

Understanding the Agricultural Input Landscape in Sub-Saharan Africa

Recent Plot, Household, and Community-Level Evidence

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Abstract

Conventional wisdom holds that Sub-Saharan African farmers use few modern inputs despite the fact that most growth-inducing and poverty-reducing agricultural growth in the region is expected to come largely from expanded use of inputs that embody improved technologies, particularly improved seed, fertilizers and other agro-chemicals, machinery, and irrigation. Yet following several years of high food prices, concerted policy efforts to intensify fertilizer and hybrid seed use, and increased public and private investment in agriculture, how low is modern input use in Africa really? This paper revisits Africa's agricultural

input landscape, exploiting the unique, recently collected, nationally representative, agriculturally intensive, and cross-country comparable Living Standard Measurement Study-Integrated Surveys on Agriculture covering six countries in the region (Ethiopia, Malawi, Niger, Nigeria, Tanzania, and Uganda). The study uses data from more than 22,000 households and 62,000 plots to investigate a range of commonly held conceptions about modern input use in Africa, distilling the most striking and important findings into 10 key takeaway descriptive results.

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**Understanding the Agricultural Input Landscape in Sub-Saharan Africa:
Recent Plot, Household, and Community-Level Evidence**

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1. Introduction

Development theory suggests that improved agricultural productivity is a primary pathway by which societies can begin down the path of economic transformation and growth and out of subsistence level poverty (Johnston and Mellor 1961; Schultz 1964). Three (potentially complementary) paths exist for increasing agricultural output: increase input use, adopt productivity-enhancing technologies, and/or increase the efficiency in use of existing inputs and technologies. Widespread evidence suggests that most smallholder farmers are “poor but efficient” (Schultz 1964; Sherlund, Barrett, Adesina 2002), such that the third of these offers only limited leverage for anything more than modest, one-off productivity gains. Most growth-inducing and poverty-reducing sustained agricultural growth then comes from expanded input use, especially of modern inputs – like improved seed, fertilizers and other agro-chemicals, machinery, and irrigation – that embody improved technologies. Asia and Latin America enjoyed tremendous increases in agricultural productivity in a relatively short period of time through rapid and widespread uptake of yield-enhancing modern agricultural inputs (Johnson, Hazell, Gulati 2003). Moreover, the bulk of the economic gains from the development and diffusion of modern inputs accrued to poor consumers as supply expansion outpaced demand growth, driving down real food prices and improving diets (Evenson and Gollin 2003).

Sub-Saharan Africa (SSA) did not participate to the same degree in the Green Revolution of the 1970s-1980s. Dissatisfied with the perceived slow progress of agricultural and food market liberalization policies, several SSA countries have made public commitments to increasing input use via the Abuja Declaration and, more broadly, under the Comprehensive Africa Agriculture Development Programme (CAADP). As an extension, several governments have recently reinstated or revitalized agricultural input subsidy schemes aimed at promoting access to chemical fertilizers and improved seeds (Minot and Benson 2009) with variable success (Jayne and Rashid 2013). In contrast to the awareness resulting from these subsidy programs, irrigation and mechanization have received far less attention, with a few notable exceptions (Houssou et al. 2013; Takeshima, Nin-Pratt, Diao 2013). That neglect may have translated into stagnation or even the reversal of progress in their promotion (Mrema, Baker, Kahan 2008; Van Koppen 2003). Meanwhile, external factors such as record high international food prices, urbanization, the rapid growth of a middle class, and transformation of some food marketing channels may have changed on-farm incentives and resulted in updates to farm management practices, including modern input use (Reardon et al. 2009). A growing international dialogue on and increased awareness about climate change and soil erosion may also be influencing farmers’ practices (Nelson et al. 2010).

Amid these changes and pressures, a major and fundamental gap remains in our understanding of the current input landscape at the country and continent level. While myriad studies look at some facet of modern input use throughout Sub-Saharan Africa, no studies, to our knowledge, focus specifically on broad patterns of farmer input use behavior or on comparisons within and among countries, and especially not in the 21st century, since the onset of what seems an African agricultural renaissance in concert with the various changes previously described. Apart from a very small set of countries where nationally-representative household survey data exist, most knowledge of modern input use is currently derived from macro-level statistics, which cannot capture the heterogeneity in within-country conditions and are prone to issues of data reliability

(Jerven 2013), or studies using small or purposively chosen samples, which may not be reliably scalable for informing national-level policy priorities.

We aim to fill this gap using newly available data from the Living Standard Measurement Study-Integrated Surveys on Agriculture Initiative (LSMS-ISA). With these nationally representative, recently collected, agriculturally intensive, and cross-country comparable data sets, we can provide an updated and unprecedentedly broad-scale picture related to a bundle of inputs used by farming households in Africa. We utilize one cross section of data collected between 2010 and 2012 in each of six countries (Niger, Nigeria, Ethiopia, Malawi, Tanzania, Uganda) encompassing over 22,000 cultivating households and 62,000 agricultural plots representing a large section—both geographically and population-wise—of Sub-Saharan Africa. Specifically, we investigate the validity of the assumption that African farmers use few modern inputs, especially those inputs typically believed to embody improved technologies. To test this overarching hypothesis, we produce thick descriptive statistics related to a number of inputs often cited as “under-used” in Sub-Saharan Africa: fertilizer, improved seed varieties, agro-chemicals (pesticides, herbicides, and fungicides), irrigation, and animal power and mechanized farm equipment. This allows us to provide evidence for or against a number of sub-hypotheses related to input use among different cross-sections of the population derived from long-held beliefs about the types of farmers and households who adopt yield-enhancing inputs (e.g., Feder and Umali 1993; Feder, Just, Zilberman 1985; Sunding and Zilberman 2001). Our aim is purely descriptive and therefore modest. We test no hypotheses as to what gives rise to the patterns we describe. But getting the basic facts right seems an essential and to-date-overlooked step in intensifying debates about how to stimulate African agricultural development.

We begin in Section 2 by reviewing the available literature and macro-statistics that are the sources of most common conceptions of input use and then describe in Section 3 our data and sample of agricultural households. In Section 4, we disaggregate data on both binary input use decisions and continuous application rates using a number of regional, household, and plot-level characteristics; investigate the joint distributions of uptake in order to identify prospective patterns of synergies among distinct “packages” of modern inputs; and dissect some of the available information on input provisioning, including input/output price ratios, the accessibility of input markets, and the incidence of purchasing inputs on credit. In Section 5, we use an R^2 decomposition technique in an attempt to uncover the primary source(s) of most of the between- and within-household level variation in binary input use decisions. The ten most striking and important findings from our analysis are distilled in Section 6.

2. Prevailing prior beliefs on the modern input use context in Sub-Saharan Africa

In this section, we describe the importance of each of the five chosen inputs to agricultural productivity and present the figures that guide “conventional wisdoms” surrounding input use patterns in SSA. Mostly, prevailing prior beliefs come from macro-level data. Because micro-level studies also inform our common conceptions and a host of work has been done on the topic, we also highlight some of the larger studies that speak broadly about national and multinational patterns based on plot- or farm-level data collected in the recent past and include a listing of such studies in Appendix 1. Where possible, we focus on nationally-representative or near-nationally-representative data, although equivalents do not exist across all countries and inputs.

2.1. Fertilizer

In an environment where initial soil productivity may be low and/or where crops are cultivated without the ability to leave plots fallow, replenishing the soil is essential for the long term viability of agriculture (Henao and Baanante 2006). Fertilizer functions as a yield sustaining and enhancing input by adding nutrients required for plant growth to the soil. Several researchers have estimated that over 50 percent of productivity gains experienced during the Green Revolution in Asia can be attributed to increased use of inorganic fertilizer alone (Hopper 1993; Tomich, Kilby, Johnston 1995). Fertilizer can be both organic (e.g., manure and compost) and inorganic (often described as “chemical” or “mineral”), which function best as complements (Weight and Kelly 1999), a practice encouraged by proponents of integrated soil fertility management (Place et al. 2003). Organic and inorganic fertilizers provide specific benefits and, therefore, do not make perfect substitutes. Moreover, Morris et al. (2007) claim that simply not enough organic matter exists to “fix” the soil nutrient deficiency issues in SSA.

Using FAOSTAT data from 2009, Minot and Benson (2009) find that SSA households apply an average 13 kilograms of inorganic fertilizer per hectare of cultivated land, a statistic that has proliferated and prompted considerable pressure within African governments to stimulate fertilizer use, perhaps most prominently within CAADP policy dialogues. While these continent-level statistics have fueled the debate on low fertilizer use, variation across countries is recognized. For example, when grouping countries by intensity of application, Morris et al. (2007) found that only Malawi (from the list of LSMS-ISA countries) fell into the high intensity category where more than 25 kilograms per hectare are applied on average. Organic fertilizer use rates are far more difficult to come by at the national level since there is often not a market for compost or manure. Household surveys, like those utilized in this study, are essentially the only method of tabulating the incidence of organic fertilizer use.

Table 1: Average kilograms of fertilizer applied per hectare of cultivated land

	FAOSTAT ¹ (2010 data)				World Bank (2009 data) ²	Literature review from household surveys ³	
	Nitrogen (N)	Phosphate (P205)	Potash (K20)	Total nutrients	Total nutrients	Total	Source
Ethiopia	10.4	10.8	0.0	21.2	17.7	17	Spielman et al. (2011)
Malawi	23.1	4.5	4.3	31.9	28.5	55.7*	Ricker-Gilbert et al. (2009)
Niger	0.3	0.1	0.1	0.5	0.4	-	-
Nigeria	2.0	0.3	0.3	2.6	2.1	-	-
Tanzania	4.4	0.6	0.7	5.7	8.7	-	-
Uganda	0.7	0.3	0.3	1.3	2.1	2.4*	Matsumoto and Yamano (2011)
<i>SSA Average</i>	<i>6.5</i>	<i>2.9</i>	<i>1.6</i>	<i>11.0</i>			
<i>LDC Average</i>	<i>11.2</i>	<i>2.8</i>	<i>1.3</i>	<i>15.3</i>			

Sources: ¹FAOSTAT. Cultivated land defined as arable land plus land under permanent crop. See more details at FAOSTAT. Sub-Saharan African estimates come from an aggregation of eastern, western, southern, and middle Africa (32 countries), per the regional breakdown on FAOSTAT. ²World Bank. World Development Indicators. ³From review of literature. Only nationally or near nationally representative studies with unconditional fertilizer application rates included in this table. See Appendix 1 for other studies and details. *Not specific to nutrient content.

