soil additive that that can reduce soil acidity is lime (Sanchez et al. 1997), however no households in our sample report using lime on their maize fields. This is surprising given that nearly every county in Kenya has soil acidity challenges, with average pH levels below the ideal level for maize production (NAAIAP 2014).[5] This likely suggests that households either do not have access to lime, that it is not profitable, or that they are unaware of its possible benefits. In addition to lime, the application of manure can counter soil acidification as well (Whalen et al. 2000).

SOM levels are low in much of Kenya, and average SOM levels are below the ideal level for maize in all counties in the country. SOM is a relatively slowly-changing characteristic of the soil. This means that it takes time to improve a poor quality, low SOM soil into a higher quality soil, high SOM soil. In many cases, this process takes several years at a minimum (Bot and Benites 2005). SOM is directly linked to productivity of plants (Bauer and Black, 1994). In regulates the amount of water that is retained in the soil (Juma 1999) and regulates the release of nutrients into the soil for plant use (Bot and Benites 2005). The application of SFM practices over one season may improve yields, but it is over multiple seasons that the majority of benefits are observed. Pretty, Toulmin, and Williams (2011) examine the benefits of conservation agriculture (CA), which includes some of our SFM practices, over a minimum of three years and found that more benefits are derived the longer the practices are used. We expect that the majority of improvements to yield and soil fertility from the use of organic fertilizer and intercropping of maize and legumes will accrue after these techniques are used for multiple seasons.

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This paper focuses on the use of inorganic fertilizer, organic fertilizer, and maize-legume intercropping on maize plots in Kenya. Following Kim, Mason, and Snapp (2017), we categorize and rank the use of these practices, alone and in combination, by the extent to which they can contribute to sustainable intensification in maize-based systems.[6] Per Kim, Mason, and Snapp, organic fertilizer and maize-legume intercropping are each considered a "sustainable" practice and inorganic fertilizer is considered an "intensification" practice. The combined use of at least one sustainable practice and inorganic fertilizer on the same plot is considered to be a form of sustainable intensification. Organic fertilizer and maize-legume intercropping are classified as sustainable practices because they can be done individually over time with fewer negative effects

[5] NAAIAP (2014) summarizes the results of soil samples collected throughout Kenya and provides county-specific soil amendment recommendations for maize cultivation. It considers a pH of 5.5 or higher and total organic carbon (TOC) levels of 2.7% or higher to be the ideal for maize production (NAAIAP 2014). TOC is one element of SOM. The equation to convert TOC to SOM is SOM(%) = 1.2 * TOC(%)

[6] In addition to the three practices considered in this study, there are other practices that can contribute to SI in maize based-systems such as rotating maize with legumes, minimum tillage, and crop residue retention and incorporation (Bultena and Hoiberg 1983; Mcdonahe, Lu, and Semalulu 2011). In the 2010 wave of the data used in this study, there is an attempt to capture *at the household level* whether crop rotations are used (although not specifying if these are maize/legume), how maize stover is predominantly used, and if minimum tillage is practiced on any field. The data suggest that 31.4% of households rotated at least one field, 27.4% of households retain maize residues to some degree, and 1.3% of households practiced minimal tillage on at least one field.

on soil quality relative to maize monocropping or maize plots without organic fertilizer (Dahmardeh et al. 2010). Indeed, when applied appropriately, the practices typically improve soil quality (or, at worst, maintain it) (Snaginga and Woomer 2009). On the other hand, the application of inorganic fertilizer alone over time without any sustainable practice results in a decrease in SOM and soil fertility (Chen 2006; Kapkiyai et al. 1999). However, when inorganic fertilizer is combined with a sustainable practice, soil health may improve (Chand, Anwar, and Patra 2006; Chen 2006; Dutta et al. 2003; Kaur, Kapoor, and Gupta, 2005).

See table 2 for a breakdown of how these three practices combine into SI categories (per Kim, Mason, and Snapp 2017) and their ranking by degree of SI. We use these SI categories and ranks (or slight modifications thereof) throughout the paper. In panel A of table 2 we see the three different practices that are applied at the plot level and combine to form eight cases, the most basic of which is the monocropping of maize with no form of fertilizer applied. This is labeled as the "None" SI category in our framework because none of the three SFM practices under consideration is used on the maize plot. In addition, we assign this category an SI ranking of 0. The categories of "intensification" and "weak sustainable" both result from the application of one practice individually: inorganic fertilizer in the case of "intensification" and maize-legume intercropping or organic fertilizer in the case of "weak sustainable". These SI categories are assigned an SI ranking of 1 and 2, respectively, for the reasons described above. The category of "strong sustainable" refers to plots where both sustainable practices are used (and is assigned an SI ranking of 3). The "weak SI" category is the combination of inorganic fertilizer and one sustainable practice (SI ranking of 4), and the "strong SI" category is the combination of inorganic fertilizer with both sustainable practices (SI ranking of 5). A discussion of the information in panel B of table 2 is provided in the data section.

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Table 2: SFM practice combinations on maize plots, SI designation and ranking, and prevalence in Kenya

	PANEL A					PANEL B				
Case	**Inorganic fertilizer?**	**Organic fertilizer?**	**Maize-legume intercrop?**	**SI category**	**SI ranking**	**Number of maize plots in sample**	**Percent of maize plots in sample by case**	**Analytical SI category**	**Analytical SI ranking**	**Percent of maize plots by analytical SI category/ ranking (excluding case 1)**
1	No	No	No	None	0	63	1.9%	N/A (too few maize plots to include in analysis)		
2	Yes	No	No	Intensification	1	200	6.1%	Intensification	1	6.2%
3	No	Yes	No	Weak sustainable	2	46	1.4%	Sustainable	2	17.3%
4	No	No	Yes			463	14.0%			
5	No	Yes	Yes	Strong sustainable	3	51	1.6%			
6	Yes	Yes	No	Weak SI	4	503	15.3%	Weak SI	3	50.2%
7	Yes	No	Yes			1,121	34.0%			
8	Yes	Yes	Yes	Strong SI	5	848	25.7%	Strong SI	4	26.2%
Total number of maize plots: 3,295										
Maize-legume intercrop						2,935	89.1%			
Inorganic fertilizer						2,220	80.2%			
Organic fertilizer						1,448	52.3%			

Notes: Figures are based on all maize plots cultivated by balanced panel households in the 2007 and 2010 waves of the Tegemeo Agricultural Policy Research and Analysis household panel survey data set. N=3,295 total maize plots, of which 1,727 are for 2007 and 1,568 are for 2010.
Source: Authors' calculations. See text for details on data sources.

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4. Literature review

In this section, we review the two main strands of literature that are relevant to this study – previous research on: (i) the drivers of adoption of SI and SFM practices in SSA; and (ii) the effects of the NCPB and similar entities in SSA on maize market prices and smallholder farmers' maize price expectations and behavior.

4.1. Drivers of adoption of SI and SFM practices in SSA

While there have been a number of empirical studies on the drivers of adoption of SFM practices in SSA (Kamau et al. 2014; Manda et al. 2016; Teklewold et al. 2013; among others), most utilize a random utility model (Kassie et al. 2015; Manda, Smale, Mutua 2016; Marenya and Barrett 2007; Teklewold, Kassie, and Shiferaw 2013; among others). Although random utility models are common in the literature, they are very general and do not provide much insight on the specific variables that are likely to drive adoption decisions and thus that should be included in one's empirical specification. Moreover (and perhaps related to the previous point), very few studies in this literature consider the role of input prices in adoption, and, to our knowledge, no previous studies on SFM adoption in SSA consider the role of expected output prices. In this study, we build upon previous work in this literature by grounding our empirical model in a more specific theoretical model and by explicitly considering the roles of input and expected output prices.

Two studies that do consider the role of input prices – namely the price of inorganic fertilizer - are Kamau, Smale, and Mutua (2014) for Kenya and Holden and Lunduka (2012) for Malawi. Both find that an increase in the inorganic fertilizer price is associated with a decrease in its use by smallholder farmers, on average and *ceteris paribus*. Their findings differ, however, with regard to the effect of an increase in the inorganic fertilizer price on farmers' use of animal manure and other soil amendments. Holden and Lunduka (2012) find soil amendments to be substitutes for inorganic fertilizer, while Kamau, Smale, and Mutua (2014) find them to be complements. More research is needed to better understand these relationships.

Previous studies do, however, point to three key factors that consistently affect SFM adoption decisions: labor availability, land tenure security, and the gender of the household head. Given that many SFM practices are labor-intensive, labor availability is an important determinant of adoption, particularly when there are labor market imperfections (Feder, Just, and Zilberman 1985). The positive effect of family labor availability on adoption is born out in many empirical studies on the use of animal manure, other non-chemical fertilizer soil amendments, and combinations of SFM practices (Kamau, Smale, and Mutua 2014; Kassie et al. 2013; Kassie et al. 2015; Manda et al. 2016; Marenya and Barrett 2007; Teklewold et al. 2013). However, Koppmair, Kassie, and Qaim (2016) find that the number of prime age adults is negatively associated with manure application, and that seasonal labor is positively associated with manure use and negatively associated with chemical fertilizer use. Kamau, Smale, and Mutua (2014) similarly find a negative relationship between the number of prime age adults and the application of inorganic fertilizer to both maize and non-maize plots.

Land tenure security is also likely to be an important determinant of adoption of SFM practices, particularly those that take time to yield improvements in soil fertility and crop productivity (Feder, Just, and Zilberman 1985). Indeed, empirical findings suggest that use of animal manure and the retention of crop residues are positively correlated with more secure land tenure (Kassie et al. 2013; Kassie et al. 2015; Manda et al. 2016; Ndiritu, Kassie, and Shiferaw 2014). Silberg et al. (2017) find the same for maize-legume intercropping in Malawi. In contrast, some studies suggest that inorganic fertilizer use, which would be expected to yield benefits in the season in which it is applied (especially for nitrogenous fertilizers), increases with greater tenure insecurity (e.g., Asfaw, Manuela, and Lipper 2015; Kassie et al. 2013; Kassie and Holden 2007). However, several other studies find the opposite relationship (Kamau, Smale, and Mutua 2014; Kassie et al. 2015 Koppmair, Kassie, and Qaim 2016).

The role of land tenure security has also been considered in the context of adoption of multiple SFM practices. The results suggest that more secure property rights are associated with a higher likelihood of adoption of a combination of SFM practices or SI as defined by some of the authors (Kassie et al. 2013; Manda et al. 2016; Teklewold, Kassie, and Shiferaw 2013).

Regarding the third common determinant of SFM adoption, gender of the household head, most previous studies suggest that male-headed households are more likely than female-headed households to adopt and use SFM practices such as crop residue retention (Manda et al. 2016), maize-legume rotation (Manda et al. 2016), and inorganic fertilizer (Kassie et al. 2015; Marenya and Barrett 2007; Marenya and Barrett 2009; Murendo et al. 2016). However, Kassie et al. (2015) find that in the specific case of intercropping in Tanzania, adoption is more likely under female household headship than male household headship.

Additionally, work by Berazneva, Conrad, and Guerena (2014) is critical to our study. They develop a dynamic bioeconomic model of soil carbon at the household level in western Kenya. The practices that are examined in detail include the application of inorganic fertilizer and crop residue retention. They find that it is possible to double maize yields and create large stocks of soil carbon by incorporating both of these practices over time. However, to transition the soil from its current fertility level to a higher level requires intensive investment in chemical and organic inputs that is not currently seen in Kenya. These results are sensitive to the discount rate, which is applied to the households' decisions, with higher discount rates resulting in lower investments. While related to the current study, Berazneva, Conrad, and Guerena (2014) do not consider maize-legume intercropping as we do here, nor do they consider the effects of government policies on farmers' adoption of SFM practices.

4.2. The effects of maize marketing boards on maize market prices and smallholder farmers' maize price expectations and behavior in SSA

While, to our knowledge, no previous studies have sought to estimate the effects of entities like the NCPB on smallholder adoption of SFM practices, there have been a handful of studies on the effects of the NCPB and Zambia's equivalent, the Food Reserve Agency (FRA), on maize market prices, smallholders' maize price expectations, and the application of inorganic fertilizer. For example, Jayne, Myers and Nyoro (2008) find that the NCPB's purchases and sales of maize at non-market prices boosted average wholesale maize market prices in Kenya by approximately 20% over the period 1995-2004, and decreased the variability (coefficient of variation) of these prices by over 35%. Mason and Myers (2013) find similar effects for the FRA's practices of purchasing and selling maize at non-market prices in Zambia.

In terms of effects on smallholders' expected price of maize, Mather and Jayne (2011), using the first four waves of the panel data set we use in this study, find that NCPB activities of purchasing maize at non-market prices along with the large quantities of maize purchased raise households' maize price expectations, and that households respond to higher expected maize prices by increasing their use of inorganic fertilizer on maize and by producing larger quantities of maize. We move beyond Mather and Jayne's (2011) research by considering the effects of the NCPB not only on inorganic fertilizer use but also on maize-legume intercropping, organic fertilizer use, and combinations of the three practices and on the degree of SI. For Zambia, Mason, Jayne, and Myers (2015) similarly find that FRA's activities raise farmers' expected maize price, but rather than incentivizing maize intensification (as in the Mather and Jayne finding for Kenya), it instead results in *extensification* of maize production in Zambia. [7] They find that the FRA is incentivizing the expansion of area dedicated to maize production, without reducing the absolute area planted to other plants. They find limited evidence that the increased area being dedicated to maize cultivation is partially coming at the expense of reduced fallow lands.

These findings highlight the potential for NCPB policies to influence smallholder farmers' behavior and technology adoption decisions despite the fact that very few smallholders sell directly to the NCPB. We hypothesize that the NCPB's maize purchase activities affect the adoption of SFM practices through a similar price mechanism. Ultimately, whether NCPB activities incentivize adoption of these practices and affect the degree of SI of maize production in Kenya is an empirical question – hence this study.

5. Conceptual framework

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Rather than take a random utility model approach to modeling smallholder farmers' adoption of SI and SFM practices as most previous studies have done, we instead utilize a profit maximization approach. Profit maximization has been widely used within the SFM adoption literature (e.g., Antle et al. 2006; Oluoch-Kosura, Marenya, and Nzuma,2001; Teklewold et al. 2013; among others). It can be adapted to incorporate time, so that dynamics of the particular technologies are explicitly modeled. Our conceptual model follows that of Morgan et al. (2017), who adapt Berazneva, Conrad, and Guerena's (2014) approach, among others'. Berazneva, Conrad, and Guerena model Kenyan farmers' use of inorganic fertilizers and retention of crop residues and how these practices dynamically change soil organic carbon, which is closely related to SOM. They start from the farmer's profit maximization problem and then incorporate this into an agricultural household model.

Per the seminal work of Singh, Squire, and Strauss (1986), when agricultural households face complete and perfectly competitive markets for land, labor, credit, and insurance (or if only *one* market is missing or imperfect) and the household is the appropriate unit of analysis, then a household's production decisions are separable from its consumption decisions. Although multiple market imperfections or missing markets are likely in the rural Kenyan context (especially for credit and insurance), to maintain tractability of the conceptual model we abstract away from these complexities and assume that separability holds. In this case, the household behaves like a profit-maximizing producer when making its agricultural technology adoption, input demand, and output supply decisions – the first two of which are of interest in this paper.