While major household surveys and complementary analysis on fertilizer use exists in certain Sub-Saharan countries, cross-country studies at the same level are far more difficult to come by. As such, our best means of comparing fertilizer use rates across countries is to rely on macro-

level data from sources like FAOSTAT and the World Bank's World Development Indicators. Table 1 provides these statistics for 2010 and 2009, respectively, the years when most of the LSMS-ISA surveys we use were fielded, for the six countries of interest here, in addition to regional and least developed countries (LDC) classification averages. Notice that Ethiopia and Malawi fall above the SSA average reported by FAOSTAT while Niger, Nigeria, Tanzania, and Uganda all fall below. As further ammunition for the claim that fertilizer use is low in SSA, the regional average falls below the average for all LDCs. As a means of comparison to existing micro-evidence from farmers' fields, the final column shows the average fertilizer use rate described in what we deem to be the largest and most-nationally representative study which includes input rates in recent years.¹

2.2. *Improved crop varieties*

Because the characteristics of planted seeds will impact the productive capacity of the crop that emerges, the germplasm of seeds is a very important factor for ensuring and bolstering yields. These characteristics might include more grain, drought (or other climate) tolerance, disease resistance, better complementarity with inorganic fertilizers, etc. While breeding activities exist for a range of other purposes – for example, increasing the nutrient value of crops or more leaf material to help with long term soil health – many of the desired attributes seek to increase productivity or decrease risk, both with the intention of increasing overall yields. The need for and therefore research into how to “improve” varieties is different between crop types. Because maize, a major staple in eastern and southern Africa, is cross-pollinating, progeny hybrid seeds will never directly match those of the parents and vigor decreases with replication. These issues are not important when using open pollinating varieties (OPVs) or when cultivating self-pollinating crops like rice and wheat (Fischer, Byerlee, Edmeades 2009; Smale et al. 2011). The equivalently important crops in western Africa are pearl millet and sorghum, two crops for which breeding did not start until the 1980s since they were not part of Green Revolution advances in the 1960s (Evenson and Gollin 2003).

Internationally cross-comparable studies of improved variety use are not readily found given the importance of different crops across countries, the potential unsuitability of particular improved varieties given differences in agro-ecological conditions, and the difficulty in collecting this information when many seeds can be saved between seasons. Further, neither FAOSTAT nor the World Bank provides disaggregation of seed use by improved or traditional varieties. Instead, the best source of cross-country information on the topic is newly available data from the Consultative Group on International Agricultural Research (CGIAR)'s Diffusion and Impact of Improved Varieties in Africa (DIIVA) project, which estimated the total hectares under 21 improved crop varieties in 29 countries in SSA, including all six of the LSMS-ISA countries, for the 2009/10 season (see Alene et al. 2011 for more on the project and initial findings). In Table 2, we include the statistics for some of the main crops in each of the LSMS-ISA countries for which data are available.

Other researchers have used national estimates of seed sales to estimate improved variety adoption rates. For example, for maize, Smale, Byerlee, and Jayne (2011) aggregate data from

¹ One major reason for different rates of use found throughout studies, we find, is that some researchers refer to the total kilograms of inorganic fertilizer applied while others refer to only the actual nutrient contributions.

other studies and estimate that 44 percent of maize area in eastern and southern Africa (apart from South Africa) and 60 percent in western and central Africa are covered with improved maize seed. To our knowledge, no equivalent studies exist for other major crops in SSA, apart from the preliminary results from the DIIVA project included in Alene et al. (2011). Aggregating evidence using micro-level data found in other studies is similarly challenging due to the slightly different types of seeds (e.g., hybrid, OPV, etc.) and crops included. For more on studies at the country-level, see Appendix 1.

Table 2: Estimated adoption of improved varieties of select crops

	1998		2009	
	Total hectares under crop	Percent of land under improved varieties	Total hectares under crop	Percent of land under improved varieties
Ethiopia				
Barley	897,360	11.0	913,863	33.8
Maize	1,881,000	8.5	1,768,120	27.9
Durum wheat	797,998	80.0	1,163,056	77.8
Malawi				
Maize	1,243,000	13.8	1,609,000	43.0
Groundnuts	170,517	10.0	266,946	58.0
Niger				
Millet	-	-	6,513,140	11.5
Sorghum	-	-	2,544,740	15.1
Cowpea	-	-	5,203,530	17.0
Groundnuts	-	-	588,651	11.9
Nigeria				
Maize	4,255,000	40.0	3,708,000	95.0
Cowpea	-	-	3,768,193	39.0
Sorghum	-	-	4,736,730	20.0
Millet	-	-	3,749,600	35.0
Tanzania				
Maize	1,646,000	4.2	2,961,330	35.4
Rice	-	-	627,600	13.0
Sorghum	622,400	2.0	874,219	37.7
Groundnut	-	-	535,000	32.1
Uganda				
Maize	574,000	8.9	887,000	54.0
Banana	-	-	915,877	6.2
Groundnut	196,000	10.0	253,000	55.0

Source: CGIAR's DIIVA project. More information can be found at: <http://www.asti.cgiar.org/diiva>

2.3. *Agro-chemicals: Pesticides, insecticides, herbicides, fungicides*

Pests, diseases, and weeds can considerably suppress crop yields. When weeds are present, a growing plant must compete for sunlight, moisture, and soil nutrients, which reduces its chances of survival. Insects and mites can eat grains or the leaves and roots at any stage of plant growth. Diseases and fungi, too, can ruin an entire field of crops. Actual losses to major crops from all of these types of “pests” are estimated to be about 30 percent of attainable yields as collected from sources around the world (Oerke and Dehne 2004). In an effort to control these unfortunate agricultural realities, farmers can apply agro-chemicals in the form of pesticides, herbicides, fungicides, and insecticides. These agro-chemicals can function as a substitute or complement to increased labor (e.g., manual weeding) or other organic techniques (e.g., the introduction of

natural pest predators). Gianessi and Williams (2011) contend that herbicide use, in particular, remains a major unexploited means of increasing yields and saving labor on SSA farms.

In their global analysis, Zhang, Jiang, and Ou (2011) found that only 3 percent of global pesticide consumption came from Africa while 2 percent of all pesticide consumption came from South Africa alone, leaving only 1 percent for the remainder of the continent. In their review, Abate, van Huis, and Ampofo (2000) find that most pesticide use in SSA is on commercial export crops—coffee, cotton, cocoa—which means most pesticide use in the region is predicted to be used for fighting migratory pests like locusts not the larger set of possible yield inhibitors. Because most analysis of this sort relies on official government estimates using outdated data and given even limited household-level evidence showing a steady increase in pesticide use over time (Williamson, Ball, Pretty 2008) and findings that households source pesticides from unregulated and informal markets (Williamson 2003), these figures might dramatically understate pesticide use in Sub-Saharan Africa.

Again, the statistics provided by FAOSTAT represent, to the best of our knowledge, the only cross-country comparable evidence of low agro-chemical use. Even then, data are inconsistently available across years and is over a decade old for several countries. Table 3 provides the most recently available data by country. Because of inconsistently collected data, we are unable to provide a regional average estimate for any year in the recent past. Comparing use rates to those found in large-scale household surveys provides a great challenge. In studies with the largest and most recently collected data that we found, only the percentage of households using agro-chemicals was provided. Those numbers, where available, are included in Table 3 as a reference and comparison.

Table 3: Total agro-chemical use per hectare of cultivated land

	FAOSTAT ¹ (various years) – average application rate (kg/ha)						Literature review ²	
	Year	Pesticides	Insecticides	Herbicides	Fungicides	Total	% hh using	Source
Ethiopia	2001	0.003	0.012	0.039	0.001	0.055	21	Taffesse (2008)
Malawi	2009	0.028	-	-	-	0.028	3	Zezza et al. (2007)
Niger	2010	0.001	0.001	-	-	0.002	-	-
Nigeria	-	-	-	-	-	-	10.5	Akramov (2009)
Tanzania	1997	0.001	0.002	0.002	-	0.005	-	-
Uganda	1995	0.001	0.006	0.001	0.004	0.013	3	Okoboi (2010)

Sources: ¹FAOSTAT. Data presented from most recently available year. Many different types of agro-chemicals categorized into four categories by authors. Cultivated land defined as arable land plus land under permanent crop. See more details at FAOSTAT. ²From review of literature. See Appendix 1 for other studies and details.

Some argue that increased use of pesticides in SSA should not be applauded given the many negative environmental and health externalities that farmers often do not consider (Wilson and Tisdell 2001). Also, because overuse of pesticides can exacerbate the problem of unwanted pests by encouraging the growth of resistant pests, incorrect application practices can spur increased pest pressure and reliance on stronger and more dangerous chemicals over time. Because of this, the academic literature has mostly focused on the negative health and environmental context surrounding often unregulated pesticide use (e.g., Antle and Pingali 1994) instead of garnering a better picture of who is using pesticides and the possible correlation of agro-chemical use with other variables. A larger set of integrated pest management techniques is often suggested as an alternative (Grzywacz et al. 2013).

2.4. Irrigation

This study refers to irrigation broadly as the supply of additional water used in agriculture to supplement rainfall and is, in a sense, better interpreted as water control. Irrigation functions as a yield-enhancing input through various different mechanisms: (1) allowing farmers to reduce the risk of crop losses from low or variable rainfall, (2) enabling farmers to cultivate year-round instead of at the whim of rainfall, (3) acting as a complement to fertilizer and modern seed varieties, and (4) permitting farmers to better time their harvests in order to take advantage of season price fluctuations (Burney and Naylor 2012; Rosegrant, Ringler, De Jong 2009). Using global data to study total factor productivity, Fuglie (2008) finds that irrigated land is twice as productive as rainfed land after controlling for other factors. In SSA specifically, Fuglie and Rada (2013) report that average yields on irrigated fields are 90 percent higher than on nearby rainfed fields. Further, Evenson, Pray, and Rosegrant (1999) find that one of the key factors in agricultural productivity growth in Green Revolution India was public investments in irrigation.

The lack of irrigation is generally assumed as a starting point in the discussion of low input use; however, most large studies on irrigation in Africa are either project specific, regional in nature, or very out of date (Biswas 1990; Moris, Thom, Humpal 1987; Rosegrant and Perez 1997). In one of the most recent and disaggregated looks at irrigation across the region, Svendsen, Ewing, and Msangi (2009) use FAO and AQUASTAT data to show that Sub-Saharan Africans withdraw about one-quarter as much water as the per capita global average. Similarly, Rosegrant, Ringler, and De Jong (2009) claim that less than 3.5 percent of all agricultural land in Sub-Saharan Africa is irrigated. This is in spite of claims that a huge potential exists (You et al. 2011; Pavelic et al. 2013). Kay (2001) estimates that irrigated areas expand by an average of 1,150 hectares per year in SSA, with rates above 2,000 hectares per year in Tanzania, Niger, and Nigeria.

Table 4: Area equipped for and actually irrigated

	AQUASTAT/FAOSTAT ¹ (various years)						World Bank ² (various years)	
	Area Equipped for Irrigation			Area Actually Irrigated			Area Actually Irrigated	
	Total ha	% of land	Year	Total ha	% of land	Year	% of ag land	Year
Ethiopia	289,600	2.54	2001	-	-	-	0.5	2011
Malawi	73,500	2.15	2006	26,900	0.79	2006	0.5	2008
Niger	73,660	0.52	2005	65,610	0.46	2005	0.2	2011
Nigeria	293,200	0.81	2004	218,800	0.61	2004	-	-
Tanzania	184,300	1.81	2002	-	-	-	-	-
Uganda	14,420	0.16	2010	12,450	0.14	2010	-	-

Sources: ¹AQUASTAT country data sheets for most recent year with available data. Percent of land values calculated using total arable land plus permanent crop land from FAOSTAT. See more details at FAOSTAT. For more on the AQUASTAT data and project, see Frenken (2005). ²World Bank. World Development Indicators.

Table 4 provides a picture of the most recently available national-level statistics on irrigation by AQUASTAT, the same data used by Rosegrant, Ringler, and De Jong (2009), and from the World Bank's World Development Indicators as a comparison. To our knowledge, comparable statistics from micro-level studies of household irrigation use do not exist. Most of the studies included in our review (Appendix 1) focus on particular areas of the country where irrigation schemes are found or focus on irrigated area under a specific crop. As we study smallholder irrigation use with the LSMS-ISA data, it is important to note the finding by Svendsen, Ewing, Msangi (2009) that large-scale irrigation projects currently make up the most significant portion

of irrigated land in SSA despite the claim by Rosegrant et al. (2009) that small-scale irrigation projects are not only more manageable, but also more profitable. Rosegrant et al. (2009) also point out that irrigation projects, regardless of size, are generally only economically viable for cash crop or other high value crop production. They also claim that irrigation is most often utilized when in the presence of complementary inputs and, like Mwendera and Chilonda (2013), rural services. Water rights are clearly an issue for whether or not irrigation is a viable option, although Shah et al. (2002) points to a number of other studies that show that land rights, too, play an important role given the longer term and semi-permanent nature of irrigation investments.

2.5. *Farm power and mechanization*

Traditional agricultural practices in SSA rely on human power channeled through hoes, shovels, cutlasses, and other hand tools to bring new land under cultivation, prepare fields for planting, and harvest crops. Mechanized equipment and/or animal traction can be employed to increase the timeliness of field preparation and expand farm size all while saving labor. The process of moving from hand tools to animal-powered or motorized land preparation devices like tractors is referred to as mechanization and is seen as one way to increase agricultural productivity,² and farm profitability when the right conditions exist. The most comprehensive theory of mechanization processes in Sub-Saharan Africa is likely provided by Pingali, Bigot, and Binswanger (1987). From their (now rather dated) review of over 50 sites in Africa, we understand that the use of animal power or mechanized equipment is an evolutionary process of the farming system, not a one-time use decision like some of the other inputs surveyed in this paper, and largely influenced by population pressures. Moreover, major constraints in most smallholder African farming systems (e.g., farm size constraints, livestock disease constraints) exist that prohibit a profitable transformation from mostly human-powered agricultural production to animal or machine intensive operations (Sims and Zienzle 2006).

While studies on tractor use and animal draught power use decisions are far less prevalent than those of the other inputs identified in this paper, the consensus appears to be that reliance on human power for agriculture is still hugely dominant and limits productivity increases (e.g., Sims and Zienzle 2006). In an overview of the current state of mechanization of Sub-Saharan Africa using FAOSTAT/AGS data, Mrema (2011) finds that there were 2 tractors per 1000 ha of arable land in 1980 but only 1.3 in 2003, as compared to the more than doubling of tractor prevalence in Latin American and Asia over the same time frame. Pingali (2007) also observes a decrease in tractor use over time in SSA. Using data from 1998, Clarke and Bishop (2002) report that 65 percent of land under cultivation was done by hand, 25 percent using draught animal technology (DAT), and 10 percent using engine power. Ashburner and Kienzle (2011) show a decrease in mechanization in SSA, claiming that primary preparation carried out by hand tools is currently at 80 percent, with DAT only at 15 percent and the remaining 5 percent using tractors.

² Pingali and Binswanger (1984) found a decreasing relationship between farming intensity and yield per hectare across 52 countries in Africa, Asia, and Latin America. Using the same data, however, they find a positive and significant relationship between farming intensity and labor productivity.

Table 5 provides the most recent FAOSTAT data on tractor use in Sub-Saharan Africa. While tractors are only one possible instrument for mechanized agricultural production,³ these statistics represent the only known macro-data set for comparing the mechanization status across countries. Further, because it may not be profitable for individual farmers to own a tractor and, therefore, more likely that she or he would access a tractor via a rental market instead, aggregate statistics that merely count tractors may understate the use of mechanized inputs more broadly. Draught animal power may also be an important means of mechanization, although most reviews of livestock prevalence fail to disaggregate animals that would provide power to the farm (e.g., oxen, cattle, and donkey).

Table 5: Total number of tractors by country for most recently available year

	Year	Total Number of Tractors	Tractors Per 1000 People		People Per 1 Tractor	
			Total Pop.	Rural Pop.	Total Pop.	Rural Pop.
Ethiopia	-	-	-	-	-	-
Malawi	1968	692	0.16	0.17	6,197	5,854
Niger	2006	375	0.03	0.03	35,893	29,899
Nigeria	2007	24,800	0.17	0.32	5,925	3,103
Tanzania	2002	21,207	0.59	0.77	1,690	1,300
Uganda	1977	2,076	0.18	0.19	5,569	5,171

Source: FAOSTAT. For total and rural population definitions, see FAOSTAT.

3. Data and sample selection

The sample used in this analysis includes all households that cultivated at least one agricultural plot in a recent wave of LSMS-ISA data in Ethiopia (2011/12), Malawi (2010/11), Niger (2011/12), Nigeria (2010/11), Tanzania (2010/11), and Uganda (2010/11). For those countries where two seasons of agricultural data are available (Malawi, Niger, Tanzania, Uganda) our analysis focuses on the main agricultural season. Because the surveys are nationally representative (apart from Ethiopia which is representative of the rural and small town population only) and not necessarily representative of the farming population, the portion of the total sample that we use differs across countries. Since most input use is observed at the agricultural plot, not household, level, many of the statistics that follow will also be calculated at the plot level.⁴ Table 6 describes the sample size for each country used in this analysis. Across the six countries, our sample includes 22,565 households and 62,387 plots, which represents nearly three-quarters of all households in the full surveys and is overwhelmingly rural.

Great attention was paid to ensure that computed input variables and covariates are as comparable as possible across countries despite sometimes large differences in how questions were asked or what type of information was extracted from survey respondents. Caveats to lack of comparability or reasons why statistics may vary due in large part to differences in survey design are provided where it seems appropriate. Otherwise, Appendix 2 provides more detail on

³ Sometimes the term “tractorization” is used to describe the transition towards tractors specifically, but does not capture the spirit of mechanization more generally.

⁴ While we use the term “plot” throughout this analysis for simplicity, the actual unit of land described in each of these surveys may differ: Ethiopia-field within parcel by holder; Malawi-plot; Niger-parcel within field; Nigeria-plot; Tanzania-plot; Uganda-parcel (aggregating input use across plots on a parcel).

what is included in the aggregation of each input type by country. For differences in how the questions were asked, it is best to refer to the survey instruments and enumerator manuals themselves, available through the World Bank’s LSMS-ISA web site.

Table 6: Number of households and plots included in this analysis versus overall survey sample

Country	Survey year	Name of main ag season	Overall survey sample		Sub-sample used in this analysis (main season)			
			No. of hh	% of hh in “rural” areas	No. of hh	% of overall survey sample in analysis	% of hh in “rural” areas	No. of plots
Ethiopia	2011/12	Meher	3,969	98.9	2,852	86.6	99.7	23,051
Malawi	2010/11	Rainy	12,271	84.4	10,086	83.2	93.5	18,598
Niger	2011/12	Rainy	3,968	61.2	2,208	77.9	93.8	6,109
Nigeria	2010/11	-	5,000	59.0	2,939	49.9	84.6	5,546
Tanzania	2010/11	Long rainy	3,924	69.1	2,372	66.6	85.9	4,794
Uganda	2010/11	First	2,716	83.5	2,108	73.8	93.7	4,289
<i>Sample size across countries</i>			<i>31,848</i>	<i>76.0</i>	<i>22,565</i>	<i>73.0</i>	<i>91.9</i>	<i>62,387</i>

Note: All surveys are nationally representative except Ethiopia, which was only conducted in rural areas (with a few households in “small towns”). In Ethiopia, only one of the two seasons is captured in the surveys. “Rural” areas are defined differently across countries. The sample sizes described above are not weighted, but percentages are. The aggregated sample size across the six countries includes simple summations and unweighted averages.