To model farmer choices over SFM practices, we follow Morgan et al. (2017). Their model uses a discrete dynamic optimization framework where the farmer's objective is to maximize the discounted expected value of profit from a plot over an infinite time horizon. Maize is cultivated on a plot of homogenous quality. We represent a composite measure of soil fertility at the beginning of a season t as x_t, where $t \in \{1, 2, 3, \dots\}$. The application of fertilizers

[7] This is likely related to Zambia having a lower population density than Kenya.

is one determinant of the soil fertility change from t to $t+1$, therefore the quantities of fertilizers applied to the plot are included in the model. Organic fertilizer applied to a plot in the form of animal manure and/or compost in season t is represented by m_t, and inorganic fertilizer applied is represented by f_t. Available SFM practices other than the application of inorganic or organic fertilizer are defined by the discrete set $\mathbf{\Phi}_k$ where $\emptyset_{k,t} \in \mathbf{\Phi}_k$ and denotes the farmer's choice of practices in time period t. It is $\mathbf{\Phi}_k$ that captures maize-legume intercropping in our case, and also SFM practices that we are not analyzed in this study such as fallowing, crop residue retention, and other practices that affect soil fertility. It is the choice of $\emptyset_{k,t}$ in which maize is intercropped with a legume in addition to the choice of f_t and m_t that determine the SI category and ranking of a particular plot in our framework (panel A of table 2). For example, if a plot manager chooses to use no inorganic fertilizer or manure/compost, but intercrops maize and legumes, then $f_t = 0, m_t = 0,$ and $\emptyset_{k,t}$ corresponds to maize-legume intercropping.

Continuing per Morgan et al. (2017), crop yields ($\boldsymbol{y}_{k,t}$) are modeled as a function of the composite measure of soil fertility (x_t), inorganic and organic fertilizer application levels (f_t, m_t), the choices of other practices ($\emptyset_{kt}$), practice-specific labor ($L_{k,t}$), and weather conditions ($\boldsymbol{Z}_t$):

(1) $\boldsymbol{y}_{k,t} = \boldsymbol{y}_{k,t}(x_t, f_t, m_t, \emptyset_{k,t}, L_{k,t}, \boldsymbol{Z}_t)$.

The alternative practices applied to a maize plot require that the production vary based upon the particular choices of any given plot manager. The k subscript on the production function $\boldsymbol{y}_{k,t}$ allows for the production function to vary according to the practices applied to the particular plot. This is particularly important when analyzing the production function of an intercropped maize plot, in which the decision to intercrop has consequences for the production of both the maize and legume crop, for example. This ensures both outputs of intercropped plots are captured in the production function. In addition, the *k* subscript on the labor term allows the labor requirements of each of the practices to vary.

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The soil fertility transition equation (i.e., the change in soil fertility from one season to the next) is defined as

(2) $x_{t+1} = x_t + g_k(x_t, f_t, m_t, \emptyset_{k,t}, L_{k,t}, \boldsymbol{Z}_t)$,

which depends on soil fertility in the previous season as well as the practices applied to the plot. The soil fertility transition equation, $g_k(\cdot)$ varies in functional form depending on the SFM practices applied, so the net gains or losses of practices and combinations are captured accurately.[8] As with Morgan et al. (2017) we assume the initial level of soil fertility is given by

(2.1) $x_0 = \alpha > 0$.

Expected profits in period *t* are:

[8] Antle, Stoorvogel, and Valdivia (2006), show that there are multiple equilibria of soil fertility levels depending on which cultivation (SFM) practices a farmer chooses to apply to a plot from one season to the next. Over multiple seasons, the SFM and cultivation practice choices result in the soil either increasing or decreasing in fertility, which results in either a high fertility soil having higher productivity or the opposite.

(3) $\pi_{k,t}^{e} = \boldsymbol{p_t^e y_{k,t}} - w_t^f f_t - w_t^m m_t - c_{k,t}(x_t, \emptyset_{k,t}) - w_t^L L_{k,t}$

where $\boldsymbol{p}_t^e$ is a vector of expected output prices as of planting to be received at the next harvest and

(4) $\boldsymbol{p_t^e} = (p_t^{m.e}, \boldsymbol{p_{k,t}^{o,e}})$

where $p_t^{m,e}$ is the expected maize price and ($\boldsymbol{p_{k,t}^{o,e}}$) is a vector of prices of the other crops intercropped on the maize plot; w_t^f is the price of inorganic fertilizer; w_t^m is the price of organic fertilizer; $c_{k,t}(x_t, \emptyset_{k,t})$ is the per-plot cost of implementing the SFM practices applied, and w_t^L is the agricultural labor wage.

With respect to the expected output prices, in this study we are mainly concerned with the prices of maize and legumes. We assume naïve expectations for the legume prices. Given our focus on the potential effects of the NCPB on smallholders' adoption of SFM practices/SI through a maize price mechanism, additional care is needed when modeling farmers' expected maize price. To do so, we follow Mason et al. (2015) and Mather and Jayne (2011) and use a quasi-rational expectations-like approach to modeling expected maize prices (Nerlove and Fornari 1998) (equation 5 below). In this approach, a farmer's expected harvest-time maize price is proxied by the predicted value of the harvest-time maize price from a regression of the observed harvest-time maize price on information plausibly known to the farmer as of planting time or at the time that SFM decisions are made. (The empirics of this are discussed in the next section). Since the NCPB does not announce its pan-territorial maize price or how much maize it aims to purchase until harvest time, only past NCPB maize prices and quantities purchased can affect farmers' maize price expectations. We model the expected maize price as a function of these variables ($\boldsymbol{NCPB_{t-1}}$) as well as market factors (e.g., input and lagged output prices, $\boldsymbol{M_{t-1}}$), household characteristics ($\boldsymbol{HH_t}$), and naïve expectations about weather conditions ($\boldsymbol{Z_{t-1}}$):

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(5) $p_t^{m,e} = p^{m,e}(\boldsymbol{NCPB}_{\boldsymbol{t-1}}, \ \boldsymbol{M}_{\boldsymbol{t-1}}, \boldsymbol{HH_t}, \boldsymbol{Z_{t-1}})$

The household's goal is to maximize the discounted value of future profits over an infinite time horizon with respect to the discount factor β . This can be seen in equation 6 below.

(6) $\max_{f_t, m_t, \emptyset_{kt}, L_{it}} \sum_{t=0}^{\infty} \beta^t \left[\pi_{k,t}^{e} = \boldsymbol{p_t^e y_{k,t}} - w_t^f f_t - w_t^m m_t - c_{k,t}(x_t, \emptyset_{k,t}) - w_t^L L_{k,t}\right]$

subject to equations 2, 2.1, 4, and 5 above.

Equation 6 is a reduced form optimization problem faced by the individual farmers. By holding the soil fertility dynamics constant, we are able to solve equation 6 for the optimal levels of inputs ($f_t, m_t,$ and $L_{k,t}$) and optimal choice of SFM practices ($\emptyset_{k,t}$, which in this paper is the choice to intercrop maize with legumes or not). This can be seen in the maximization of profit equation:

$$(7)\ \max_{f_t, m_t, \emptyset_{kt}, L_{kt}} \boldsymbol{p_t^e} \boldsymbol{y_{k,t}} - w_t^f f_t - w_t^m m_t - c_{k,t}\left(x_0, \emptyset_{k,t}\right) - w_t^L L_{k,t}$$

Although a dynamic optimization would be preferred, we use a static optimization setup in order to obtain the current period's expected profit. For each SFM practice (the use of inorganic fertilizer, organic fertilizer, and practices $\emptyset_{k,t}$), first order conditions result in the expected solutions, where the marginal revenue product is equal to marginal factor cost.

Solving for the optimal input levels (f_i^*, m_i^*, L_i^*) given each choice of $\emptyset_{k,t}$ then allows us to solve for the optimal practices ($\emptyset_{k,t}^*$):

$$(8.0)\ \max_{\emptyset_{k,t}} \{\pi_1, \pi_1, \dots\ \pi_n \,|\, f_i^*, m_i^*, L_i^*\}$$

$$(8.1)\ \emptyset_{k,t}^* = f(\boldsymbol{p_t^e}, x_0, \boldsymbol{Z_t}, w_t^f, w_t^m, w_t^L)\ ,$$

In addition to the reduced form for $\emptyset_{k,t}^*$ (equation 8.1), we can solve for the optimal use of inorganic fertilizer, organic fertilizer, and labor, which all have the same theoretical determinants as $\emptyset_{k,t}^*$ (i.e., the same right-hand side variables). Equation 8.1 and its analogues for these inputs guide our empirical specifications below, since in this study, the choice of intercropping the maize with legumes ($\emptyset_{k,t}$) in addition to the choices to use inorganic and/or organic fertilizer determine the SI category and ranking of each plot.

Given this model and the economic theory it reflects, a few hypotheses can be formed. The first hypothesis is that an increase in the lagged NCPB maize price or maize quantities purchased will raise a farm household's expected maize price. In turn, we hypothesize that the household's expected maize price will affect their SFM adoption decisions and these adoption decisions will push the household towards either more or less SI according to our categories and rankings.

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6. Empirical strategy

The main functions from our conceptual framework that we seek to estimate are equations 5 and 8.1. The estimation proceeds in three main steps: (i) estimating the effects of the NCPB's past maize purchase price and quantities purchased, and other factors, on a farmer's expected maize price; (ii) estimating the effects of the expected maize price (and other factors) on a farmer's maize-related SFM and SI decisions; and (iii) combining the results from (i) and (ii) through the use of the chain rule to obtain the estimated effects of the NCPB variables on SFM and SI adoption decisions. All of this analysis is conducted at the plot level and focuses on maize plots only.

6.1. Step 1: Estimating the household's expected maize price

Our empirical model to estimate the effects of the NCPB's past maize purchase prices and quantities on a household's expectation of the maize price it will receive at harvest time is shown in equation 9, which is related to equation 5 in the conceptual framework. Our analysis of SFM adoption decisions focuses on the main growing season only, so the maize price on the left-hand side of equation 9 is for the main growing season.

(9) $p_{i,t}^{m} = \beta_0 + \beta_1 NCPBq_{d,t-1} + \beta_2 NCPBp_{v,t-1} + \beta_3 M_{r,t-1} + \boldsymbol{M_{v,t-1}\beta_4} + \boldsymbol{HH_{i,t}\beta_5} + \boldsymbol{Z_{v,t-1}\beta_6} + c_i + \varepsilon_{i,t}$

(10) $p_{i,t}^{m} = \boldsymbol{\Omega_{w,t-1}\beta} + c_i + \varepsilon_{i,t}$

Where $p_{i,t}^{m}$ is household i's observed maize sale price at harvest time in agricultural year t; the $\boldsymbol{\beta}'$s are vectors of parameters to be estimated; c_i is the time-constant unobserved heterogeneity; and $\varepsilon_{i,t}$ is the time-varying error term. *d* indexes the division, *r* indexes the region, and *v* indexes the village. The scalar $NCPBq_{d,t-1}$ is the lagged division-level quantity of maize purchased by the NCPB. $NCPBp_{v,t-1}$ is the lagged NCPB pan-territorial maize purchase price adjusted for transportation costs from the household's village to the nearest NCPB depot. (The construction of this variable is discussed further in the Data section.) $M_{r,t-1}$ is the lagged plentiful season maize price, which is the three months' post-harvest average maize price at the main wholesale market in the household's region. $\boldsymbol{M_{v,t-1}}$ contains village level input prices for inorganic fertilizer, land rental, and farm labor, among others**.** $\boldsymbol{HH_{i,t}}$ is a vector of household level characteristics as of planting time (e.g. education, distance measures, assets, etc.). One specific set of asset variables that is necessary to discuss in more detail is the transportation asset variables. Due to the low numbers of households that owned transportation assets, we chose to combine all two-wheeled vehicles and all four-wheeled vehicles into one variable for each class.[9] Lastly, $\boldsymbol{Z_{r,t-1}}$ is a vector of regional level rainfall-related variables. See table 3 for a full listing and summary statistics for the variables included in this regression.

Equation 10 is a simplified version of equation 9 to facilitate the following discussion. In equation 10, $\boldsymbol{\beta}$ is the vector of parameters to be estimated and $\boldsymbol{\Omega_{w,t-1}}$ is a composite vector of all of the determinants in equation 9 at the w level, where w is the level at which the data are defined (i.e., $d, r, v,$ and i) and the t-1 subscript here should be interpreted as signifying that all variables are realized at or before planting time . To estimate equation 10, we use correlated random effects pooled ordinary least squares (CRE-POLS). The data used to estimate equation 10 are from sample households that sold maize because it is only for these households that we observe the maize price received at harvest time. 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 ($\boldsymbol{\Omega_{w,t-1}}$) conditional on the unobserved heterogeneity (c_i). That is $\mathrm{E}\left(\varepsilon_{i,t} \middle| \boldsymbol{\Omega_{w,t-1}}, c_i\right) = 0, t = 1,2, \ldots T$, meaning that the observed covariates at any time t are not correlated with the error term $\varepsilon_{i,t}$ at any time t. In addition to strict exogeneity we must assume that $c_i = \psi + \boldsymbol{\bar{\Omega}_w \xi} + a_i$ and $c_i | \boldsymbol{\Omega_w} \sim Normal(\psi + \boldsymbol{\bar{\Omega}_w \xi}, \sigma_a^2)$, where $\boldsymbol{\bar{\Omega}_w}$ is the average of the $\boldsymbol{\Omega_w}$ determinant variables for each household across all time periods 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 the main empirical models (Chamberlain 1984; Mundlak 1978; Wooldridge 2010). One benefit to using CRE over fixed effects (FE), an alternative

[9]Only 22 households owned a motorcycle, 114 for cars, and 15 for trucks. The ownership of a car or truck was combined into one variable, which resulted in 121 observations or 4.36% of sample households. Eight households owned both a car and a truck. Similarly, the 22 observations of households owning a motorcycle were combined with a variable that indicated owning a bicycle. This new variable had 1,247 observations, indicating 47.7% of sample households owned either a bike and/or a motorcycle. Thirteen households owned both a bicycle and a motorcycle.