Many of the inputs we are interested in are best compared per unit of cultivated land, particularly application rates. In all of these surveys, farmer-reported plot sizes are complemented with global positioning system (GPS)-based measures of some plots for comparison. Given evidence that self-reported measures of land size may contain bias and cause the misrepresentation of particular relationships (Carletto, Savastano, Zezza 2013), multiple imputation is used to arrive at a full set of GPS-based plot sizes where self-reported values are used as an instrument following the methodology described by Palacios-Lopez and Djima (2014).⁵ Apart from estimating plot size, we clean only the transformed input use per hectare (generally kg/ha) values. Cleaning rules by input variable are described in more detail in the sections that follow and generally involve winsorizing at the 99th percentile under the assumption that all extreme values are due to measurement error.⁶

Despite a purposively chosen sample of main season cultivators, we apply household level sampling weights to and account for the complex survey design to construct nationally representative statistics (or, in the case of Ethiopia, representative of rural areas and small towns only). Further, household level weights multiplied by plot size (in hectares) are applied at the plot level so as to not overweight very small units of cultivation. All monetary values are standardized to USD using official yearly-averaged exchange rates from the World Bank. For all countries where the first year of data collection was 2010 (Malawi, Nigeria, Tanzania, Uganda), we use the 2010 average exchange rate. For the remaining two countries (Ethiopia and Niger) the average 2011 rate was applied instead.⁷

⁵ For all owned plots in Uganda, we also subtract off the portion that the household claimed to leave fallow.

⁶ Winsorizing is the process of replacing extreme or outliers beyond a specific percentile with the value observed at that percentile. We prefer this method to trimming, which drops extreme values instead of replacing them.

⁷ We use the following USD conversion factors: 16.90 for Ethiopia, 150.49 for Malawi, 471.87 for Niger, 150.30 for Nigeria, 1409.27 for Tanzania, and 2177.56 for Uganda: <http://data.worldbank.org/indicator/PA.NUS.FCRF>.

4. Observed input use and provisioning patterns

In this section, we investigate input use at various levels – national, regional, household, and plot – as viewed through agro-ecological, market, and demographic lenses. Our choices of disaggregating variables are motivated by patterns reported in the existing literature, by commonly held conceptions about input use, and by the covariates available across surveys. We then investigate some of the joint-input use decisions given known complementarities and a limited set of input provisioning statistics.

4.1. *National level input use*

Fertilizer

Table 7 describes overall national fertilizer use statistics, including both organic and inorganic fertilizer applications. For inorganic fertilizer, we attempt not only to aggregate total fertilizer use, but also to separate out the main nutrients. In order to extract a nutrient value, in some cases, assumptions are made about the exact type of fertilizer described in the questionnaires (see Appendix 2). Application rates are cleaned on the high end by winsorizing at the 99th percentile. In some countries, we observe unreasonably extreme values in inorganic fertilizer use below the 99th percentile, and therefore apply additional curtailing by replacing total inorganic fertilizer application rates over 700 kg/ha, nitrogen application rates above 200 kg/ha, and phosphorous application rates above 100 kg/ha with those values.⁸ For organic fertilizer application rates described in the text, we apply no corrections beyond winsorizing at the 99th percentile.

Subtle differences in how fertilizer application rates were collected may contribute to some differences in observed rates across countries (for more on this issue, see Appendix 2). For example, in Malawi and Tanzania, only up to two types of fertilizer could be reported for a given plot.⁹ To the extent that farmers use more than two types, our estimates will therefore be downwardly biased in those two countries. In Nigeria, fertilizer application at the plot level was split into three categories: saved, free, and from commercial sources. In this case, we expect some respondents may have double-counted fertilizer on the same plot where fertilizer was partially free and commercially purchased, leading to over-estimates of actual application rates.

Table 7 shows that around 35 percent of all households in our sample used inorganic fertilizer on their plots in the included main season, with tremendous heterogeneity use across the six countries. Uganda has, by far, the fewest number of inorganic fertilizer users with Malawi at the other extreme. Application rates are high in Malawi and Nigeria, both with government input subsidy programs, and Ethiopia, where the government sets (and subsidizes) fertilizer prices but does not consider it a subsidy program (Rashid et al. 2013). Among fertilizer users, farming households in Tanzania, another country with a government fertilizer subsidy, apply at average rates very similar to Ethiopian households. Of the six countries, the application rates we compile

⁸ This represents an upper-bound limit associated with inorganic fertilizer use in the United States under irrigated corn conditions.

⁹ This is not an issue in Ethiopia where only DAP and UREA are currently available for purchase.

using the LSMS-ISA data match the macro-statistics reported in Table 1 reasonably closely in four countries (see grayed column).¹⁰

Organic fertilizer is used by an estimated 29 percent of households in our data. This figure likely represents a very low bound since the LSMS-ISA surveys do not include all possible organic nutrient sources used by farmers, like crop residues, which may be an important source of nutrients (Berazneva, Lee, Place 2014). The large degree of heterogeneity in percentages across countries, to some extent, mimics the slight differences in what is considered an organic fertilizer in the survey questionnaires, with Ethiopia and Niger having more options than the other countries. In Nigeria, we only observe if a household applies “composite manure” which may be the reason for the low percentage of households there. The rates of application in organic fertilizer are inconsistently observed (not shown). Of those countries with continuous application rate data, the 3 percent of Nigerians who apply organic fertilizer claim to do so at an average rate of nearly 650 kilograms per hectare; 20 percent of Tanzanians at over 1100 kilograms per hectare; and 13 percent of Ugandans at around 550 kilograms per hectare.

Table 7: Average household-level organic and inorganic fertilizer use trends

	Organic		Inorganic							
	% of cultivating households using	% of cultivating households using	Use (kg/ha) across all households (includes zeros)		Use (kg/ha) across only fertilizer using households (excludes zeros)					
			mean total	mean nutrients	median total	mean total	mean N	mean P	mean K	mean nutrients
Ethiopia	66.4	55.5	45.0	25.2	60.0	81.0	23.0	22.5	-	45.5
Malawi	17.6	77.3	146.0	56.3	148.9	188.8	53.1	19.4	0.4	72.8
Niger	55.1	17.0	4.5	1.7	3.5	26.3	7.6	2.6	-	10.3
Nigeria	3.4	41.4	128.2	64.3	227.9	310.1	93.9	30.8	30.8	155.5
Tanzania	20.3	16.9	16.2	7.7	61.0	95.6	32.0	7.0	6.6	45.6
Uganda	12.6	3.2	1.2	0.7	9.3	37.5	11.5	8.3	1.0	20.7
<i>Average</i>	<i>29.2</i>	<i>35.2</i>	<i>56.9</i>	<i>26.0</i>	<i>85.1</i>	<i>123.2</i>	<i>36.9</i>	<i>15.1</i>	<i>9.7</i>	<i>58.4</i>

Note: All summary statistics are weighted at the household level. Household level fertilizer values are calculated by taking the total inorganic fertilizer used overall the total land area cultivated. Nutrient values represent the actual nutrient content in all applied fertilizers. Extreme high values are winsorized at the 99 percent level. When unreasonably high application rates remain after winsorizing, additional replacements are made consistently across all countries (see text for details). The grayed column represents the values best compared with macro-statistics from Table 1. The “average” row includes simple (unweighted) averages across the statistics reported at the country level.

Improved seed varieties and commercial seed purchases

The LSMS-ISA surveys are not designed with the purpose of estimating overall improved seed variety adoption or current main season usage. Ethiopia and Niger are the only countries where any seed applied to a plot is categorized as improved or traditional no matter if it was purchased, saved, or given for free. In Malawi, we are able to make the distinction only for maize, tobacco, groundnuts, and rice, despite the existence of other improved crop varieties on the market (e.g., for cassava, beans, cowpeas, soybeans, pigeon peas). In Tanzania and Uganda, we only observe the seed type when it was purchased in this season, which likely under-estimates total improved

¹⁰ There are many possible reasons for the mismatches in the remaining two countries: differences in land area definition used between the two estimates (cultivated land versus land available for cultivation, including temporary fallow; differences in time frame used (calendar year versus main agricultural season); differences in included sample (smallholders versus all of agricultural production); etc. This paper does not concern itself with rectifying these differences in methodology.

seed variety use, particularly for crops where improved seeds are saved for use in later years. In Nigeria, we do not observe any seed varietal characteristics. For these reasons, we do not focus much of our analysis on improved seed varieties beyond what we can say in those countries for which we have a reasonably good picture of improved seed utilization.