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

Explanatory variable	Mean	Std. Dev.	Min.	25th Percentile	50th Percentile	75th Percentile	Max
Transportation cost-adjusted NPCB maize price (t-1, real 2010 Ksh/kg)	14.382	6.877	1	9.732	17.034	19.766	27.786
NCPB purchases of maize at divisional level (Mt, t-1)	18.213	70.973	0	0	0	1.192	401.5
Plentiful season average wholesale price of maize (real 2010 Ksh/kg)	28.294	5.76	21.252	24.641	26.413	34.151	40.32
Village median land rental rate (real 2010 Ksh/acre/year)	4426.779	2065.259	1000	3000	4000	5500	12334.26
Village level average CAN price per Kg (real 2010 Ksh)	45.251	6.040	30	41.286	45.222	49.125	67.838
Village level average DAP price per Kg (real 2010 Ksh)	58.523	5.387	40	55	58.79	62.25	75
Village median farm wage (real 2010 Ksh/hour)	21.253	5.832	10	16.67	20.43	25.7	38.54
=1 if female-headed HH	0.225	0.418	0	0	0	0	1
Age of the HH head (years)	59.352	12.965	20	50	59	69	107
=1 if Head has 1-3 years of formal education	0.086	0.281	0	0	0	0	1
=1 if Head has 4-9 years of formal education	0.432	0.495	0	0	0	1	1
=1 if Head has 9-12 years of formal education	0.200	0.400	0	0	0	0	1
=1 if Head has 13 or more years of formal education	0.084	0.277	0	0	0	0	1
Number of prime age adults (age 15 to 59)	3.161	1.913	0	2	3	4.25	16.17
=1 if the HH had stores in the prior survey	0.375	0.484	0	0	0	1	1
=1 if the HH had a cart in the prior survey	0.038	0.191	0	0	0	0	1
=1 if the household had a bicycle or motorcycle in the prior survey	0.046	0.21	0	0	0	0	1
=1 if the household had a car or truck in the prior survey	0.477	0.499	0	0	0	1	1
=1 if the HH had a radio in the prior survey	0.903	0.296	0	1	1	1	1
=1 if the HH had a tv in the prior survey	0.281	0.449	0	0	0	1	1
Value of other assets in prior survey (real 2010 1000s*Ksh)	388.722	1877.876	2.088	58.455	122.957	327.32	61670.45
Km to nearest market place for farm produce	4.211	4.224	0.1	1.5	3	6	31.5
Km to the nearest motorable road	0.457	0.843	0	0.1	0.2	0.5	15
Km to the nearest place to get extension advice	4.794	4.583	0	2	4	6	69
Total landholdings owned as of previous survey (acres)	6.657	14.634	0	2	3.5	6.5	328
Main season rain (mm) t-1	459.842	233.699	38.36	266.95	495.17	643.66	888.67
Fraction of 20 day periods with <40mm rain for main season t-1	0.368	0.294	0	0.08	0.29	0.63	1
Year is 2010 (=1)	0.4936	0.500	0	0	0	1	1

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

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approach to control for time constant unobserved heterogeneity (c_i), is that CRE allows us to utilize all observations of maize sales, whereas FE would only utilize observations for households that sold maize in both of our panel observations (2007 and 2010). In addition to strict exogeneity we assume that the variables included in $\boldsymbol{\Omega_{w,t-1}}$ are known to the household at the time SFM decisions are made, equation 10 is an accurate reflection of household behavior, and that the parameters are time invariant.

Once equation 10 is estimated, we can use the covariates to generate a predicted maize price $\widehat{p_{i,t}^{m}}$ for all households, whether they sold maize or not (per equation 11). This is possible because the values of the observed explanatory variables in equation 10 are known for all households (both maize sellers and non-sellers).

$$(11)\quad \widehat{p_{i,t}^{m}} = \boldsymbol{\Omega_{w,t-1}}\widehat{\boldsymbol{\beta}} + \widehat{c_i}$$

A challenge that we face in estimating equation 10, however, is that only 41.19% of households in our sample sold maize. (We only use maize growing households in our analysis; 98.64% of households in the full dataset grow maize.) This leads to the possibility that the estimates of the parameters in equation 10 are biased due to selection bias if the households that sold maize are non-randomly different in unobserved, time-varying ways from those that chose not to sell. We therefore test for selection bias due to incidental truncation following the procedure outlined in Wooldridge (2002, p. 572). This test involves estimating a CRE Tobit regression in which the dependent variable is the quantity of maize sold by the household and the explanatory variables are the same as in the main maize price regression (equation 10). The residuals from this regression, $\widehat{u_{i,t}}$ are then included as an additional regressor in the maize price regression as shown in equation 12. A t-test of the residuals tests the null hypothesis of no selection bias against the alternative of selection bias. Results of this test suggest that we fail to reject the null of no selection bias in our maize price expectation regression (P>0.10). The results of this test can be seen in column (C) of table 6 below.

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$$(12)\quad p_{i,t}^{m} = \boldsymbol{\Omega_{w,t-1}}\boldsymbol{\beta} + \alpha\ \widehat{u_{i,t}} + c_i + \varepsilon_{i,t}$$

6.2. Step 2: Estimating the effects of the expected maize price and other factors on SFM/SI adoption decisions

To estimate the effects of the expected maize price and other factors on maize growers' plot-level SFM/SI adoption decisions, we bring equation 8.1 for maize-legume intercropping (and its analogues for inorganic and organic fertilizer use) to the data and specify the following general empirical model:

$$(13.0)\quad G_{i,j,t} = \widehat{\boldsymbol{p^{e}}}_{\boldsymbol{t}}\boldsymbol{\gamma_1} + \boldsymbol{w_{v,t}}\boldsymbol{\gamma_2} + \boldsymbol{HH_{i,t}}\boldsymbol{\gamma_3} + \boldsymbol{HH_{i,t-1}}\boldsymbol{\gamma_4} + \boldsymbol{A_{i,j,t}}\,\boldsymbol{\gamma_5} + \boldsymbol{Z_{v,t-1}}\boldsymbol{\gamma_6} + \boldsymbol{X_0}\,\boldsymbol{\beta_7} + c_i + \varepsilon_{i,j,t}$$

$$(13.1)\quad G_{i,j,t} = \boldsymbol{D_w}\boldsymbol{\gamma} + c_i + \varepsilon_{i,j,t}$$

where equation 13.1 is a more compact representation of equation 13.0, and $\boldsymbol{D_w}$ and $\boldsymbol{\gamma}$ capture, respectively, all the explanatory variables and parameters in equation 13.0. G_{ijt} represents the dependent variable of interest, which is either a binary variable equal to one if a given SFM practices was used by household *i* on plot *j* in the main season of agricultural year *t* (and equal to zero otherwise); the SI category of the plot; or the SI ranking of the plot. (The particular estimators used in each case are discussed below). The vector, $\boldsymbol{p_{i,t}^e}$, contains the household's predicted maize price $\widehat{p_{i,t}^m}$ (as a proxy for its expected maize price per section 6.1) and the lagged bean price (as a proxy for its expected legume prices). $\boldsymbol{w_{v,t}}$ is a vector of input prices (for inorganic fertilizer, maize seed, bean seed, agricultural labor, and land rental at the village mean level). $\boldsymbol{HH_{i,t}}$ is a vector of household characteristics including the, sex, age, and education of the household head, number of prime age adults, and distance measures from the household to the nearest market, extension service, and NCPB depot. In addition to these household characteristics we also control for lagged household asset variables ($\boldsymbol{HH_{i,t-1}}$).[10] $\boldsymbol{Z_{v,t-1}}$ captures the lagged weather (rainfall) conditions, which proxy for the household's anticipated weather conditions in season *t,* and also includes a vector of agro-ecological zone (AEZ) indicator variables. The land tenure status of a plot is captured in $\boldsymbol{A_{i,j,t}}$, with the base category being rented-in land, and other tenure types being family owned land, land owned without a deed, and land owned with a deed. $\boldsymbol{X_0}$ is a vector containing two indicator variables for soil fertility. These relate directly to the x_0 variable in our conceptual framework. One dummy variable is equal to one if the soil has moderate soil fertility constraints (and zero otherwise), and the other dummy variable is equal to one if the soil has severe soil fertility constraints (and zero otherwise); the excluded category is no or slight soil constraints. See the data section for more details on the soil variables. See table 4 for a full listing and summary statistics for the variables included in this regression.

As discussed in section 2, in addition to being engaged in maize marketing, the NCPB has also recently begun subsidizing fertilizer and maize seed. Households purchase the subsidized inputs at NCPB depots. Access to the subsidy is controlled for in our regressions via the inclusion of the distance to the nearest NCPB depot variable. Failure to control for access to NCPB subsidized fertilizer could result in omitted variables bias.

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[10] Lagged (last survey) asset variables are used because the current values captured on the survey are as of the time of the interview, which is after the SFM decisions being analyzed are made.

Table 4. Summary statistics of explanatory variables in the SFM adoption regressions

Explanatory variable	Mean	Std. Dev.	Min	25^{th} Percentile	50^{th} Percentile	75^{th} Percentile	Max
Expected (predicted) maize price (real 2010 Ksh/kg)	19.25	1.889	12.466	17.977	19.263	20.488	24.857
Bean price (real 2010 Ksh/kg, regional wholesale, t-1)	69.27	17.172	50.183	50.572	79.236	83.859	99.31
Village level average DAP price per Kg (real 2010 Ksh)	58.523	5.387	40	55	58.79	62.25	75
Maize seed price (Village mean real 2010 Ksh/kg)	66.766	43.191	0	36.3	61.48	89.99	229.73
Bean seed price (Village mean real 2010 Ksh/kg)	12.358	9.501	0	5.38	10.15	17.54	60
Village median farm wage (real 2010 Ksh/hour)	21.253	5.832	10	16.67	20.43	25.7	38.54
Village median land rental rate (real 2010 Ksh/acre/year)	4426.779	2065.259	1000	3000	4000	5500	12334.26
=1 if HH farmed land owned by relative	0.022	0.139	0	0	0	0	1
=1 if HH owns land, but doesn't hold the deed	0.382	0.486	0	0	0	1	1
=1 if HH owns land and holds the deed	0.545	0.498	0	0	1	1	1
=1 if female-headed HH	0.225	0.418	0	0	0	0	1
=1 if Head has 1-3 years of formal education	0.086	0.281	0	0	0	0	1
=1 if Head has 4-9 years of formal education	0.432	0.495	0	0	0	1	1
=1 if Head has 9-12 years of formal education	0.200	0.400	0	0	0	0	1
=1 if Head has 13 or more years of formal education	0.084	0.277	0	0	0	0	1
Age of the HH head (years)	59.352	12.965	20	50	59	69	107
Number of prime age adults (age 15 to 59)	3.161	1.913	0	2	3	4.25	16.17
Km to the nearest NCPB depot	20.892	15.429	0.2	9	17	30	80
Km to the nearest place to get extension advice	4.794	4.583	0	2	4	6	69
Km to the nearest market for farm produce	4.211	4.224	0.1	1.5	3	6	31.5
Plot size in acres	0.702	1.985	0	0.1	0.25	0.75	80
Total landholdings owned as of previous survey (acres)	6.657	14.634	0	2	3.5	6.5	328
Tropical Livestock Units owned as of one year ago	3.628	7.123	0	1.2	2.22	4.15	182.9
Village level average TLU per acre in survey (t-1)	0.654	0.347	0.08	0.42	0.59	0.8	2.67
=1 if HH land is considered moderately nutrient constrained	0.466	0.499	0	0	0	1	1
=1 if HH land is considered severely nutrient constrained	0.137	0.344	0	1	1	0	1
Main season rain (mm) t-1	459.842	233.699	38.36	266.95	495.17	643.66	888.67
Fraction of 20 day periods with <40mm rain for main season t-1	0.368	0.294	0	0.08	0.29	0.63	1
Year is 2010 (=1)	0.4936	0.500	0	0	0	1	1

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

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6.2.1. Logistic regressions of the adoption of individual SFM practices

As a first analysis, we examine plot-level adoption decisions of the individual SFM practices (maize-legume intercropping, the use of inorganic fertilizer, and use of organic fertilizer). In this case,

$$(14.0)\ G_{i,j,t} = \begin{cases} 1 \text{ if household } i\text{'s plot } j \text{ has the particular practice applied} \\ 0 \text{ otherwise} \end{cases}$$

An unobserved latent variable $G^*_{i,j,t}$ is defined such that it takes the form of equation 14.1 with the error term v_{ijt} following a standard logistic distribution:

$$(14.1)\ G^*_{i,j,t} = \boldsymbol{D_w}\boldsymbol{\gamma} + c_i + v_{i,j,t}, \text{ where } G_{i,j,t} = 1 \text{ if } G^*_{i,j,t} > 0, and\ G_{i,j,t} = 0 \text{ if } G^*_{i,j,t} \leq 0$$

These models are estimated via a maximum likelihood CRE logistic regression. The use of CRE here and for the other second step models (CRE multinomial logit and CRE ordered logit) avoids the incidental parameters problem associated with using an FE approach in the context of nonlinear-in-parameters econometric models, especially when the panel is short. The incidental parameters problem causes FE logit estimates, for example, to be inconsistent (Wooldridge 2010, p.271). Equation 14.2 shows the unobserved effects logit specification in which Λ represents the logistic function (Wooldridge 2013).

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$$(14.2)\ P\left(G_{i,j,t} = 1 \middle| \boldsymbol{D_w}, c_i\right) = \Lambda(\alpha_0 + \boldsymbol{D_w}\boldsymbol{\gamma_w} + c_i)$$
$$\text{where } \Lambda(.) = \exp(.)/[1 + \exp(.)]$$

The predicted price of maize $\widehat{p^m_{i,t}}$ being a generated regressor requires that we correct the CRE logit standard errors via bootstrapping in all regressions in which the variable is statistically significant, as was done in Mason, Jayne, and Myers (2015) and Mather and Jayne (2011). This is done for all of the second step models.

6.2.2. Multinomial logit model of SI category (SFM practice combinations)

A CRE multinomial logit regression is used when the dependent variable $G_{i,j,t}$ is the SI category into which a given maize plot falls. Due to a small number of observations in some SI categories in our analytical sample, we have to use a slightly modified set of SI categories for the analysis relative to what is in panel A of table 2. The analytical SI categories are summarized in panel B of table 2. Only 63 maize plots in our sample (1.9%) fall in case 1, which is maize plots where none of the three SFM practices considered are used. Although this case would intuitively make sense to be the base case in both the multinomial and ordered logit models, due to the small number of observations, it cannot be econometrically identified as a separate category. These observations are thus dropped from the analytical sample for all models including the CRE logit models of adoption of individual practices. This case is dropped rather than being combined with another case or SI category because it is fundamentally different from the seven other cases. For case 1, none of the SFM practices considered is applied, whereas all other cases involve the adoption of at least one SFM practice.

Similarly, case 3 and case 5 have too few observations for individual identification with 46 and 51 observations (maize plots), respectively. These cases are combined with case 4 to form a general "sustainable" category that encompasses the original "weak sustainable" (cases 3 and 4) and "strong sustainable" (case 5) categories (see table 2). The new, general "sustainable" category has 560 maize plots, or 17.3% of the sample after case 1 is dropped.

In the CRE multinomial logit regression, the dependent variable ($G_{i,j,t}$) represents the four analytical SI categories: "intensification" (assigned a value of 1), "sustainable" (assigned a value of 2), "weak SI" (assigned a value of 3), and "strong SI" (assigned a value of 4). It is important to note that in the multinomial logit context, the value that the dependent variable takes on in no way indicates an order (i.e. 4 is not better or worse, more or less than 2) (McFadden 1984, Wooldridge 2010). Multinomial logit regression models require that the sum of all probabilities be equal to unity. Equation 15 is the basic form of an unobserved effects multinomial logit model, where $G_{i,j,t}$ is the analytical SI category of a plot, and *b* takes the value associated with this category.

$$(15)\ P\left(G_{i,j,t} = b \middle| \boldsymbol{D_w}, c_i\right) = \frac{\exp\left(\boldsymbol{D_w}\boldsymbol{\gamma_b} + c_i\right)}{1 + \sum_{h=1}^{4} \exp\left(\boldsymbol{D_w}\boldsymbol{\gamma_{h}} + c_i\right)}, b = 1, 2, 3, or\ 4$$

After estimation via maximum likelihood, average partial effects (APEs) are calculated. This allows us to identify how a marginal change in a given determinant affects the probability of being in a given SI categories (Wooldridge 2010).