Table 8: Percent of households using improved seed varieties and commercially purchased seeds

	Number of households that cultivate crop	Improved seed varieties		Commercially purchased seeds
		% of cultivating households using improved variety	% of area cultivated with this crop under improved variety	% of cultivating households that purchased a commercial seed (irrespective of variety)
Ethiopia				
Barley	717	2.2	3.2	29.9
Maize	1,760	23.7	33.7	40.7
Teff	1,088	3.3	2.4	21.5
Wheat	692	10.6	12.0	34.0
Coffee	723	6.4	1.5	-
Malawi				
Maize	9,861	56.2	40.5	31.5
Tobacco	1,485	3.2	2.8	14.2
Groundnuts	2,735	48.9	21.6	26.1
Rice	496	29.4	36.7	20.6
Niger				
Millet	2,176	1.2	1.1	-
Sorghum	1,436	1.0	1.1	-
Rice	60	13.7	5.4	-
Cowpea	1,797	1.6	1.1	-
Groundnut	625	1.6	3.6	-
Nigeria				
Maize	1,247	-	-	24.0
Cowpea	1,336	-	-	1.7
Sorghum	1,107	-	-	11.8
Millet	683	-	-	12.9
Tanzania				
Maize	1,715	-	-	29.8
Rice	435	-	-	22.7
Sorghum	246	-	-	19.5
Groundnut	320	-	-	28.5
Uganda				
Maize	1,246	-	-	36.6
Banana	1,010	-	-	0.9
Sorghum	372	-	-	37.9
Groundnuts	523	-	-	46.4

Note: The grayed column is best compared with the macro-statistics found in Table 2. Commercial seed can be of any variety. Included crops are most frequently occurring (apart from cassava and beans). Commercial seed purchases for Niger are excluded due to inconsistency in English translation of survey instrument and how the data was supposedly collected from respondents.

In Table 8 we show the percent of households and land under cultivation where an improved variety was used for major crops in the three countries for which we can disaggregate this way. In Malawi, over half of the maize cultivating households (which include nearly everyone) use a modern maize variety as compared to one-fourth in Ethiopia. Of those that use improved maize

seed in Ethiopia and Malawi, 51 and 22 percent, respectively, also planted a local or traditional variety on their farm, showing some degree of on-farm diversification in seed choice, likely due to the diversity in seed attributes demanded by smallholders (Lunduka, Fisher, Snapp 2012). In Niger, the use of improved varieties is very low across staple crops. The percentage of land under an improved variety (grayed column) is the best means of comparison with the DIIVA estimates displayed in Table 2. Niger is the only country of the three for which the LSMS-ISA data do not well-match the DIIVA data.¹¹ In the other two, we find that about one-third of the area under maize cultivation is seeded with improved varieties.

Then, given the lack of comparable data available to provide a complete picture of improved seed variety use, we also include the percentage of cultivating households that purchased commercial seeds in the given main season. Commercially purchased seeds are not necessarily equivalent to improved seed varieties since households may choose to purchase traditional variety seeds instead or may plant saved improved varieties instead of newly purchased ones. However, a tabulation of commercial seed purchases helps us to better understand the robustness of the commercial seed market and the extent to which households are actively engaging with it in a given agricultural season. Across the board, we find that generally less than one-third of all cultivating households are purchasing a commercial seed for one of these major crops; however, maize seed is generally more likely to be purchased this season than other major crops.

Agro-chemicals

Questions on agro-chemical use appear differently across surveys. In all countries, we observe whether or not any agro-chemical was applied. However, the binary variables disaggregated by type are more difficult to compare and have implications for potential under-counting. In half of the countries (Ethiopia, Niger, Nigeria), separate questions are asked for each possible type (pesticide, herbicide, fungicide), which should enable a more complete understanding of agro-chemical use. In other countries, only the main type (Tanzania and Uganda) or two primary sources (Malawi) are enumerated, meaning a complete picture of agro-chemical use is not possible in these latter three cases. Instead, we show which types were described as most important or most frequently occurring in our data.

We present overall agro-chemical use statistics in Table 9. In general, the percent of cultivating households applying an agro-chemical in the main growing season appears higher than conventional wisdom holds, with over 16 percent of all households applying to their fields in the main cultivating season. These percentages are even higher in Ethiopia and Nigeria, where agro-chemicals are used by 30 to 33 percent of cultivators, which are slightly above what is reported in other major studies from our literature review, as shown in Table 3. Further, the statistics we describe are only related to chemicals applied to crops on the field, not those also used in storage. Using the same LSMS-ISA data, Kaminski and Christiaensen (2014) find that 63 percent of maize growing households in Uganda, 49 percent in Tanzania, and 11 percent in Malawi used some form of spraying or smoking of their crops while in storage, suggesting that on-field usage is definitely not exhaustive of the full set of possible chemicals used in African agriculture.

¹¹ In Niger, a relatively high percentage of respondents said their seed was from “unspecified sources” (classified here as not improved), which may be the reason for the mismatch.

Table 9: Percent of cultivating households using agro-chemicals (pesticide, herbicide, fungicide)

	% of cultivating households using any agro-chemical	By type (if full set provided)			1 st -most important type	2 nd - most important type
		Pesticide	Herbicide	Fungicide		
Ethiopia	30.5	8.4	27.2	3.5	-	-
Malawi	3.0	-	-	-	Insecticide	Herbicide
Niger	7.8	1.9	0.7	5.5	-	-
Nigeria	33.0	18.2	21.9	-	-	-
Tanzania	12.5	-	-	-	Herbicide	Pesticide
Uganda	10.7	-	-	-	Insecticide	Herbicide
<i>Average</i>	<i>16.3</i>	-	-	-	-	-

Notes: First and second most important types are household-reported in Malawi, Tanzania, and Uganda where use rates by type are not provided (observed at plot level). The “average” row includes simple (unweighted) averages across the statistics reported at the country level.

Application rates of these agro-chemicals are very difficult to compute since some are purchased in concentrate while others are ready for application. Despite these differences, we attempt to create comparable kg/ha statistics by assuming liters and kilograms are equivalent and treat other units accordingly.¹² If it is the case that some of what we observe is agro-chemical amount in concentrated form, then we would expect our applications rates to be lower than the actual mixed agro-chemical volumes. Like inorganic fertilizer levels, we limit extreme values by winsorizing application rates at the 99th percentile. Because very high values still exist after applying this standard cleaning rule, we also replace values above 500 kg/ha with that value. The average unconditional rates of use are estimated to be less than 1 kilogram per hectare in all countries where we can observe these data (all but Ethiopia) except Nigeria (8.8 kg/ha) and Tanzania (1.2 kg/ha). Conditional rates of use, however, show relatively high levels for agro-chemical users, including 26.8 kg/ha in Nigeria, 10.0 kg/ha in Malawi, and 9.3 kg/ha in Uganda. Application rates are higher than expected, especially considering the caveats previously explained.

Irrigation

Like the other inputs, the way we observe irrigation incidence is different across surveys and may better be defined as “water control.” In Ethiopia, Nigeria, and Uganda, we observe a binary variable for whether or not the plot was irrigated, meaning it is up to the household and/or enumerator to decide if a plot is irrigated or otherwise. In the remaining three countries (Niger, Malawi, and Tanzania), we infer from the source of water whether or not a plot was irrigated. If a plot is any more than rainfed, we qualify the plot as irrigated, although the level of sophistication can vary dramatically between plots with different types of irrigation technologies and methods (see Appendix 2).

Table 10 displays the range of irrigation statistics we can tally from the LSMS-ISA data. Across the six countries, we find that about 5 percent of households use some form of irrigation, covering about 2 percent of land under cultivation. While slightly higher than the AQUASTAT/FAO numbers presented in Table 4, the estimates still show a very low incidence of irrigation across these countries. Moreover, households that are observed with some water

¹² A large number of other assumptions were made to standardize agro-chemical application rates. In Niger, most people purchase agro-chemicals in “bags” which we assumed were also equivalent to 1 kilogram. In Nigeria, there are several “other” units (e.g., bottles, cans) that we assume are equivalent to liters and, therefore, also kilograms.

control on farm generally irrigate only about half of all the land they cultivate. Like our finding that households choose to cultivate both improved and traditional varieties of the same crop within the same season, we expect that this on-farm diversification in watering strategies represents an expression of risk preferences and possibly some level of heterogeneity of within-farm agro-ecological conditions and crop choice. As expected, great heterogeneity exists across countries. Ethiopia and Niger have the highest percent of cultivating households with some form of irrigation in the main season with Malawi at the lowest end.¹³

Table 10: Percent of cultivating households with irrigation and irrigation scheme access

	Total ha of cultivated land under irrigation by smallholders	% of all cultivated land under irrigation by smallholders	% of households with at least some irrigation on farm	Most common water source for irrigating households	Average % of cultivated land that is irrigated at household level (excludes zeros)	% of households living in a community with an irrigation scheme
Ethiopia	163,087	1.3	8.7	River	28.2	50.2
Malawi	4,090	0.2	0.4	Bucket	61.5	18.8
Niger	136,383	1.4	6.9	Well	34.7	5.4
Nigeria	274,681	2.5	4.1	Divert stream	67.1	-
Tanzania	239,493	1.8	3.6	Flooding	61.4	-
Uganda	174,972	3.5	3.9	-	82.6	-
<i>Average</i>	<i>165,451</i>	<i>1.8</i>	<i>4.6</i>	<i>-</i>	<i>55.9</i>	<i>24.8</i>

Note: Total irrigated area at the country level involves plots cultivated in either season. The grayed column is best compared with the macro-statistics found in Table 4. For Uganda, this variable is observed at the parcel level with no variation by season. Most common water source is tabulated at the plot level instead of household level. The “average” row includes simple (unweighted) averages across the statistics reported at the country level.

In the community level surveys, we observe whether an irrigation scheme exists in three of the six LSMS-ISA countries. Community schemes may be important in areas where setting up irrigation facilities on-farm may be an unfeasible strategy for farming households. We match those variables to the household-level to determine which households live in communities where an irrigation scheme is present; however, household-level use of community-level irrigation schemes is unobserved. Half of all cultivating households in Ethiopia live in a community with an irrigation scheme, with far fewer in Malawi and Niger. Even so, the percent of households living in communities with an irrigation scheme is far larger than the percent of households utilizing on-farm irrigation techniques in Ethiopia and Malawi, which may imply that households are utilizing other options beyond what we observe on-farm. In the other direction, in those communities with irrigation schemes, 34 percent of households also have on-farm irrigation in Niger, compared to 14 percent in Ethiopia and only 1 percent in Malawi.