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6.2.3. Ordinal logit regression of the degree of SI adopted (SI ranking)

The final model we estimate is a CRE ordered logit model of the maize plot-level degree of SI (SI ranking). It is appropriate to apply CRE ordered logit to a dependent variable of SI ranking due to the ordered nature of the variable. Unlike the multinomial logit regression, the ordered logit's dependent variable value is no longer arbitrarily assigned. A plot ranked as a 1 ("intensification" category) on our SI scale in panel B of table 2 is less sustainably intensified than a plot ranked as a 2 ("sustainable" category), which is less sustainably intensified than a plot ranked as a 3 ("weak SI" category), and so on. Comparisons between the differences in ranking is not informative in this model, meaning that the difference between 1 and 2 is not necessarily the same as 2 to 3 and so on. Similar to the other approaches, the ordered logit uses a maximum likelihood approach to estimation (Wooldridge 2010).

The ordered logit model is provided in equation 16.0 below, where we see how the cut points between the differently ranked categories are designed, with μ_n being the estimated threshold cuts between categories ($n = 1, 2, 3, 4$).

$$(16.0)\ G_{i,j,t} = \begin{cases} 1 \text{ if SI category: "Intensification" if } -\infty \le G^*_{i,j,t} \le \mu_1 \\ 2 \text{ if SI category: "Sustainable" if } \mu_1 \le G^*_{i,j,t} \le \mu_2 \\ 3 \text{ if SI category: "Weak SI" if } \mu_2 \le G^*_{i,j,t} \le \mu_3 \\ 4 \text{ if SI category: "Strong SI" if } \mu_3 \le G^*_{i,j,t} \le \infty \end{cases}$$

Equations 16.1 shows the probability that household *i's* plot *j* at time *t* will have a particular ranking, and how the estimated cut points are used in estimating the probabilities a particular plot is within a specific ranking.

$$\boldsymbol{P}\left(G_{i,j,t} = 1 \middle| \boldsymbol{D_w}\boldsymbol{\gamma}, c_i\right) = \boldsymbol{\Lambda}(\mu_1 - \boldsymbol{D_w}\boldsymbol{\gamma_w} + c_i)$$

$$\boldsymbol{P}\left(G_{i,j,t} = 2 \middle| \boldsymbol{D_w\gamma}, c_i\right) = \boldsymbol{\Lambda}(\mu_2 - \boldsymbol{D_w\gamma_w} + c_i) - \boldsymbol{\Lambda}(\mu_1 - \boldsymbol{D_w\gamma_w} + c_i)$$

$$(16.1)\ \boldsymbol{P}\left(G_{i,j,t} = 3 \middle| \boldsymbol{D_w\gamma}, c_i\right) = \boldsymbol{\Lambda}(\mu_3 - \boldsymbol{D_w\gamma_w} + c_i) - \boldsymbol{\Lambda}(\mu_2 - \boldsymbol{D_w\gamma_w} + c_i) - \boldsymbol{\Lambda}(\mu_1 - \boldsymbol{D_w\gamma_w} + c_i)$$

$$\boldsymbol{P}\left(G_{i,j,t} = 4 \middle| \boldsymbol{D_w\gamma}, c_i\right) = 1 - \boldsymbol{\Lambda}(\mu_3 - \boldsymbol{D_w\gamma_w} + c_i)$$

Due to the complex nature of this estimation technique the partial effects equations are also provided in equation 16.2, where p_x $(x = 1,2,3,4)$ is the probability that a plot falls within a specific SI rank:

$$\frac{\partial p_1}{\partial D_k} = -\beta_k\, \boldsymbol{\Lambda}\left(\mu_1 - \boldsymbol{D_w\gamma_w} + c_i\right)$$

$$(16.2)\ \frac{\partial p_4}{\partial D_k} = \beta_k\, \boldsymbol{\Lambda}\left(\mu_4 - \boldsymbol{D_w\gamma_w} + c_i\right)$$

$$\frac{\partial p_x}{\partial D_k} = \beta_k \left[\boldsymbol{\Lambda}\left(\mu_{x-1} - \boldsymbol{D_w\gamma_w} + c_i\right) - \boldsymbol{\Lambda}\left(\mu_x - \boldsymbol{D_w\gamma_w} + c_i\right)\right], \quad \boldsymbol{0 < x < 4}$$

6.3. Step 3: Estimating the effects of the NCPB variables on SFM/SI adoption decisions

Step 3 combines the results from steps 1 and 2 to compute the APE of a given NCPB variable on the SFM/SI outcome of interest using the chain rule:

$$(17)\ \frac{\partial G_{i,j,t}}{\partial NCPB_{\boldsymbol{t-1}}} = \frac{\partial G_{i,j,t}}{\partial\, \widehat{p_{i,t}^m}} X \frac{\partial\, \widehat{p_{i,t}^m}}{\partial NCPB_{\boldsymbol{t-1}}}.$$

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Standard errors for this APE are obtained via bootstrapping to account for the two-step estimation.

6.4. Threats to internal and external validity

We face several threats to internal validity. The most significant relates to the assumptions of the CRE approach. Strict exogeneity may be a strong assumption for some variables. There is an additional cause for concern, which is how the transportation cost-adjusted NPCB maize price variable is constructed. We assume that the reported distance to the nearest NCPB depot is constant over the previous year, however we know that in the previous *four* years this distance has changed for some households in our sample, making it possible that in some cases the distance used to adjust the NCPB price for transportation costs is not accurate. This measurement error could result in biased estimates (Wooldridge 2015). A final threat to internal validity is our sample itself. We use the last two waves of a five-wave panel. Due to the attrition rate being so small from the fourth to the fifth wave we chose to not test for bias as a result of attrition. Attrition bias would arise if the households from the fourth wave that could not be re-interviewed for the fifth wave (32 households, 2.5% of the fourth wave sample) were different in non-random, unobserved ways from the households that were re-interviewed.

Similarly, there exist threats to external validity as well. One key threat is that the NCPB operates in different ways than other grain marketing boards in the region in that during the period of analysis it purchased predominately from traders and large farmers, and very little from smallholder farmers. Also, Kenya is different in many ways from its regional neighbor's; for example, it is more densely populated and land holdings tend to be smaller. In addition to this we already see a high level of SFM practice adoption in Kenya, as can be seen at the bottom of table 2. In addition to this, it is common for empirical studies of adoption to have different findings in different populations; the same would be expected for this research. For these reasons, we should be careful not to overgeneralize the findings to other settings.

7. Data

The data used in our analysis comes primarily from the Tegemeo Institute of Agricultural Policy and Development's "Tegemeo Agricultural Policy Research and Analysis (TAPRA)" household panel surveys.[11] The TAPRA data are a five-wave panel, collected in 1997, 2000, 2004, 2007, and 2010, however our analysis uses only the final two waves. We focus on the final two waves in order to utilize the households' reported distances to their nearest NCPB depot. This information was not captured in previous waves. Attributing the distance from one wave to another is not accurate due to the NCPB operating different depots in different years.

The TAPRA surveys aimed to provide nationwide data on agricultural household activities, such as plot level input decisions, plot level harvest data, agricultural input and output prices, and household assets, among other household information. TAPRA surveys cover 120 villages in 24 districts across the country (Argwings-Kodhek et al.1998). A total of 1,540 rural agricultural households were interviewed in the first survey wave; however, households in two districts (Turkana and Garissa) were not interviewed after 2000 due to these districts primarily having pastoral agricultural activity and low maize production. Of the original 1,540, 1,500 households 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 wave and 1,275 in the final wave.

After removing the first three panel waves, we are left with an analytical sample that draws on the 2007 and 2010 TAPRA surveys and includes 1,275 panel households and 3,295 total maize plots. Almost all of the smallholders in our survey data cultivate maize, however there are 35 (21 in 2007 and 14 in 2010) households that do not. We have removed these households from our analytical sample.

In addition to the TAPRA data, we utilize geo-referenced data from a number of sources. Weather-related variables for historical rainfall are from the CGIAR Climate Research Unit (CRU) (Hijmans et al. 2005) and are at a ten-square km resolution, which we consider to be at approximately the village level. Soil data at the same resolution are from the Harmonized World Soil Database (HWSD 1.2) (FAO/IIASA/ISRIC/ISS-CAS/JRC. 2008). The specific HWSD 1.2 variable that we draw upon for our empirical models is the SQ1 variable, which is a composite measure of nutrient availability that contains information on soil texture, soil organic carbon, soil pH, and total exchangeable bases (the sum of exchangeable cations of important nutrients in the soil (e.g., calcium, magnesium, potassium, sodium, etc.)) (Rayment and Higginson 1992). The SQ1 variable is a categorical variable that has three values, "no or slight constraints," "moderate constraints," and "severe constraints." We convert this to a set of dummy variables, as discussed in the empirical strategy section. Soil and weather variables are merged with the TAPRA data at the village level. The NCPB related variables of maize purchase price and quantities come from the NCPB itself. Finally, the regional wholesale price data used in the analysis were collected over the time of the TAPRA surveys in major wholesale markets (Mather and Jayne 2011).

Regarding data on the SFM practices analyzed here, the TAPRA survey includes manure and compost as individual practices, however we group these together as "organic fertilizer". Of the 1,448 observations of maize plots with organic fertilizer use in the final two panels of the survey, 1,408 were manure and 47 were compost. A few (seven) plots had both manure and compost applied. For the practice of maize-legume intercropping, we focus on the most commonly intercropped legumes in our sample, which are mixed beans, cowpeas, pigeon peas, groundnuts, soy beans, and green grams. A

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[11] The Tegemeo Institute is headquartered in Nairobi, Kenya and is part of the Division of Research and Extension of Egerton University.

breakdown of their individual prevalence as an intercropped legume with maize is shown in table 5. Mixed beans are by far the legume that is most commonly included in maize-legume intercrops (at 81.1% of all maize-legume intercropped plots). Cowpeas are a distant second at 19.8% of maize-legume intercropped plots. From table 2 we see that intercropping was our most commonly observed practice, with almost 90% of maize plots having maize and legumes cultivated together. For the use of inorganic fertilizer, the survey instrument captures many different varieties and blends of inorganic fertilizer, all of which are considered inorganic fertilizer in our analysis. Inorganic fertilizer is applied to 80.2% of maize plots.[12]

One critical variable for our analysis is the price at which the NCPB bought maize in a given agricultural year. The NCPB maize price is pan-territorial but the NCPB only buys maize at its depots, and households incur implicit or explicit transportation costs to move their maize to the depot, reducing the effective NCPB price that they receive. To reflect this, we adjust the NCPB pan-territorial price for approximate transportation costs (per kg of maize) to the nearest NCPB depot. Because there is wide variation (and likely measurement error) in households' reported distances to the NCPB depot among households in a given village, we use the village mean distance to the depot instead of a household's self-reported distance. Maize transportation costs per kg per km are based on village mean transportation costs per kg per km of fertilizer. This is the same approach that was used by Mather and Jayne (2011).

Table 5: Maize-legume intercrops in Kenya by legume type (pooled 2007 & 2010 sample)

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Legume	Number of maize-legume intercropped plots in sample	Percent of maize-legume intercropped plots in sample (N=3,017)	Percent of all maize plots in sample (N=3,387)
Beans	2,381	81.1%	72.3%
Cowpeas	580	19.8%	17.6%
Pigeon pea	159	5.4%	4.8%
Green grams	135	4.6%	4.1%
Ground nuts	53	1.8%	1.6%
Soy beans	30	1.0%	0.9%

Notes: Some maize-legume intercropped plots include more than one legume. Figures are based on all maize-legume intercropped plots (N=2,935) and all maize plots (N=3,295) cultivated by balanced panel households in the 2007 and 2010 waves of the Tegemeo Agricultural Policy Research and Analysis household panel survey data set. Runner beans are excluded from the table due to only 1 plot using them, but this plot is included in the intercropped category for our analysis.
Source: Authors' calculations. See text for details on data source.

8. Results

We begin by reporting the first step results: the estimated effects of the NCPB variables and other factors on a household's expected maize price. We then report the second step results: the effects of the expected maize price and other factors on the household's SFM practice and SI adoption decisions. Finally, we discuss the step three results for the NCPB's influence on the adoption of SFM practices and SI.

[12] The two most commonly used inorganic fertilizers in our data are diammonium phosphate (DAP) and calcium ammonium nitrate (CAN). DAP is applied to 56% of maize plots, while CAN is applied to 29%; 23% 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 on their application.

8.1. Expected maize price determinants

The mechanism through which we expect the NCPB's maize purchase activities (quantities and prices) to influence SFM practice and SI adoption decisions is by influencing a household's expected maize price. Estimation results from the regression of households' maize price received at harvest on NCPB activities in the previous year and other variables observable to households at the time they make SFM practice decisions are shown in table 6. There are three specifications: column A is the main specification as described in the empirical strategy section; column B is a robustness check and includes only purely exogenous variables (i.e., 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 6.1 (because we only observe the maize price received for households that sell maize). The results in all three columns are similar, which increases our confidence in the results. The Tobit residuals are not statistically significant in column C (P=0.448), indicating that we fail to reject the null hypothesis of no selection bias. Given these results, we use the main specification (column A) in the second step analyses of the effects of the expected maize price on households' SFM/SI decisions.

The results in column A suggest that a one shilling increase in the lagged NCPB maize price (about a 7% increase) raises a household's expected maize price by an average of 0.112 Ksh/kg, *ceteris paribus* (P=0.007); that is, roughly 11.2% of the marginal NCPB price increase is passed on to the household's expected maize price. The positive effect of the lagged NCPB price on households' expected maize price is consistent with *a priori* expectations and with previous findings in the literature (e.g., Jayne, Myers, and Nyoro (2008) and Mather and Jayne (2011)). Also, consistent with previous findings in the literature (e.g., Mason, Jayne, and Myers (2015); and Mather and Jayne (2011)), the level of NCPB purchases has no statistically significant effect on households' expected maize price (P=0.346).

In addition to the NCPB-related variables, there are several other statistically significant factors affecting a household's expected maize price. For example, the number of prime age adults (age 15-59) is associated with a higher expected maize price (P=0.067). Having an additional prime age adult (mean number of prime age adults is 3.1) results in a 0.269 Ksh/Kg increase in the price expectation. In addition, we find that compared to the omitted category of no formal education, having a household head in the highest educated category (13 years of education or more) raises the maize price a household can expect to receive (P=0.001). Past rainfall conditions are also significant contributors to the maize price expectation, with an increase of 1 mm of rain in the previous main cropping season decreasing the expected maize price by 0.01Ksh/Kg (P=0.001). Similarly, an increase in rainfall stress during the previous main growing season results in a decrease of the expected maize price (P=0.002). The quantity of rain in the previous season suggests that more rain results in the household expecting lower maize prices. This is intuitive as it suggests that the household would expect a higher supply of maize and therefore lower prices. The result for the fraction of rain stress in the previous season is counterintuitive to economic theory and our expectations. We expected that with an increase of rain-stress there would be an increase in the expected maize price due to reduced supply. More research is needed to identify the reason for this counterintuitive finding.

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Table 6. Maize price regression results (CRE-POLS)

Dependent variable: Maize price received at harvest (real Ksh/Kg)	(A)			(B)			(C)		
Explanatory variables (observed when SFM decisions made)	**Coef.**	**Sig.**	**p-val**	**Coef.**	**Sig.**	**p-val**	**Coef.**	**Sig.**	**p-val**
Transportation cost-adjusted NPCB maize price (t-1, real 2010 Ksh/kg)	0.112	***	0.007	0.107	**	0.011	0.112	***	0.004
NCPB purchases of maize at divisional level (Mt, t-1)	0.002		0.346	0.001		0.545	0.002		0.321
Plentiful season average wholesale price of maize (real 2010 Ksh/kg)	0.021		0.738	0.014		0.827	0.021		0.738
Village median land rental rate (real 2010 Ksh/acre/year)	0.0002		0.354	0.0002		0.39	0.0002		0.341
Village level average CAN price per Kg (real 2010 Ksh)	0.009		0.879	0.012		0.838	0.009		0.876
Village level average DAP price per Kg (real 2010 Ksh)	-0.079		0.14	-0.073		0.161	-0.079		0.121
Village median farm wage (real 2010 Ksh/hour)	0.021		0.716	0.027		0.635	0.021		0.703
=1 if female-headed HH	0.225		0.449	-0.162		0.54	0.225		0.441
Age of the HH head (years)	0.021		0.539	-		-	0.021		0.58
=1 if Head has 1-3 years of formal education	-0.306		0.552	-		-	-0.306		0.545
=1 if Head has 4-9 years of formal education	0.554		0.17	-		-	0.554		0.149
=1 if Head has 9-12 years of formal education	0.565		0.201	-		-	0.565		0.197
=1 if Head has 13 or more years of formal education	2.050	***	0.001	-		-	2.050	***	0.001
Number of prime age adults (age 15 to 59)	0.269	*	0.067	-		-	0.269	*	0.061
=1 if the HH had stores in the prior survey	-0.418		0.157	-		-	-0.418		0.141
=1 if the HH had a cart in the prior survey	-0.645		0.194	-		-	-0.645		0.175
=1 if the household had a bicycle or motorcycle in the prior survey	0.334		0.207	-		-	0.334		0.205
=1 if the household had a car or truck in the prior survey	-0.846		0.29	-		-	-0.846		0.311
=1 if the HH had a radio in the prior survey	-0.566		0.235	-		-	-0.566		0.237
=1 if the HH had a tv in the prior survey	-0.043		0.877	-		-	-0.043		0.885
Value of other assets in prior survey (real 2010 1000s*Ksh)	0.000002		0.986	-		-	0.000002		0.996
Km to nearest market place for farm produce	-0.045		0.33	-0.048		0.277	-0.045		0.329
Km to the nearest motorable road	-0.220		0.289	-0.242		0.24	-0.220		0.298
Km to the nearest place to get extension advice	0.001		0.99	-0.004		0.945	0.001		0.99
Total landholdings owned as of previous survey (acres)	-0.026		0.169	-		-	-0.026		0.196
Main season rain (mm) t-1	-0.010	***	0.001	-0.009	***	0.002	-0.010	***	0
Fraction of 20 day periods with <40mm rain for main season t-1	-6.371	***	0.002	-6.606	***	0.001	-6.371	***	0.001
Year is 2010 (=1)	2.244	***	0.002	2.284	***	0.001	2.244	***	0.002
Residuals from tobit regression	-		-	-		-	-0.00002		0.488

Notes: ***, **, 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 (500 complete replications) to account for the generated regressor (Tobit residuals).
Source: Authors' calculations. See text for details on data sources.

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8.2. Determinants of maize-legume intercropping on maize plots

The results from the CRE logit regressions for the determinants of maize-legume intercropping on maize plots are reported in column A of table 7. We first note that a household's expected (predicted) maize price from our step one analysis has no statistically significant effect on the use of this practice overall (P=0.882). In contrast, the price of the most commonly intercropped legume, beans, is statistically significant and positive. A 1 Ksh/kg increase in bean price raises the probability of intercropping the maize with legumes by 0.6 percentage points (P=0.058), on average and other factors constant. A 1 Ksh/kg increase in the bean price is equivalent to a 1.5% increase in this price from its sample mean. This is the only input or output price that is found to be a significant determinant of the decision to intercrop maize or not. Also, we find no significance for the NCPB distance in this decision (P>0.10).

For land tenure, we find that different tenure statuses are statistically significant (P≤0.10) determinants of maize-legume intercropping, as was found by many others (Manda et al. 2016; Kassie et al. 2013, 2015; Ndiritu, Kassie, and Shiferaw 2014; among many others). The stronger a farmer's land property rights, the more likely they are to adopt intercropping. Relative to rented-in maize plots, maize-legume intercropping is significantly more common on plots that the household owns (with or without a title deed) and on plots owned by a relative of the household (P≤0.001). We find that for plots owned with a deed compared to plots rented, there is an increase of 10.2 percentage points in the likelihood of intercropping, a 7.7 percentage point increase for those owned without deed, and a 6.8 percentage point increase for plots owned by a relative. This is likely because when a farmer is more confident that they will be able to benefit from investments in the soil that mainly manifest after the current year (e.g., maize-legume intercropping), they may be more likely to make such investments.

Expected rainfall conditions also are significant in the model of adopting intercropping. The results suggest that an increase in the lagged quantity of rain (mm) is positively associated with the use of maize-legume intercropping on maize plots (P=0.047). In addition to this determinant, we also note that the plot size is important to the intercropping decision. A one-acre increase (mean maize plot size is 1.37 acres) results in a 1.3 percentage point increase in the probability of intercropping maize and legumes (P=0.049). This could be due to the increased reliance a household has on a larger plot of maize to produce a good harvest. The larger the plot, the more likely it is one of the families' main sources of agricultural income and intuitively, the more likely the household may be protective of its productive capacity and therefore make SFM investments to ensure its future profits. The final statistically significant determinant of adopting intercropping with legumes on a particular maize plot is the village level average tropical livestock units (TLU) per acre from the previous survey. This variable was included in the adoption decision models to act as a proxy for the manure available in the village, which can be used as organic fertilizer. A negative relationship is observed where the greater the density of TLUs, the less likely intercropping is used (P=0.089). Additionally, plot size is found to be a significant determinant of the intercropping decision.

8.3. Determinants of inorganic fertilizer use on maize plots

Results for the CRE logit regression for the use of inorganic fertilizer are reported in column B of table 7. Inorganic fertilizer use is the only individual SFM practice we examine whose adoption is influenced by the NCPB's maize purchase price through the hypothesized maize price mechanism. A one Ksh/kg increase in the expected maize price is associated with a 2.2 percentage point decrease in the probability of inorganic fertilizer use (P=0.072). More research is required to explain this finding, which is not what we would expect to observe. The price of inorganic fertilizer itself is also significant in

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Table 7. Factor affecting use of individual SFM practices on maize plots (CRE-Logit results)

	(A)			(B)			(C)		
Dependent variable:	**Maize-legume intercropping (=1)**			**Inorganic fertilizer (=1)**			**Organic fertilizer (=1)**		
Explanatory variables	**APE**	**Sig**	**p-val.**	**APE**	**Sig**	**p-val.**	**APE**	**Sig**	**p-val.**
Transportation cost-adjusted NPCB maize price (real 2010 Ksh/kg)	-0.001		0.882	-0.022	*	0.072	-0.024		0.176
Bean price (real 2010 Ksh/kg, regional wholesale, t-1)	0.006	*	0.058	0.001		0.685	0.014	***	0.001
Village level average DAP price per Kg (real 2010 Ksh)	-0.004		0.209	-0.007	*	0.054	-0.009	*	0.073
Maize seed price (Village mean real 2010 Ksh/kg)	-0.00005		0.886	-0.0003		0.476	0.0004		0.395
Bean seed price (Village mean real 2010 Ksh/kg)	0.001		0.561	0.0003		0.848	0.005	**	0.019
Village median farm wage (real 2010 Ksh/hour)	-0.005		0.140	0.002		0.442	0.003		0.526
Village median land rental rate (real 2010 Ksh/acre/year)	0.000004		0.740	0.00003	**	0.011	0.00002		0.179
=1 if HH farmed land owned by relative	0.068	***	0.001	-0.163	*	0.087	0.191	**	0.012
=1 if HH owns land, but doesn't hold the deed	0.077	***	0.000	-0.130	***	0.002	0.241	***	0.000
=1 if HH owns land and holds the deed	0.102	***	0.000	-0.104	***	0.003	0.229	***	0.000
=1 if female-headed HH	-0.007		0.726	0.0001		0.996	0.001		0.958
=1 if Head has 1-3 years of formal education	0.023		0.364	0.008		0.824	0.001		0.972
=1 if Head has 4-9 years of formal education	0.001		0.961	-0.007		0.798	-0.010		0.762
=1 if Head has 9-12 years of formal education	-0.001		0.976	0.053	*	0.089	-0.072	*	0.050
=1 if Head has 13 or more years of formal education	0.029		0.412	0.087	**	0.024	-0.006		0.903
Age of the HH head (years)	-0.002		0.390	-0.001		0.587	-0.001		0.860
Number of prime age adults (age 15 to 59)	0.005		0.585	0.002		0.873	0.013		0.342
Km to the nearest NCPB depot	0.0001		0.896	-0.0001		0.857	0.0001		0.953
Km to the nearest place to get extension advice	0.0002		0.940	-0.004		0.190	0.004		0.282
Km to nearest market place for farm produce	0.00002		0.993	0.002		0.448	-0.0004		0.913
Plot size in acres	0.013	**	0.049	0.058	***	0.000	-0.053	***	0.001
Total landholdings owned as of previous survey (acres)	-0.0002		0.886	0.003		0.245	-0.002		0.636
Tropical Livestock Units owned as of one year ago	0.002		0.662	-0.011	**	0.030	0.014	**	0.022
Village level average TLU per acre in survey (t-1)	-0.089	*	0.089	0.003		0.961	0.011		0.883
=1 if soil is moderately constrained	-0.019		0.280	0.028		0.199	-0.00001		1.000
=1 if soil is severe constrained	-0.009		0.743	-0.010		0.722	0.013		0.746
Main season rain (mm) t-1	0.0003	**	0.047	-0.0003	*	0.095	-0.0002		0.470
Fraction of 20 day periods with <40mm rain for main season t-1	-0.176		0.101	-0.278	*	0.071	-0.576	***	0.002
Year is 2010 (=1)	0.263	**	0.036	0.105		0.384	0.462	***	0.000
Agro-ecological zone included	Yes			Yes			Yes		

Notes: ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. p-values based on standard errors clustered at the household level and bootstrapped (500 complete replications) to account for the generated regressor (expected maize price predicted from first stage regression).
Source: Authors' calculations. See text for details on data sources.

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determining the use of inorganic fertilizer (P=0.054). An increase of one Ksh/Kg (about a 1.7% increase) in the DAP fertilizer price decreases the probability that a plot has inorganic fertilizer applied by 0.7 percentage points. The final price that is significant in the decision to use inorganic fertilizer on a plot is the village median land rental rate (P=0.011). For a 1000 Ksh increase per acre per year (about 22.5%), we see an increase of 3 percentage points in the probability of using inorganic fertilizer, on average and all else constant. None of the other price variables are statistically significant determinants of maize-legume intercropping on maize plots.

Inorganic fertilizer use is very high in our sample, with approximately 80% of maize plots having the practice applied, and approximately 84% of households using it on at least one maize plot. Much like adopting maize-legume intercropping, the tenure of the particular plot is an important determinant of adoption of inorganic fertilizer. We see that all tenure statuses compared to rented land have a negative effect on the use of inorganic fertilizer. Compared to all other tenure types, a plot that is rented is 10-16 percentage points more likely to have inorganic fertilizer applied (P≤0.087). It could be the case that if inorganic fertilizer is used on a rented in plot in a non-sustainable way the household is not required to rent (or may not be able to rent) it in the future and therefore does not have to bear the costs of its actions. This is completely dependent though on the soil fertility levels to begin with along with the practices other than inorganic fertilizer use that are applied. Although inorganic fertilizer can be harmful to soil fertility if misused, there are plenty of ways to make it a positive contributor to the building up of soil nutrients.

Somewhat surprisingly, the control for access to NCPB-subsidized fertilizer – the distance to the nearest NCPB depot – is not statistically significant (P=0.857). This may be because of the very low involvement of smallholder farmers in the program during the study period in our sample, or due to other factors.[13] Plot size is a statistically significant (P=0.000) determinant of the use of inorganic fertilizer as well: the larger the maize plot, the higher the probability of a farmer using inorganic fertilizer on it. We estimate that for a one acre increase in plot size, there is a corresponding increase of 5.8 percentage points in the probability of using inorganic fertilizer on the plot. This may be due to the increased reliance a household may have on larger plots of maize to produce a good harvest, knowing that the use of inorganic fertilizer is likely to result in higher expected yields. Animal holdings as of the previous survey are also a statistically significant (P=0.030) determinant of inorganic fertilizer use on maize plots. The more animals held previously, the less likely the household is to apply inorganic fertilizer, suggesting that perhaps the household instead uses organic fertilizer derived from its livestock.

Finally, the rainfall-related variables are again statistically significant in the probability of use of inorganic fertilizer (P=0.095 for total rainfall and P=0.071 for fraction of rain stress periods in previous main season). With an increase in the previous season's rain stress we observe a decrease in the probability of using inorganic fertilizer. This is likely the case because fertilizer requires larger amount of rain and if the needed rain or water does not occur, maize yields can be less than without the inorganic fertilizer being applied. Unexpectedly, we also see that an increase in rain also has a negative APE, suggesting that an increase in total rainfall of 100 mm (about 21%) results in 3 percentage point loss in likelihood of adopting inorganic fertilizer; however, this effect is not precisely measured (P=0.095). This could be due to the

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[13] Only 1.69% of sample households obtained NCPB fertilizer in 2010.

varied nature of the rains in the previous main seasons, but more research is required to fully understand this relationship. [14]

8.4. Determinants of organic fertilizer use on maize plots

Results for the CRE logit regression for the use of organic fertilizer are reported in column C of table 7. There are several price related variable that are statistically significant determinants of plot-level adoption decisions for organic fertilizer use on maize. We find that for an increase of one Ksh/Kg in the bean output price (about 1.5%), a maize plot is 1.4 percentage points more likely to have organic fertilizer applied to it (P=0.001). The bean seed input price is also a significant determinant. For a one Ksh/Kg increase in the bean seed input price at planting time, the household is 0.5 percentage points more likely to apply organic fertilizer. This may suggest that as the price of bean seed for planting increases, the household shifts from intercropping maize and legumes to using organic fertilizer; however we found no evidence of this on the decision to adopt maize-legume intercropping.

Similar to the case of intercropping, the results also suggest that stronger land tenure increases the probability of use of organic fertilizer, with family owned or household owned land being more likely to have organic fertilizer applied than rented in land. More specifically, compared to rented in land, maize plots that are family owned, or owned without or with a deed are at least 19.1 percentage points more likely to have organic fertilizer applied to them. This is likely for similar reasons as those provided in section 8.2. Additionally, plot size is negatively correlated with the use of organic fertilizer (P=0.001), with results suggesting that a one acre increase in plot size results in a 5.3 percentage point decrease in probability of use. This could be that the household does not have access to the quantity of organic fertilizer needed to cover larger fields. They may choose to apply the organic fertilizer they have access to on smaller fields where they have the ability to apply more appropriate quantities of organic fertilizer instead of applying it thinly over a larger field.[15] We also note a similar negative effect with the rain stress variable as we found in the other SFM practices, suggesting that consistent rain is desirable for organic fertilizer use (P=0.002).