Mechanization

Mechanization is a process and may express itself through the utilization of different technologies across different cultivating environments. That said, the LSMS-ISA surveys provide a picture of current use or ownership of inputs associated with mechanization: traction animals and farming machinery. In only a limited number of surveys do we observe whether or not particular types of traction animals or equipment were used on individual plots in the main growing season. In all other countries, we can only ascertain whether traction animals and farm machinery are *owned*. In the case of farm machinery, we can be fairly certain that the observed equipment is used in agriculture. Traction animals, however, may not necessarily be used for

¹³ Note that most of the irrigation in Niger is concentrated in the contre season, not the main season, so the estimates included here underestimate the total incidence of irrigation used year round.

plowing or land clearing, particularly when a lower limit exists for the number of animals necessary to plow (e.g., two oxen is a standard assumption) or a plow is not available for attaching to the animals.

Table 11: Average household-level animal traction and mechanization levels

	Animal traction			Mechanized farm equipment				
	All livestock (TLU) (includes zeros)	% of hh with traction animals	Traction animals (TLU) (excludes zeros)	Number of tractors in country (unrestricted weighted sample)	% of households that own a tractor	% of households that rent a tractor	% of hh that own any equipment	% of hh that rent any equipment
Ethiopia	4.6	79.8	4.8	-	-	-	73.6	-
Malawi	0.4	2.4	3.3	707	<0.1	<0.1	0.8	1.1
Niger	2.5	37.8	3.2	6,286	0.3	0.2	77.5	13.6
Nigeria	2.6	19.9	7.3	449,688	1.6	-	9.4	-
Tanzania	3.0	22.5	8.3	170,250	2.2	3.0	16.4	19.1
Uganda	2.2	30.4	4.3	11,574	0.2	0.5	13.6	15.1
<i>Average</i>	<i>2.6</i>	<i>32.1</i>	<i>5.2</i>	<i>127,701</i>	<i>1.1</i>	<i>1.2</i>	<i>31.9</i>	<i>12.2</i>

Note: Tropical livestock values (TLU) were computed using the Sub-Saharan African equivalents found in Njuki et al. (2011). For the number of tractors summation, the full sample – not what is found in Table 6 – is used in order to more accurately predict the number of tractors at the national level. The “average” row includes simple (unweighted) averages across the statistics reported at the country level.

Observable mechanization levels are described in Table 11. As a means of comparison, we create an aggregate of all livestock observed at the household level and compare that to an aggregate of explicitly traction animals (i.e., bulls, cows, steers, heifers, donkeys, ox, horses, and mules).¹⁴ Livestock aggregation is done using tropical livestock units (TLU) using the Sub-Saharan African equivalents found in Njuki et al. (2011) where one TLU is roughly equivalent to 250 kg of live weight. We find that 32 percent of households across the six countries own animals that are considered suitable for traction activities. Ethiopia appears the best equipped to employ their existing livestock in agriculture while Niger, Nigeria, Tanzania, and Uganda all have moderate animal traction potential. Moreover, given that the average livestock ownership levels for animal traction is always above two, it appears the households should also not be constrained by the lack of sufficient animal power to plow fields.

Tractor ownership at the household level remains quite low, with around 1 percent of households across all countries claiming to own a tractor. The incidence of tractor rental appears no more robust, with a similar percentage of households engaging in the tractor rental market. As a means of comparison with the FAO statistics in Table 5, we estimate the number of tractors in the country (grayed column), as aggregated across the full sample and weighted to a national level using the population weights. The estimates in Nigeria and Tanzania far exceed those reported by the FAO in Table 5 likely due (in part but not entirely) to differences in the year the data were obtained and the small sample size off of which national ownership rates are estimated. The

¹⁴ Overall livestock ownership may give some indication of potential organic matter left on plots in the form of animal manure while ownership specific to the aforementioned large animals functions as a metric of potential animal power that could be used for traction. Cultivating households in Ethiopia have the highest values, which is commensurate with the high percentage of households applying organic fertilizer to their plots in Table 7. Malawi, on the other hand, has a very low amount of livestock and low percentage of households using organic manure. To the extent that animal manure is the largest contributor to on-farm organic fertilizer use, the amount of livestock available to farmers appears a major constraint to adding those complementary nutrients back into the soil.

Malawi numbers are virtually identical, despite the huge time variation, which may signal that tractor use in Malawi has stagnated, as hypothesized about SSA more generally (Pingali 2007).

The incidence of farm machinery other than tractors varies tremendously across countries. Appendix 2 describes the different types of farm implements observed in the surveys that we deem suitable as an indication of on-farm mechanization. Across the six countries, about 32 percent of households own and 12 percent of households rent some type of farm equipment that could be used for mechanization. The use of other mechanized farm implements apart from tractors, therefore, is far greater in all countries apart from Malawi; however, differences in included equipment type by survey likely contributes to some of the heterogeneity in percentages across countries.

Beyond ownership, in Nigeria we observe that 27 percent of cultivating households used animal traction on their plots while 25 percent used machines on their plots, where 47 percent of households use one or the other. Given both of these values are far more than the percent of households owning traction animals and mechanized equipment, this suggests that the rental market for both is at least fairly substantial in Nigeria where the government has dedicated significant resources to the promotion of agricultural mechanization in recent years (Takeshima, Nin-Pratt, Diao 2013). In Niger, we observe community tractor access in the community level surveys. When matching those variables to the household level, we find about 9 percent of households living in communities where a tractor is available. Because this value is far greater than the 0.2 percent of households that claim to rent a tractor, it must be the case that either these tractors go under-utilized or using the community tractor is not considered renting. In fact, none of the households in these communities with tractor access claim to rent. In Ethiopia, households are asked about the number of oxen they use to plow their fields. 42 percent of cultivating households claimed to use no oxen, 22 percent claimed to use only one, and 27 percent claimed to use two. Of the 64 percent of households with one or no oxen, about 30 percent said they applied manual labor to their fields instead with the remaining 70 percent saying they rented or borrowed another ox or used a different animal for plowing. Of these three countries with a fuller set of mechanization data, Nigeria and Ethiopia show signs that traction animals or mechanized inputs are being used in addition to or in replacement of human labor. Using the same data, Binswanger-Mkhize and Savastano (in review) find that mechanization in Nigeria does not appear to have been responsive to increases in population pressures.

4.2. *Regional level input use*

In this section, we provide a lower level of geographic disaggregation to the national level statistics discussed previously. Here, we explore input use variability across geo-referenced agro-ecological zones and administrative regions.

Agro-ecological zones

We explore within-country variability using cross-country comparable geo-referenced agro-ecological zones from Harvest Choice¹⁵ in Table 12. These categories are constructed around

¹⁵ We utilize the 16-class agro-ecological zone data provided by Harvest Choice, following from the FAO/IIASA methodology: http://harvestchoice.org/data/aez16_clas.

local rainfall and vegetative conditions, thereby offering a good proxy for agricultural suitability, and help to cluster and compare relatively similar areas within and across countries. One of the most important things to note from this table is that, with a few exceptions, there are few obvious patterns by agro-ecological zone. In all countries households in the cool/sub-humid zone are more likely to apply inorganic fertilizer, while the incidence of irrigation is highest in the warm-arid areas, likely because the payoff to irrigation is higher where rainfall is lower (Binswanger-Mkhize and Savastano in review). Given the ease of cross-country comparability, we will return to these categorizations, in addition to a range of other geo-referenced agro-climatic variables, later in this paper.

Table 12: Differences in input use between households across standard agro-ecological zones

	No. of households (weighted)	% using organic fertilizer	% using inorganic fertilizer	Avg total inorganic fertilizer (kg/ha)	% using any improved seed	% using agro-chemicals	% using irrigation	% owning any ag equipment
Warm-arid								
Ethiopia	15	0	0	0	7	0	64	51
Niger	256	15	9	20	2	18	13	65
Warm/semiarid								
Ethiopia	102	56	24	27	7	34	7	80
Malawi	5,165	19	73	118	-	4	<1	1
Niger	1,993	60	18	3	3	6	6	79
Nigeria	1,113	9	63	197	-	42	6	19
Tanzania	220	23	8	5	-	5	12	13
Warm/humid								
Nigeria	247	0	14	50	-	5	0	1
Tanzania	40	18	0	0	-	0	0	6
Uganda	1,061	4	4	1	-	13	3	18
Warm/subhumid								
Ethiopia	37	17	27	8	19	5	0	35
Malawi	3,081	13	79	185	-	1	<1	<1
Nigeria	1,553	1	29	84	-	32	3	4
Tanzania	1,084	10	12	9	-	11	3	12
Uganda	64	10	2	8	-	4	2	2
Cool/semiarid								
Ethiopia	726	66	42	33	10	16	17	87
Malawi	1,293	23	84	137	-	1	<1	1
Tanzania	124	33	15	14	-	12	0	31
Cool/humid								
Ethiopia	527	67	61	51	25	43	5	73
Tanzania	52	13	0	0	-	3	1	7
Uganda	576	15	3	2	-	11	7	12
Cool/subhumid								
Ethiopia	1,650	69	62	50	27	34	7	72
Malawi	547	14	89	210	-	4	<1	5
Nigeria	28	0	98	475	-	25	10	7
Tanzania	831	31	28	31	-	18	2	22
Uganda	384	32	1	<1	-	4	3	5

Note: All of the above fall into the “tropics” AEZ category, which is why the distinction is dropped. The AEZ categories are georeferenced to data from Harvest Choice at IFPRI and created using WorldClim climate data. A set of geovariabes specific to the household location in Uganda 2010/11 does not yet exist, so we use the variables from 2009/10, meaning households that move or split between the two survey rounds are not included. In Ethiopia, the warm/humid and cool/arid zones are omitted since less than 5 households appear in either.

Administrative regions

Many sub-national descriptive statistics are cited in other publications according to administrative regions corresponding to sub-national government levels. These provide a level of disaggregation that policy makers and anyone more familiar with the geography of a particular country can easily comprehend.

Table 13: Differences in input use between households across administrative regions

	No. of households (weighted)	% using organic fertilizer	% using inorganic fertilizer	Avg total inorganic fertilizer (kg/ha)	% using improved seed	% using agro-chemicals	% using irrigation	% owning any ag equipment
Ethiopia								
Tigray	226	70	70	67	10	19	14	86
Afar	28	0	0	0	0	0	47	75
Amhara	821	72	52	42	25	21	13	86
Oromia	1,029	57	59	42	26	50	8	86
Somali	41	15	1	<1	4	2	8	58
Benshagul G.	69	43	34	6	21	19	15	62
SNNP	851	76	56	51	19	22	3	52
Gambelia	14	0	0	0	8	9	0	16
Harar	5	70	52	53	13	26	42	84
Diredawa	7	41	5	1	19	6	37	80
Malawi								
North	1,246	11	82	179	-	3	<1	4
Central	4,241	25	82	134	-	2	<1	1
South	4,598	13	72	148	-	4	<1	<1
Niger								
Agadez	10	18	16	16	3	30	60	50
Diffa	79	20	20	61	2	11	22	53
Dosso	331	73	35	5	2	7	7	90
Maradi	496	69	15	2	3	8	1	86
Tahoua	465	43	4	<1	2	8	8	39
Tillaberi	379	46	19	2	2	8	8	85
Zinder	472	55	16	8	3	7	6	97
Niamey	15	38	31	39	19	6	56	66
Nigeria								
North central	483	<1	42	107	-	47	4	4
North east	417	4	48	102	-	55	3	26
North west	809	10	71	238	-	39	8	14
South east	558	2	30	132	-	7	3	5
South south	351	0	13	33	-	9	1	2
South west	321	1	6	15	-	39	2	9
Uganda								
Kampala	5	33	0	0	-	33	0	0
Central	364	20	7	1	-	25	11	<1
Eastern	572	5	3	2	-	11	3	0
Northern	558	1	3	1	-	6	<1	<1
Western	630	26	1	1	-	6	3	<1

Note: The administrative regions chosen for use vary in size across countries but represent the highest level of zonal disaggregation possible. Tanzania is not included in this table because there are too many regions, the highest level of disaggregation, for the purposes of this table. Average inorganic fertilizer use statistics are unconditional (i.e., they include all farming households, including those that apply no fertilizer) and represent total values, not nutrients.

Table 13 reports average input statistics across the highest level of administrative disaggregation in each country for which the statistics remain representative, accompanied by the weighted number of cultivating households found in that region to provide an indication of the relative importance of each area to national-level agriculture. Even more so than the agro-ecological zone distinction, regional variation in input use within countries is immense, likely due to factors like input and output prices, accessibility, and past investments in infrastructure, agricultural extension services, etc. Unlike the macro-level statistics, the LSMS-ISA data allow us to uncover this sub-national heterogeneity and identify where input intensification efforts may be taking hold within countries, even when country-level statistics show overall low rates of use and especially where countries are large and/or populous.

In certain countries, particularly Ethiopia, this level of disaggregation illuminates the tremendous heterogeneity in input use across regions. With an average unconditional fertilizer application rate of 45 kg/ha, we find three regions far surpass this average (Tigray, SNNP, Harari), while five regions fall well below even 10 kg/ha (Afar, Somalie, Benshagul G., Gambelia, Diredwa). This large spread is also evident for other inputs, with ranges from 0 to 50 percent of households using agro-chemicals by region (relative to a national average of 31 percent) and 0 to 47 percent of households using irrigation (relative to 9 percent nationwide). To a slightly lesser extent, regional variation in Nigeria is also considerable. The northern regions are far more likely to use inorganic fertilizer and agro-chemicals, with the highest percentage of organic and inorganic fertilizer users found in the North West. In much smaller Malawi, regional disaggregation provides little interesting variation around the country's relatively high input use rates.

In relatively lower input countries, like Niger and Uganda, we also find some sub-national variation and patches where input use is far greater than national averages suggest. In Niger, those regions with fewer cultivating households (Agadez, Diffa, Niamey) have relatively higher input use levels than the more prominent agricultural areas; however, even Dosso has two times the proportion of inorganic fertilizer users relative to the national average. In Uganda, the largest amount of within-country variation is observed in agro-chemical use, with the major agricultural areas having lower percentages of users than the minor cultivating areas, likely due to sample selection and size.

4.3. *Household level input use*

In this section, we further disaggregate input use statistics at the household level, exploring a range of household characteristics that are often thought to be correlated with input use, including socio-demographic and farm characteristics. Because the LSMS effort, dating back to the 1980s, has largely focused on estimating and understanding poverty and welfare, a huge number of other household-level socio-economic and demographic characteristics are available through the LSMS-ISA surveys. While we limit our discussion to a fairly narrow set of covariates, much more detailed disaggregation remains possible for those who wish to pursue this line of analysis in greater depth.

Household demographics

One of the most often inferred constraints to modern input use is household purchasing power and socio-economic status. We investigate the difference across consumption quintiles between

users and non-users of the chosen inputs. While household consumption levels are clearly endogenous to the input use decision, these descriptive statistics help us to start to untangle patterns of agricultural inputs use across SSA. Consumption aggregates are compiled by the individual World Bank country offices using the LSMS-ISA surveys. Because methodologies may differ slightly, we use quintiles, rather than purchasing power parity-adjusted real monetary values, as a way of ranking households for inter-country comparison, under the assumption that any methodological differences in construction of the consumption aggregate preserve the ordering among households.

Table 14: Mean consumption per capita quintile split by users and non-users of each input type

	Inorganic fertilizer			Improved seed			Agro-chemicals			Irrigation			Mechanized equipment		
	Not Use	Use	sig	Not use	Use	sig	Not Use	Use	sig	Not use	Use	sig	Not use	Use	sig
Ethiopia	2.9	3.2	**	3.0	3.3	**	2.8	3.5	***	3.0	3.2		2.9	3.1	
Malawi	2.5	3.2	***	-	-	-	3.1	2.9		3.0	3.1		3.0	3.9	***
Niger	3.0	3.3	**	3.1	3.4		3.0	3.3	**	3.0	3.5	***	3.2	3.0	**
Nigeria	3.1	2.9	*	-	-	-	3.0	3.1		3.0	3.0		3.0	2.6	***
Tanzania	2.9	3.4	***	-	-	-	2.9	3.7	***	3.0	3.7	***	2.8	3.9	***
Uganda	2.7	3.4	***	-	-	-	2.6	3.3	***	2.7	2.9		2.6	3.1	***
<i>Average</i>	2.9	3.2	-	3.1	3.4	-	2.9	3.3	-	3.0	3.2	-	2.9	3.3	-

Note: Consumption aggregates created by each country using their own methodology where 1 is the lowest group and 5 the highest. In Nigeria, there is one consumption aggregate created using the post-planting survey and another made using the post-harvest survey. For our purposes, we create a simple average of the two. In Niger, we observe a “welfare quintile” instead of a consumption quintile, which is used in its place. *, **, and *** denote that difference in mean between groups is statistically significant using t-values of 1.645, 1.96, and 2.58 respectively. The “average” row includes simple (unweighted) averages across the statistics reported at the country level.

Table 14 shows the average consumption quintile by the binary input use decision, where 1 is the poorest/lowest and 5 is the highest. In most – but not all – cases and on average across the multi-country data, modern input users enjoy a higher average consumption quintile than do non-users, with the relationship most pronounced for inorganic fertilizer. This simple statistical association does not control for any other factors that might affect both consumption level and input use, but the association confirms the common belief that households with higher consumption levels are more likely to use modern inputs.

Table 15: Percent of households using each type of input by sex of household head

	Inorganic fertilizer			Improved seed			Agro-chemicals			Irrigation			Mechanized equipment		
	M	F	sig	M	F	sig	M	F	sig	M	F	sig	M	F	sig
Ethiopia	57	48	***	23	17	***	31	28		9	6	**	80	56	***
Malawi	79	73	***	-	-	-	3	2	***	<1	<1	**	1	<1	***
Niger	17	20		3	1	**	8	2	***	7	2	***	79	64	***
Nigeria	44	19	***	-	-	-	36	9	***	4	2	***	10	1	***
Tanzania	18	14	*	-	-	-	14	8	***	4	3		20	7	***
Uganda	4	1	***	-	-	-	12	6	***	3	5		16	8	***
<i>Average</i>	37	29	-	13	9	-	17	9	-	5	4	-	34	27	-

Note: We use the head of the household variable created by the CLSP project. These data are not yet available for Uganda 2010/11, so we use the variable for Uganda 2009/10 in its place. *, **, and *** denote that difference in mean between groups is statistically significant using t-values of 1.645, 1.96, and 2.58 respectively. The “average” row includes simple (unweighted) averages across the statistics reported at the country level.

Beyond household finances, other socio-demographic attributes of the household are often associated with modern input uptake patterns. The headship of the household is one

characteristic often believed to limit modern input use. A number of studies find that lower levels of productivity and income among female headed households can be partially attributed to lower access to improved inputs (e.g., Djurfeldt, Djurfeldt, Lodin 2013; FAO 2011). Table 15 shows that, in the LSMS-ISA countries, male headed households are indeed statistically significantly more likely to use modern inputs across almost all countries and input types.

Table 16: Percent of households using each type of input by education level of household head

	Inorganic fertilizer			Improved seed			Agro-chemicals			Irrigation			Mechanized equipment		
	No	Some	sig	No	Some	sig	No	Some	sig	No	Some	sig	No	Some	sig
Ethiopia	61	53	***	23	21		37	27	***	8	10		71	78	
Malawi	81	67	***	-	-	-	3	2	***	<1	<1		1	<1	***
Niger	22	16	*	4	2		7	8		6	7		80	77	
Nigeria	44	38	**	-	-	-	34	32		3	5	*	9	10	
Tanzania	20	8	***	-	-	-	15	5	***	4	2	***	18	12	***
Uganda	3	2	**	-	-	-	12	5	***	3	5		15	8	***
Average	39	31	-	14	12	-	18	13	-	5	6	-	32	37	-

Note: Education level split here by none (“no”) and anymore more than none (“some”), as defined by the CLSP project. These data are not yet available for Uganda 2010/11, so we use the variable for Uganda 2009/10 in its place. *, **, and *** denote that difference in mean between groups is statistically significant using t-values of 1.645, 1.96, and 2.58 respectively. The “average” row includes simple (unweighted) averages across the statistics reported at the country level.