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A plot is more likely to have organic fertilizer applied if the household had more TLUs in the previous survey. This is consistent with *a priori* expectations, given that having more TLUs likely means that a household has greater access to organic fertilizer. However, greater availability of organic manure in a household's village, which we proxy by average TLUs per acre in the village, is not statistically significant.[16] This may suggest that most farmers obtain manure from their own animal assets.

8.5. Effects of the lagged NCPB maize price on the adoption of individual SFM practices

Combining the results of step 1 with the logit model results in step 2, we compute the APE of the lagged NCPB maize price on the adoption of individual SFM practices. (Due to the

[14] This was also confirmed by the UN WFP Kenya-Long Rains Assessment for both seasons of interest (WFP 2008; WFP 2010).

[15] The mean size of all maize plots is 1.37 acres, while the mean size of maize plots with organic fertilizer applied is 1.00 acres.

[16] Because fertilizer is applied to an area of land, we have chosen to define this variable as TLU density (per acre), as opposed to the more common TLUs per village.

NCPB purchase quantity not being found to be a significant determinant of the expected maize price, no analysis of its affect is conducted.) The expected maize price has no statistically significant effect on the probability that a maize plot is maize-legume intercropped or has organic fertilizer applied to it (table 7), hence the NCPB price has no statistically significant effects on these practices. For inorganic fertilizer, though, the expected maize price is negative and statistically significant, and the combined first and second step results suggest that the NCPB is also negative and statistically significant. A 1 Ksh/Kg increase in the lagged NCPB maize price is associated with 0.3 percentage point reduction in the probability of inorganic fertilizer being applied to a maize plot (P=0.005). Intuitively, we would expect a household to respond to a higher maize price by attempting to increase maize yields and one way of doing this is through inorganic fertilizer application; however we do not find this relationship in our analysis.

8.6. Determinants of the SI category and SI ranking of maize plots

Results from the CRE multinomial logit and CRE ordered logit models for the SI category and SI ranking of maize plots are reported in columns A and B, respectively, in table 8. To facilitate the discussion of these determinants in both models and to examine the prices effects on adoption more closely, we first discuss the important price-related variables and then discuss the other determinants of adoption in both models.

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8.6.1. Prices effects

For the multinomial logit where the order is not considered we observe that only the category “Strong SI” is affected by the expected maize price. A one Ksh/Kg increase in this expected price results in a decreased likelihood of strong SI by 2.3 percentage point (P=0.093). This finding is backed up by the results of the ordered logit model: for SI rank 4 we observe the exact same finding of a 2.3 percentage point decrease in use for the same change in the expected maize price (P=0.019). In addition, the ordered logit results suggest that SI ranks 1, 2, and 3 are positively affected by the expected maize price. More specifically, a one Ksh/Kg increase in the expected maize prices results in a0.7-0.8 percentage point increase in the probability of each of these SI rankings ($P \leq 0.021$).

Bean prices affect the probability of some SI categories and all SI rankings. A 1 Ksh/Kg increase in the lagged bean price results in a 0.6 percentage point decrease in the probability of a maize plot being in the “Sustainable” SI category and an increase of 1.7 percentage points for the “Strong SI” category ($P \leq 0.047$). The ordered logit results are identical for the corresponding SI rankings (2 and 4). No other SI categories are significantly affected by the bean price per the multinomial logit results but the ordered logit results suggest that an increase in the bean price also negatively affects the probability of an SI ranking of 2 or 3. Overall, the results for rankings 1, 2, and 3 suggest that a 1 Ksh/Kg increase in the lagged bean price is associated with a 0.5 to 0.6 percentage point decrease in the probability of a maize plot having that rank (P=0.000 for all). This may suggest that as the bean price increases, the household attempts to capture both the benefits of SI through increased adoption of “Strong SI” and could also be responding to the price incentive of possibly higher bean related profits.

The price of DAP fertilizer, the form of inorganic fertilizer most commonly used in our survey data, is also an important determinant for all SI rankings and some of the SI categories. In the multinomial logit we observe that a 1 Ksh/Kg increase in the price of DAP (roughly a

1.8% increase) results in a 0.9 percentage point increase in the use of the “Weak SI” category (P=0.060), while at the same time resulting in a decrease of 1.4 percentage points in the probability of using the “Strong SI” Category (P=0.001). The ordered logit results suggest positive DAP price effects on SI rankings 1 through 3, and negative effects on SI ranking 4. The farm wage, being important in the labor input decisions of households, is a statistically significant determinant in the multinomial logit model but not in the ordered logit model. A 1 Ksh/hour increase in the wage (about 4.7%) increases the probability of using the category “Sustainable” by 0.5 percentage points (P=0.069), but decreases the probability of using the category “Weak SI” by 1.6 percentage points (P=0.002). Another input price found to have any influence on household adoption decisions is the bean seed price. An increase of one Ksh results in a 0.6 percentage point decrease in the likelihood of using “Weak SI” (P=0.015) and a 0.5 percentage point increase in the probability of using “Strong SI” (p=0.012). Neither the farm wage nor the bean seed price has a significant impact on the SI ranking of the maize plot.

The final statistically significant price-related determinant to examine is the land rental price. When land rental prices increase by 100 Ksh/acre (about 2% increase), categories “Weak SI” and “Strong SI” are more likely to be used (by 0.5 and 0.4 percentage points, respectively) (P<0.01). Per the ordered logit results, SI rankings 1 through 3 are less likely (by 0.1 percentage points each) and SI ranking 4 is 0.4 percentage points more likely (P≤0.007). The maize seed price is the only price-related variable that is not a statistically significant determinant of any SI category or SI ranking. These price-related findings are summarized in table 9.

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Table 8. Factor affecting the SI category and SI ranking of maize plots (CRE Multinomial and Ordered Logit results)

	(A) Multinomial Logit				(B) Ordered Logit			
Explanatory variables	**SI Category**	**APE**	**Sig.**	**P-val.**	**SI Ranking**	**APE**	**Sig.**	**P-val.**
Expected (predicted) maize price (real 2010 Ksh/Kg)	Intensification	0.008		0.286	1	0.007	**	0.020
	Sustainable	-0.006		0.518	2	0.008	**	0.021
	Weak SI	0.021		0.160	3	0.007	**	0.019
	Strong SI	-0.023	*	0.093	4	-0.023	**	0.019
Bean price (real 2010 Ksh/kg, regional wholesale, t-1)	Intensification	-0.007		0.285	1	-0.005	***	0.000
	Sustainable	-0.006	**	0.047	2	-0.006	***	0.000
	Weak SI	-0.003		0.643	3	-0.005	***	0.000
	Strong SI	0.017	***	0.000	4	0.017	***	0.000
Village level average DAP price per Kg (real 2010 Ksh)	Intensification	0.003		0.365	1	0.003	***	0.001
	Sustainable	0.002		0.519	2	0.004	***	0.001
	Weak SI	0.009	*	0.060	3	0.003	***	0.001
	Strong SI	-0.014	***	0.001	4	-0.010	***	0.000
Maize seed price (Village mean real 2010 Ksh)	Intensification	-0.0001		0.675	1	0.0001		0.435
	Sustainable	0.0002		0.565	2	0.0001		0.433
	Weak SI	-0.0002		0.713	3	0.0001		0.437
	Strong SI	0.0001		0.760	4	-0.0003		0.433
Bean seed price (Village mean real 2010 Ksh)	Intensification	-0.001		0.515	1	-0.001		0.118
	Sustainable	0.002		0.284	2	-0.001		0.119
	Weak SI	-0.006	**	0.015	3	-0.001		0.124
	Strong SI	0.005	**	0.012	4	0.003		0.118
Village median farm wage (real 2010 Ksh/hour)	Intensification	0.006		0.148	1	0.001		0.257
	Sustainable	0.005	*	0.069	2	0.002		0.257
	Weak SI	-0.016	***	0.002	3	0.001		0.255
	Strong SI	0.005		0.191	4	-0.004		0.253
Village median land rental rate (real 2010 Ksh/acre/year)	Intensification	0.00001		0.334	1	-0.00001	***	0.007
	Sustainable	0.00000		0.737	2	-0.00001	***	0.007
	Weak SI	-0.00005	***	0.009	3	-0.00001	***	0.007
	Strong SI	0.00004	***	0.004	4	0.00004	***	0.006
=1 if HH farmed land owned by relative	Intensification	-0.048	**	0.011	1	-0.029	**	0.035

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	Sustainable	-0.001		0.977	2	-0.035	**	0.042
	Weak SI	-0.106		0.237	3	-0.055		0.184
	Strong SI	0.155		0.114	4	0.119	*	0.094
=1 if HH owns land, but doesn't hold the deed	Intensification	-0.057	***	0.000	1	-0.052	***	0.000
	Sustainable	-0.056	***	0.001	2	-0.057	***	0.000
	Weak SI	-0.101	**	0.010	3	-0.062	***	0.000
	Strong SI	0.213	***	0.000	4	0.171	***	0.000
=1 if HH owns land and holds the deed	Intensification	-0.079	***	0.000	1	-0.058	***	0.000
	Sustainable	-0.039	**	0.050	2	-0.056	***	0.000
	Weak SI	-0.087	**	0.021	3	-0.050	***	0.000
	Strong SI	0.205	***	0.000	4	0.164	***	0.000
=1 if female-headed HH	Intensification	-0.001		0.932	1	0.002		0.740
	Sustainable	0.008		0.586	2	0.002		0.733
	Weak SI	-0.006		0.824	3	0.002		0.733
	Strong SI	0.000		0.995	4	-0.007		0.734
=1 if Head has 1-3 years of formal education	Intensification	-0.028		0.203	1	-0.004		0.738
	Sustainable	0.025		0.315	2	-0.004		0.735
	Weak SI	-0.009		0.822	3	-0.004		0.739
	Strong SI	0.013		0.748	4	0.011		0.735
=1 if Head has 4-9 years of formal education	Intensification	-0.005		0.829	1	0.003		0.720
	Sustainable	0.004		0.824	2	0.003		0.716
	Weak SI	0.025		0.480	3	0.003		0.727
	Strong SI	-0.025		0.451	4	-0.010		0.719
=1 if Head has 10-12 years of formal education	Intensification	-0.009		0.722	1	-0.002		0.871
	Sustainable	-0.024		0.282	2	-0.002		0.869
	Weak SI	0.054		0.191	3	-0.002		0.867
	Strong SI	-0.022		0.569	4	0.005		0.868
=1 if Head has 13 or more years of formal education	Intensification	-0.047	*	0.076	1	-0.008		0.552
	Sustainable	0.034		0.384	2	-0.009		0.545
	Weak SI	-0.004		0.948	3	-0.009		0.558
	Strong SI	0.017		0.756	4	0.026		0.548
Age of the HH head (years)	Intensification	-0.001		0.408	1	0.001		0.337
	Sustainable	0.003		0.208	2	0.001		0.340
	Weak SI	0.001		0.723	3	0.001		0.345

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	Strong SI	-0.003		0.387	4	-0.003		0.339
Number of prime age adults (age 15 to 59)	Intensification	-0.008		0.274	1	-0.002		0.567
	Sustainable	0.010		0.169	2	-0.002		0.562
	Weak SI	-0.004		0.764	3	-0.002		0.566
	Strong SI	0.002		0.842	4	0.006		0.564
Km to the nearest NCPB depot	Intensification	0.0002		0.665	1	-0.0004		0.186
	Sustainable	-0.002	***	0.007	2	-0.0004		0.187
	Weak SI	0.002		0.218	3	-0.0004		0.190
	Strong SI	0.0003		0.793	4	0.001		0.184
Km to the nearest place to get extension advice	Intensification	-0.002		0.447	1	0.0002		0.778
	Sustainable	0.002		0.296	2	0.0003		0.774
	Weak SI	-0.001		0.760	3	0.0002		0.780
	Strong SI	0.0001		0.963	4	-0.001		0.777
Km to nearest market place for farm produce	Intensification	0.0004		0.834	1	0.0001		0.931
	Sustainable	0.001		0.600	2	0.0001		0.930
	Weak SI	-0.003		0.518	3	0.0001		0.932
	Strong SI	0.001		0.834	4	-0.0003		0.931
Plot size in acres	Intensification	-0.002		0.561	1	-0.006	**	0.032
	Sustainable	-0.033	***	0.004	2	-0.007	**	0.033
	Weak SI	0.036	***	0.007	3	-0.006	**	0.035
	Strong SI	-0.001		0.964	4	0.019	**	0.031
Total landholdings owned as of previous survey (acres)	Intensification	0.0002		0.853	1	-0.001		0.391
	Sustainable	-0.002		0.371	2	-0.001		0.395
	Weak SI	-0.002		0.672	3	-0.001		0.399
	Strong SI	0.003		0.459	4	0.002		0.393
Tropical Livestock Units owned as of one year ago	Intensification	-0.004		0.306	1	-0.0004		0.856
	Sustainable	0.004		0.257	2	-0.0004		0.855
	Weak SI	-0.001		0.878	3	-0.0003		0.857
	Strong SI	0.0001		0.988	4	0.001		0.856
Village level average TLU per acre in survey (t-1)	Intensification	0.044		0.481	1	0.005		0.783
	Sustainable	-0.039		0.333	2	0.005		0.780
	Weak SI	0.022		0.799	3	0.005		0.784
	Strong SI	-0.027		0.700	4	-0.015		0.782
=1 if soil is moderately constrained	Intensification	-0.008		0.669	1	-0.004		0.575

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	Sustainable	0.047	**	0.018	2	-0.004		0.574
	Weak SI	-0.053	*	0.058	3	-0.004		0.578
	Strong SI	0.014		0.527	4	0.011		0.575
=1 if soil is severe constrained	Intensification	-0.029		0.237	1	-0.006		0.541
	Sustainable	0.069	**	0.025	2	-0.007		0.540
	Weak SI	-0.061		0.132	3	-0.007		0.573
	Strong SI	0.020		0.577	4	0.019		0.549
Main season rain (mm) t-1	Intensification	-0.0003		0.125	1	0.00001		0.845
	Sustainable	-0.0002		0.257	2	0.00001		0.842
	Weak SI	0.001	***	0.008	3	0.00001		0.845
	Strong SI	-0.0003		0.264	4	-0.00004		0.844
Fraction of 20 day periods with <40mm rain for main season t-1	Intensification	0.132		0.152	1	0.274	***	0.000
	Sustainable	0.368	***	0.005	2	0.291	***	0.000
	Weak SI	0.352	*	0.084	3	0.267	***	0.000
	Strong SI	-0.852	***	0.000	4	-0.831	***	0.000
=1 if year is 2000	Intensification	-0.277	*	0.097	1	-0.305	***	0.000
	Sustainable	-0.126		0.312	2	-0.095	***	0.000
	Weak SI	-0.073		0.530	3	-0.065	***	0.000
	Strong SI	0.475	***	0.000	4	0.465	***	0.000

Notes: ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. p-values based on standard errors clustered at the household level and bootstrapped (500 complete replications) to account for the generated regressor (expected maize price predicted from first step regression).
Source: Authors' calculations. See text for details on data sources.

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8.6.2. Effects of the lagged NCPB maize price on the SI category and SI ranking of maize plots

The effects of the NCPB maize price on the SI category and SI ranking of maize plots are summarized in table 10. These results combine the step 1 results and the step 2 multinomial logit and ordered logit results. The multinomial logit results suggest that a 1 Ksh/kg increase in the NCPB maize price (about a 7% increase) has a negative and statistically significant effect on the probability of a maize plot being in the "Strong SI" category (P=0.060). The ordered logit results suggest that an increase in the NCPB price is associated with 0.1 percentage point increases in the probability of SI rankings 1 through 3, and a 0.3 percentage point decrease in the probability of SI ranking 4 (P≤0.013). Due to the agreement between the models on direction of influence for "Strong SI" and SI ranking 4, we are most confident that an increase is the NCPB price induces households to move away from using all three SFM practices together on a given plot.

Taken together, the multinomial and ordered logit results suggest that an increase in the NCPB maize price likely incentivizes "Intensification"(SI rank 1), "Sustainable"(SI rank 2), and "Weak SI" (SI rank 3) while having a negative effect on the use of "Strong SI" (SI rank 4). With "Strong SI"/SI rank 4 being the set of practices with the greatest potential to contribute to SI of maize-based systems,, this may suggest that the NCPB is shifting maize management practices towards slightly less sustainable combinations.

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8.6.3. Non-Price determinants of the SI category and SI ranking of maize plots

As discussed in the literature review, several non-price variables have also been important determinants of the adoption of sustainable agricultural technologies in previous studies. The first is the tenure status of land (e.g., Manda et al. 2016; Kassie et al. 2013, Kassie et al. 2015; Ndiritu, Kassie, and Shiferaw 2014; among many others). There is wide agreement between our two models for the land tenure-related results. The multinomial logit reveals that a plot owned without a deed is 5.7 percentage points less likely to be in the "Intensification" category relative to a rented in plot, 5.6 percentage points less likely to be in the "Sustainable" category, and 1.01 percentage points less likely to be in the "Weak SI" category, but 2.13 percentage points more likely to be in the "Strong SI" category (P≤0.010). Very similar results are found in the multinomial logit model for land that is owned with a deed, and in the ordered logit model for the corresponding SI rankings. In the ordered logit, we also see that the tenure category of land owned by a relative is statistically significant in a negative relationship with SI rankings 1 and 2 (P≤0.042), while ranking 4 (strong SI) is positive and statistically significant (P=0.094), suggesting that households in Kenya treat the land belonging to their relatives in a similar fashion as they do land belonging to themselves. This may suggest that they either expect to be able to derive the benefits of a stronger application of SI from family land in the future or there is a mechanism of cultural responsibility and respect towards family belongings.

Table 9: Summary of the effects of prices on the SI category and SI ranking of maize plots

An increase in:	"Intensifi-cation"	"Sustainable"	"Weak SI"	"Strong SI	SI rank 1	SI rank 2	SI rank 3	SI rank 14
	Multinomial logit: SI category				Ordered logit: SI ranking			
NCPB purchase price through expected maize price	0	0	0	-	+	+	+	-
Expected maize price	0	0	0	-	+	+	+	-
Lagged bean price	0	-	0	+	-	-	-	+
DAP price	0	0	+	-	+	+	+	-
Maize seed price	0	0	0	0	0	0	0	0
Bean seed price	0	0	-	+	0	0	0	0
Farm wage	0	+	-	0	0	0	0	0
Land rental rate (price/acre)	0	0	-	+	-	-	-	+

Notes: 0 indicates no statistically significant effect of a change in the price (p>0.10); + (-) represents a positive (negative) and statistically significant (p≤0.10) relationship between the category/ranking and price.
Source: Summarized from tables 8 and 10. See text for details on data sources.

Table 10. Effects of the lagged NCPB maize price on the SI category and SI ranking of maize plots (combined results of step 1 and the step 2 CRE multinomial and ordered logit models)

	(A) SI category				**(B) SI ranking**			
Explanatory variables	**SI Category**	**APE**	**Sig.**	**P-val.**	**SI Ranking**	**APE**	**Sig.**	**P-val.**
Transportation cost-adjusted NPCB maize price (t-1, real 2010 Ksh/kg)	Intensification		*0*		1	0.001	**	0.013
	Sustainable		*0*		2	0.001	**	0.013
	Weak SI		*0*		3	0.001	**	0.011
	Strong SI	-0.003	*	0.060	4	-0.003	**	0.012

Notes: ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively and *0* denotes that there was found to be no expected maize price effect, so no NCPB price effect. p-values based on standard errors clustered at the household level and bootstrapped (500 complete replications) to account for the multi-step analysis.
Source: Authors' calculations. See text for details on data sources.

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Plot size has also been shown to be an important determinant by other studies and is significant in our results as well. Kassie et al. (2015) and Ndiritu, Kassie, and Shiferaw (2014) in Kenya find a negative relationship between plot size and intercropping, with which our findings disagree in the case of the logit regression (a one acre increase in plot size is associated with a 1.3 percentage point increase in probability of use, P=0.049); however, in our multinomial and ordered logit regressions, results are mixed. Ndiritu, Kassie, and Shiferaw (2014) and Kamau, Smale, and Mutua (2014) find a positive relationship between plot size and inorganic fertilizer use in Kenya as well, which we also observe in our logit results (a one acre increase in plot size is associated with a 5.8 percentage point increase in probability of use, P=0.000); however again the ordered logit and multinomial logit results are mixed. These mixed results suggest that more research is needed into the effects of plot size on adoption decisions of different SFM practices and combinations thereof.

An NCPB-related but non-price determinant of adoption is the distance to the nearest NCPB depot, which is used as a proxy for household access to the NCPB input subsidy. In our results, we find that this determinant has no effect on the use of practice combinations in the multinomial logit model except for the "Sustainable" category. For a 1 Km increase in the distance of a household from the nearest depot, there is a decrease of 0.2 percentage points in the probability of a plot being in the "Sustainable" category (P=0.007). The explanation for this is unclear, as we might expect an increase in distance would raise the probability of "Sustainable". Surprisingly, no changes are observed in the categories or rankings involving the application of inorganic fertilizer. In general, the distance to the NCPB depot has little or no statistically significant effect on the SI category or SI ranking of maize plots.

We find that the sex of the household head has no statistically significant effect on the SI category or SI ranking of maize plots. For the most part, we find no significance to the adoption decision for the household head's education and age as well. We also observe that if soil nutrient availability is moderately constrained relative to the base category of no/slight constraints the use of the category "Sustainable" is 4.7 percentage points more likely, while the use of the category "Weak SI" is 5.3 percentage points less likely ($P \leq 0.06$). If soil nutrient availability is severely constrained relative to no/slight constraint then it is 6.9 percentage points more likely to be in the "Sustainable" category (P=0.025). Soil quality is not found to be a statistically important determinant of the SI ranking of maize plots.

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9. Conclusions, policy implications, and areas for further study

Kenya and numerous other countries in SSA face challenges associated with declining soil fertility and its negative effects on maize yields and agricultural productivity more generally (Eicher 2009; Montpellier Panel 2013; NAAIAP 2014). Sustainable intensification (SI) is a framework to think about how cultivation practices are affecting the sustainability of yields into the future along with other desired outcomes (Pretty and Bharucha 2014; Royal Society 2009; Garnett and Godfray 2012). Soil fertility management (SFM) practices have the potential to contribute to SI, slowing or reversing soil fertility declines (Liebman and Dyck 1993; Snapp et al. 2010). To promote these SFM practices and SI we need to better understand how government policies influence their adoption by households. A major policy that has again become popular in several SSA countries is maize price support programs, which are typically implemented by maize marketing boards. The activities of these boards may have unintended consequences of pushing farmers away from some SFM technology combinations and towards others, potentially resulting in *unsustainable* intensification of maize production. This study addresses the question of whether the Kenyan NCPB's maize purchase activities affect the decisions of smallholders in Kenya to adopt critically important SFM farming practices and the degree of SI of their maize production. We also analyze the effects of input and crop output prices on these adoption decisions – variables that economic theory predicts will be important determinants but that most previous studies on SFM adoption have ignored.

This analysis is based on categorizing combinations of SFM practices and ranking them by their potential to contribute to SI in maize-based systems (Kim, Mason, and Snapp 2017). The three practices considered are the intercropping of maize and legumes, the application of inorganic fertilizer, and the application of organic fertilizer. The lowest ranking we use is associated with the use of inorganic fertilizer only (SI category "Intensification", SI rank 1). Applying organic fertilizer and/or intercropping the maize with legumes is assigned to a SI category of "Sustainable" and SI ranking of 2. Integrating inorganic fertilizer with one of the practices in the "Sustainable" SI category is deemed the "Weak SI" category/SI rank 3. Finally, integrating all three practices together results in the highest degree of SI in our framework and categorized as "Strong SI"/SI rank 4.

The main conclusions of this article are that increases in the previous year's NCPB price raise households' expected maize price, which in turn induces them to decrease their use of the package of SFM practices with the highest potential to contribute to SI in maize-based systems ("Strong SI"/SI ranking 4). At the same time, an increase in the previous year's NCPB price increases the use of sets of practices with lower SI rankings (1, 2, and 3). Some of these may be beneficial to longer-term soil health, but to a lesser degree than the highest SI ranked-package. This is likely the case for "Weak SI"/SI rank 3 but probably not the case for "Sustainable"/SI rank 2 and especially "Intensification"/SI rank 1. This raises questions as to whether the NCPB is stimulating maize production increases that can be sustained over time or that are short-lived.

Findings also suggest that several different input and expected output prices are statistically significant determinants of households' SFM adoption decisions and the degree of SI of their maize production. Increases in a farmer's expected maize price and in the price of inorganic fertilizer raise the probability of their maize plots having an SI ranking of 1, 2, or 3 on the 4-point scale, but reduce the probability of an SI ranking of 4. This finding is not necessarily what we would expect and further research is needed to fully understand this relationship. The opposite pattern holds for the expected bean price – the legume that is most commonly intercropped with maize in Kenya – and for the land rental price; increases in these prices reduce the probability that a maize plot has an SI ranking 1, 2, or 3, and raise the probability of it having the highest SI ranking of 4. Changes in the other input prices considered (the maize seed price, bean seed price, and farm wage rate) have little or no effect on the SI category or ranking of maize plots. The observed relationship with land rental prices may be a good sign for Kenya's future in particular, with increasing land rental prices and higher population density than its regional neighbors (Muyanga and Jayne 2010).

SFM practices have the most benefit in the long run, so the conclusion reached that the NCPB's maize purchase activities affect households' adoption decisions the following growing season needs to be further researched to determine if the effects persist over time. Another area for further research is how the effect of the NCPB's policies of reducing price risk (found by Jayne, Myers, Nyoro 2008) may influence farmers' decisions to adopt SFM practices.

Although the NCPB does not have explicit policy goals related to shaping the incentives for households to sustainably intensify their maize production, this is an (unintended)

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consequence of the NCPB's current policies nonetheless. The NCPB, or the Kenyan government more broadly, may want to consider secondary policies to offset NCPB-induced reductions in the use of the practices that can contribute most to SI. However, further research is needed to identify specific policies that can cost-effectively incentivize SI of maize production in Kenya.

10. References

Akroyd, S., & Smith, L. (2007). Review of public spending to agriculture. *A Joint Study by the Department for International Development and the World Bank*, *5*

Antle, John M., Jetse J. Stoorvogel, and R Valdivia. 2006. "Multiple equilibria, soil conservation investments, and the resilience of agricultural systems." *Environment and Development Economics* 11:477-492.

Asfaw, S., Coromaldi, M., and L. Lipper. 2015. "Adaptation to climate risk and food security. Evidence from smallholder farmers in Ethiopia" FAO. Rome.

Argwings-Kodhek, G., Jayne, T.S., Nyambane, G., Awuor, T., and T. Yamano. 1998. "How Can Micro-Level Household Information Make a Difference for Agricultural Policy Making: Selected Examples from the KAMPAP Survey of Smallholder Agriculture and Non-Farm Activities for Selected Districts in Kenya." Working paper No. 57056, Department of Agricultural, Food, and Resource Economics., Michigan State University.

Arslan, A., McCarthy, N., Lipper, L., Asfaw, S., & A. Cattaneo 2014. "Adoption and intensity of adoption of conservation farming practices in Zambia." *Agriculture, Ecosystems & Environment*, *187*, 72-86.

Bationo, A., Buerkert, A., Sedogo, M., Christianson, B., and A.U. Mokwunye, 1995. "A critical review of crop residue use as soil amendment in the West African semi-arid tropics." In J.M. Powell et al. (ed.) *Livestock and sustainable nutrient cycling in mixed farming systems of sub-Saharan Africa. Vol. 2*. Tech. Pap. Int. Livestock Ctr. for Africa, Addis Ababa, Ethiopia. pp. 305-322

Bauer, A., and A. L. Black. 1994. "Quantification of the effect of soil organic matter content on soil productivity." *Soil Science Society of America Journal* 58(1):185-193.

Berazneva J., Conrad, J., and J. Guerena, 2014. "Agricultural productivity and soil carbon dynamics: a bioeconomic model" Paper presented at AAEA annual meeting, Minneapolis, MN, 27-29 July.

Bot, A., and J. Benites. 2005. *The importance of soil organic matter: Key to drought-resistant soil and sustained food production*. Rome, Italy: Food & Agriculture Org. No. 80.

Brams, E. A. 1971. "Continuous cultivation of West African soils: Organic matter diminution and effects of applied lime and phosphorus." *Plant and Soil*, *35*(1), 401-414.

DRAFT

Burt, O. R. 1981. "Farm level economics of soil conservation in the Palouse area of the Northwest." *American journal of agricultural economics* 63:83-92.

Caswell, G. H., and A. K. Raheja. 1972. "Report of the Board of Governors." *Samaru, Nigeria: Institute for Agricultural Research*.

Chamberlain, G. 1984. Panel data, in *Handbook of Econometrics, Vol. 2* , ed. Grilliches Z. Intriligator M.D., 1248-318. Amsterdam: North Holland Press

Chen, J. 2006. "The combined use of chemical and organic fertilizers and/or biofertilizer for crop growth and soil fertility." Presented at International workshop on sustained management of the soil-rhizosphere system for efficient crop production and fertilizer use, Bangkok, Thailand, 16-26 October.

Dahmardeh, M., Ghanbari, A., Syahsar, B. A., and Ramrodi, M. 2010. “The role of intercropping maize (Zea mays L.) and Cowpea (Vigna unguiculata L.) on yield and soil chemical properties.” *African Journal of Agricultural Research*, *5*(8), 631-636.

Doole, G., and G. Hertzler. 2011. “Optimal Dynamic Management of Agricultural Land-Use: An Application of Regime Switching” *Journal of Agricultural and Applied Economics* 43(1):43-56.

Drechsel, P., and L. A. Gyiele. 1999. *The economic assessment of soil nutrient depletion: Analytical issues for framework development*. Bangkok, Thailand: IBSRAM.

Drechsel, P., Gyiele, L., Kunze, D., & Cofie, O. 2001. “Population density, soil nutrient depletion, and economic growth in sub-Saharan Africa.” *Ecological economics*, 38(2), 251-258.

Eicher, C. K. 2009. “Building African scientific capacity in food and agriculture.” *Review of Business and Economics*, 1(2), 238-257.

FAO/IIASA/ISRIC/ISS-CAS/JRC, 2012. Harmonized World Soil Database (version 1.2). FAO, Rome, Italy and IIASA, Laxenburg, Austria.

Feder, G., Just R., and D. Zilberman. 1985. "Adoption of agricultural innovations in developing countries: A survey." *Economic development and cultural change* 33(2):255-298.

Food and Agricultural Organization. FAOSTAT database. 2017. Available at: http://faostat.fao.org/faostat/

"Food Security Report (Prepared by Kenya Agricultural Research Institute | Food Security Portal." n.d. Accessed 09 Apr. 2017, http://www.foodsecurityportal.org/kenya/food-security-report-prepared-kenya-agricultural-research-institute

DRAFT

Garnett, T., and C. Godfray. 2012. "Sustainable intensification in agriculture. Navigating a course through competing food system priorities." Food climate research network and the Oxford Martin programme on the future of food, University of Oxford.

Godfray, H. C. J., & Garnett, T. 2014. “Food security and sustainable intensification.” *Phil. Trans. R. Soc. B*, *369*(1639), 20120273.

Haggblade, S., and P. Hazell. 2010. “*Successes in African agriculture: Lessons for the future*.” Intl Food Policy Res Inst, 2010.

Holden, S., and R. Lunduka. 2012. "Do fertilizer subsidies crowd out organic manures? The case of Malawi." *Agricultural Economics* 43:303-314.

Skovgård, H., and P. Päts. 1997. "Reduction of stemborer damage by intercropping maize with cowpea." *Agriculture, ecosystems & Environment* 62(1):13-19.

Jayne, T. S. 2012. “Managing food price instability in East and Southern Africa.” *Global Food Security*, *1*(2):143-149.

Jayne, T. S., Chapoto, A. and Govereh, J. 2010. “Grain marketing policy at the crossroads: Challenges for eastern and southern Africa”, in: A. Sarris and J. Morrison (eds.), Food Security in Africa: Market and Trade Policy for Staple Foods in Eastern and Southern Africa (Rome. Italy: FAO, pp. 115–157.

Jayne, T. S., Mason, N. M. and Burke, W. J. 2015. “Agricultural input subsidy programs in Africa: An assessment of recent evidence”, Background report prepared for the World Bank flagship report on Options for Agricultural Expenditure in Africa, 2015.

Jayne, T.S., Myers, R., and J. Nyoro. 2008. "The effects of NCPB marketing policies on maize market prices in Kenya." *Agricultural Economics* 38(3):313-325.

Jayne, T. S., and S. Rashid. 2013. “Input subsidy programs in sub-Saharan Africa: a synthesis of recent evidence.” *Agricultural economics 44*(6): 547-562.

Jayne, T. S., Takavarasha, T., Attwood, E. A., & Kupfuma, B. 1993. “Postscript to Zimbabwe’s Maize Success Story: Policy Lessons for Eastern and Southern Africa.” Staff Paper. Department of Agricultural, Food, and Resource Economics

Juma, N.G. 1999. *The pedosphere and its dynamics. A systems approach to soil science. Volume 1: introduction to soil science and soil resources*. Sherwood Park, Canada: Salman productions.

Kamau, M., Smale, M., and M. Mutua. 2014. "Farmer demand for soil fertility management practices in Kenya’s grain basket." *Food security* 6(6):793-806.

Kassie, M., and Holden, S. 2007. “Sharecropping efficiency in Ethiopia: threats of eviction and kinship.” *Agricultural economics*, *37*(2-3), 179-188.

DRAFT

Kassie, M., Jaleta, M., Shiferaw, B., Mmbando, F., and M. Mekuria. 2013. "Adoption of interrelated sustainable agricultural practices in smallholder systems: Evidence from rural Tanzania." *Technological forecasting and social change* 80(3):525-540.

Kassie, M., Teklewold, H., Jaleta, M., Marenya, P., and O. Erenstein. 2015. "Understanding the adoption of a portfolio of sustainable intensification practices in eastern and southern Africa." *Land Use Policy* 42:400-411.

Kenya, Republic of, Ministry of Agriculture, Livestock and Fisheries (MoALF). 2014. *Subsidy fertilizer distribution guidelines.* Available at. http://kenyalaw.org/kenya_gazette/gazette/volume/MTE1NQ-- /Vol.CXVII-No.33

Kim, J., N.M. Mason, and S. Snapp. 2017. "Drivers of sustainable intensification of maize production: Panel survey evidence from Tanzania." Draft working paper. Michigan State University Department of Agricultural, Food, and Resource Economics and Department of Plant, Soil, and Microbial Sciences.

Koppmair, S., Kassie, M., and M. Qaim. 2016. "Farm input subsidies and the adoption of natural resource management technologies." Paper presented at AAEA Annual Meeting, Boston, MA, 31July–2 August.

Lal, R. 1995. "The role of residues management in sustainable agricultural systems." *Journal of Sustainable Agriculture* 5(4): 51-78.

Lee, D.R. 2005 "Agricultural sustainability and technology adoption: Issues and policies for developing countries." *American Journal of Agricultural Economics* 87:1325-1334.

Levine, N. K., Mason, N. M., and Morgan, S. N. 2016. "Do input subsidies crowd in or crowd out other soil fertility management practices? Panel survey evidence from Zambia." Paper presented at African Association of Agricultural Economists (AAAE) Annual Meeting, Addis Ababa, Ethiopia, 23-26 September.

Liebman, M., and E. Dyck. 1993. "Crop rotation and intercropping strategies for weed management." *Ecological applications* 3(1):92-122.

Manda, J., Alene, A. D., Gardebroek, C., Kassie, M., & Tembo, G. 2016. "Adoption and impacts of sustainable agricultural practices on maize yields and incomes: evidence from Rural Zambia." *Journal of Agricultural Economics*, *67*(1), 130-153

Marenya, P., and C. Barrett. 2007. "Household-level determinants of adoption of improved natural resources management practices among smallholder farmers in western Kenya." *Food policy* 34(2):515-536.

Marenya, P., and C. Barrett. 2009."Soil quality and fertilizer use rates among smallholder farmers in western Kenya." *Agricultural Economics* 40(5):561-572.

DRAFT

Mason, Nicole M., and Thomas S. Jayne. 2014. "Fertiliser subsidies and smallholder commercial fertiliser purchases: crowding out, leakage, and policy implications for Zambia." *Journal of Agricultural Economics* 65(2): 527-528.

Mason, N.M., Jayne, T.S., and R. Myers. 2015. "Smallholder supply response to marketing board activities in a dual channel marketing system: The case of Zambia." *Journal of Agricultural Economics* 66(1):36-65.

Mather, D.L., and T.S. Jayne. 2011. "The impact of state marketing board operations on smallholder behavior and incomes: the case of Kenya." Working paper, Department of Agricultural, Food, and Resource Economics and Department of Economics, Michigan State University.

McFadden, D. 1980 "Econometric models for probabilistic choice among products." *Journal of Business* : S13-S29.

Morgan, S., J. Kim, D. Olson, and N.M. Mason. 2017. "A dynamic model of smallholder farmers' soil fertility management practice decisions." Draft working paper. Michigan State University Department of Agricultural, Food, and Resource Economics.

Mundlak, Y. 'On the pooling of time series and cross section data', Econometrica, Vol. 46, (1978) pp. 69–85.

Murendo, C., Gwara, S., Mpofu, N., Pedzisa, T., Mazvimavi, K., & Chivenge, P. 2016. "The adoption of a portfolio of sustainable agricultural practices by smallholder farmers in Zimbabwe." Paper presented at African Association of Agricultural Economists (AAAE) Annual Meeting, Addis Ababa, Ethiopia, 23-26 September.

Muyanga, M., and Jayne, T. S. 2014. "Effects of rising rural population density on smallholder agriculture in Kenya." *Food Policy*, *48*, 98-113.

Kenya, Republic of, National Accelerated Agriculural Inputs Access Program (NAAIAP). 2014. *Soil suitability evaluation for mainzeproduction in Kenya.* Available at. http://kenya.soilhealthconsortia.org/?wpfb_dl=3

National Cereals and Produce Board (NCPB). *National Cereals and Produce Board of Kenya - Offline* N.P., N.D., Web. 09 Apr 2017 at:http://www.ncpb.co.ke/index.php?option=com_content&task=view&id=34&Itemid=50

Ndiritu, S.W., Kassie, M., and B. Shiferaw. 2014. "Are there systematic gender differences in the adoption of sustainable agricultural intensification practices? Evidence from Kenya." *Food Policy* 49:117-127.

Nerlove, M., and I. Fornari. 1998. "Quasi-rational expectations, an alternative to fully rational expectations: an application to US beef cattle supply." *Journal of Econometrics* 83 (1/2): 129-161.

DRAFT

Nyameino, D. 2010 “Role of National Cereals and Produce Board (NCPB) In Producer Price Stabelization in Kenya” ACTESA / COMESA Workshop*, Lilongwe, Malawi, 2 August*

Nyoro, J., Kiiru, M., and T.S. Jayne. 1999. “Evolution of Kenya’s Maize Marketing Systems in the Post Liberalization Era.” Tegemeo Institute of Agricultural Policy and Development Working Paper 2a, Tegemeo Institute of Agricultural Policy and Development, Egerton University.

The Montpellier Panel, 2013, *Sustainable Intensification: A New Paradigm for African Agriculture*, London

Oluoch-Kosura, W. A., P. P. Marenya, and M. J. Nzuma. 2001. “Soil fertility management in maize-based production systems in Kenya: Current options and future strategies.” In D.K. Friesen and A.F.E. Palmer, eds. *Integrated Approaches to Higher Maize Productivity in the New Millennium.* Nairobi Kenya: Digital Works Ltd, pp. 350-355

Power, A. G. 1988. "Leafhopper response to genetically diverse maize stands." *Entomologia Experimentalis et Applicata* 49(3):213-219.

Pretty, J., and Z. P. Bharucha. 2014. “Sustainable intensification in agricultural systems.” *Annals of Botany* 114:1571-1596.

Pretty, J, Toulmin, C. and S. Williams. 2011. "Sustainable intensification in African agriculture." *International journal of agricultural sustainability* 9(1) : 5-24.

Rayment, G.E., and F.R. Higginson. 1992. *Australian Laboratory Handbook of Soil and Water Chemical Methods.* Melbourne: Inkata Press Pty Ltd.

Royal Society. 2009. "Reaping the Benefits: Science and the Sustainable Intensification of Global Agriculture."

Sanchez, Pedro A., Shepherd, K., Soule, M., Place, F., Buresh, R., Izac, A., Mokwunye, U., Kwesiga, F., Ndiritu, C., and P. Woomer. 1997. "Soil fertility replenishment in Africa: an investment in natural resource capital." *Replenishing soil fertility in Africa*replenishingsoi : 1-46.

Sanchez, P. A., & Logan, T. J. (1992). Myths and science about the chemistry and fertility of soils in the tropics. *SSSA Special Publication*, *29*, 35-35

Sanginga, N., & Woomer, P. L. (Eds.). (2009). *Integrated soil fertility management in Africa: principles, practices, and developmental process*. CIAT.

Silberg, T., Richardson, R., Hockett, M., and S. Snapp 2017. “Cereal-Legume Intercropping in Central Malawi: Determinants of Practice” Draft working paper. Michigan State University Department of Community Sustainability

DRAFT

Singh, I., Squire, L. and Strauss, J. (eds.) *Agricultural Household Models: Extensions, Applications*, and Policy. Baltimore: The Johns Hopkins University Press, 1986.

Snapp, S. S., Blackie, M. J., Gilbert, R. A., Bezner-Kerr, R., and Kanyama-Phiri, G. Y. 2010. “Biodiversity can support a greener revolution in Africa.” *Proceedings of the National Academy of Sciences*, *107*(48), 20840-20845.

Snapp, S., Grabowski, P., Musumba, M., Palm, C., Chikowo, R., and Bekunda, M. 2016. “Development of a sustainable intensification indicators framework: reports from the frontline in Malawi.” *Experimental Agriculture*, *38*:411-431.

Steiner, K. G. 1982. *Intercropping in tropical smallholder agriculture with special reference to West Africa*.

Teklewold, H., Kassie, M., and B. Shiferaw. 2013. "Adoption of multiple sustainable agricultural practices in rural Ethiopia." *Journal of Agricultural Economics* 64(3):597-623.

Teklewold, H., Kassie, M., Shiferaw, B., & Köhlin, G. 2013. Cropping system diversification, conservation tillage and modern seed adoption in Ethiopia: Impacts on household income, agrochemical use and demand for labor. *Ecological Economics*, *93*, 85-93.

DRAFT

Timmer, C. P., Falcon, W. P., Pearson, S. R., & World Bank. Agriculture and Rural Development Dept. Economics and Policy Division. 1983. *Food policy analysis* (Vol. 1983, pp. 1-301). Baltimore: Johns Hopkins University Press.

Vanlauwe, B. 2004. "Integrated soil fertility management research at TSBF: the framework, the principles, and their application." *Managing nutrient cycles to sustain soil fertility in sub-Saharan Africa*: 25-42.

United Nations, World Food Programme. 2010. *The 2010 long rains season assessment report.* Kenya.

United Nations, World Food Programme. 2008. *Kenya - Long Rains Assessment, August 2008.* Kenya.

Vanlauwe, B, and K.E. Giller. 2006. "Popular myths around soil fertility management in sub-Saharan Africa." *Agriculture, ecosystems & environment* 116(1): 34-46.

Van Ittersum, M.K., Van Bussel, L.G., Wolf, J., Grassini, P., Van Wart, J., Guilpart, N., Claessens, L., de Groot, H., Wiebe, K., Mason-D’Croz, D. and Yang, H., 2016. “Can sub-Saharan Africa feed itself?” *Proceedings of the National Academy of Sciences*, *113*(52):14964-14969.

Vondolia, K., H. Eggert, and J. Stage. 2012. “Nudging Boserup?: The impact of fertilizer subsidies on investment in soil and water conservation.” Environment for Development Discussion Paper Series, 12-08.

Wong, M.T.F., E. Akyeampong, S. Nortcliff, M.R. Rao, and R.S. Swift. 1995. “Initial responses of maize and beans to deceased concentrations of monomeric inorganic aluminum with application of manure or tree prunings to an Oxisol in Burundi.” *Plant and Soil* 171(2):275-282.

Wooldridge, J. W. 2002. *Econometric Analysis of Cross Section and Panel Data.* Cambridge, Massachusetts: The MIT Press.

Wooldridge, J. M. 2010. *Econometric Analysis of Cross Section and Panel Data,* 2nd ed. Cambridge, MA: MIT Press.

Wooldridge, J.M. 2013. *Introductory econometrics: A modern approach (5th edition)*. Mason, OH: South Western, Cengage Learning.

Zentner, R.P., Campbell, C.A., Biederebeck, V.O., Miller, P.R., Selles, F., and Fernandez, M.R., 2001. “In search of a suitable cropping system for the semi-arid Canadian Prairies.” *Journal of Sustainable Agriculture* 18: 117–136

Zentner, R.P., Campbell, C.A., Biederebeck, V.O., Selles, F., Lemke, R., Jefferson, P.G., Gan, Y., 2004. “Long-term assessment of management of an annual legume green manure crop for fallow replacement in the Brown soil zone.” *Canadian Journal of Plant Science* 83: 475– 482.

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