The education level of the household head is another often-mentioned correlate with input use. We use the standardized household head education level classifications provided by the World Bank’s Comparative Living Standards Project (CLSP)¹⁶ and further aggregate to “no education” and “any education” categories given differences in education systems and requirements across countries. Table 16 shows that household heads with no formal education are more likely to use modern inputs, with the strongest association around inorganic fertilizer use and weakest around irrigation. While still a correlation and not a causal relationship, this pattern runs strikingly contrary to what is typically hypothesized – that formal education status is a good proxy for human capital and therefore should be correlated with modern input use.

Table 17: Mean household size by users and non-users of each input type

	Inorganic fertilizer			Improved seed			Agro-chemicals			Irrigation			Mechanized equipment		
	Not use	Use	sig	Not Use	Use	sig	Not use	Use	sig	Not use	Use	sig	Not use	Use	sig
Ethiopia	4.9	5.5	***	5.1	5.5	***	5.1	5.5	***	5.2	5.7	***	4.6	5.5	***
Malawi	4.4	4.8	***	-	-	-	4.7	5.3	***	4.7	5.6	**	4.7	6.1	***
Niger	6.7	7.1		6.7	7.5		6.7	7.1		6.7	7.8	***	6.1	6.9	***
Nigeria	5.6	6.8	***	-	-	-	5.7	6.9	***	6.0	6.9	**	5.9	7.7	***
Tanzania	5.5	5.3		-	-	-	5.4	5.6		5.4	5.6		5.0	7.4	***
Uganda	5.2	5.4		-	-	-	5.1	5.9	**	5.2	5.3		5.1	6.3	***
Average	5.4	5.8	-	5.9	6.5	-	5.5	6.1	-	5.5	6.2	-	5.2	6.7	-

Note: The household size variable comes from the CLSP project for all countries except Uganda where the data are not yet available (the consumption aggregate files contained this value for use instead). *, **, and *** denote that difference in mean between groups is statistically significant using t-values of 1.645, 1.96, and 2.58 respectively. The “average” row includes simple (unweighted) averages across the statistics reported at the country level.

¹⁶ For more information on the CLSP project, see: <http://iresearch.worldbank.org/CLSP/index.aspx>

The number of household members is another possibly important correlate with input use if labor use is a function of household labor endowments, consistent with the hypothesis that multiple rural market failures cause rejection of the separation hypothesis for most African agricultural households (Dillon and Barrett in review). In Table 17, we show that larger households are indeed statistically significantly more likely to use improved inputs. As with all of the other correlates we describe, we emphasize that household size may be endogenous to input use in that households that successfully reap the benefits of larger harvests with improved input use may affect household composition decisions regarding fertility, fostering, marriage, and migration.

Cooperative farming arrangements

We do not observe, in any country, which households belong to an agricultural cooperative. But, through the community-level surveys, we do know, in all countries except Malawi, in which communities an agricultural cooperative exists. Only in Niger do we observe whether or not these cooperatives explicitly provide inputs. Of those communities with a cooperative in Niger, 68 percent of households live near a cooperative that provides inputs in the village.

Table 18: Differences in input use between households where an agricultural cooperative exists in the community

	% using organic fertilizer	% using inorganic fertilizer	Avg total inorganic fertilizer (kg/ha)	% using improved seed	% using agro-chemicals	% using irrigation	% owning any ag equipment
Ethiopia							
Coop in village (n=212)	60	60	55	34	39	6	84
Other (n=2,880)	67	55	44	21	30	9	75
<i>significance</i>						*	
Niger							
Coop in village (n=344)	53	14	8	6	7	15	72
Other (n=1,905)	55	18	4	2	8	5	79
<i>significance</i>				**		**	
Nigeria							
Coop in village (n=813)	4	57	188	-	42	6	10
Other (n=1,603)	5	38	117	-	28	3	10
<i>significance</i>		***	***		***	*	
Tanzania							
Coop in village (n=63)	8	13	15	-	2	<1	5
Other (n=169)	13	9	5	-	5	3	6
<i>significance</i>							
Uganda							
Coop in village (n=70)	10	4	2	-	27	2	16
Other (n=1,508)	13	3	1	-	10	4	13
<i>significance</i>					***		

Note: "n" identifies the number of households. The average inorganic fertilizer statistics are unconditional and represent total, not nutrient, values. Community-level data are not collected for all surveyed areas of Tanzania, the reason for the smaller sample size. Community-level cooperative information is not available in Malawi. *, **, and *** denote that difference in mean between groups is statistically significant using t-values of 1.645, 1.96, and 2.58 respectively.

Table 18 reports the difference in input use across households located in communities with an agricultural cooperative and those without. Apart from Nigeria, a low correlation exists between cooperative placement and household input use. In Tanzania, despite the smaller sample, there is no difference in input use across any of the inputs. Households in communities with cooperatives are more likely to use agro-chemicals in Nigeria and Uganda while households in Niger and Nigeria in communities with cooperatives are more likely to irrigate. Inorganic fertilizer use only appears associated with the presence of a cooperative in Nigeria.

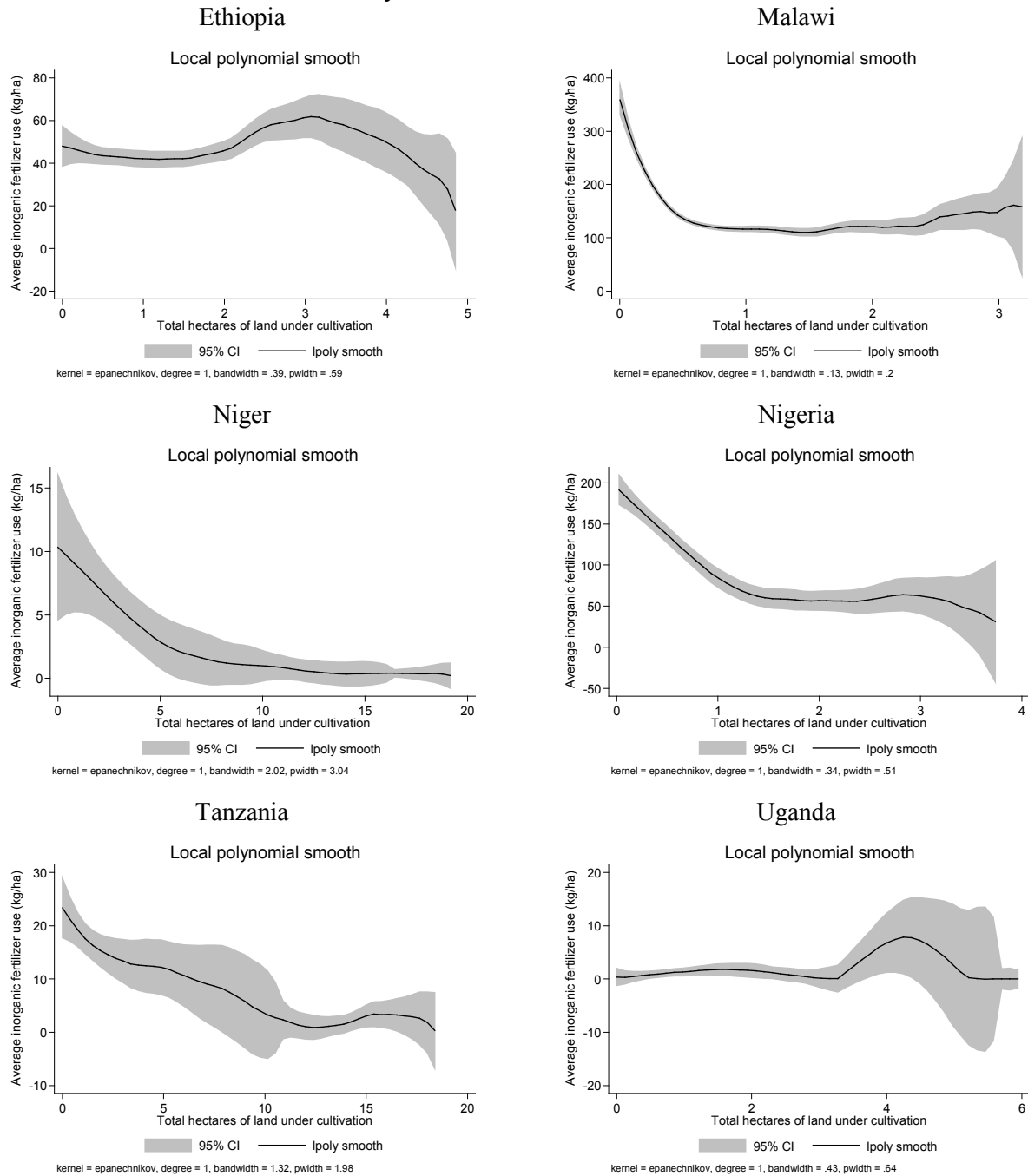
Like all of the other covariates included in our descriptive analysis, these variables are likely to be endogenous – i.e., cooperatives may form where agricultural conditions are better suited to input use – and cooperative placement may be correlated with other variables not controlled for in simple descriptive statistics. Nonetheless, the lack of correlation between cooperative location and household input use across four of the six LSMS-ISA countries is a potentially surprising and interesting finding, particularly given the common wisdom that agricultural cooperatives offer one of the principal channels through which households acquire modern inputs.

Farm size

The inverse (negative) relationship between farm size and productivity is a well-studied and fairly entrenched phenomenon in the agricultural development literature (Carter 1984; Feder 1985; Barrett et al. 2010). What is less well-documented with data from farmers' fields is the relationship between input use intensity and farm size (important exceptions include Croppenstedt, Demeke, Meschi 2003; Doss 2003). Moreover, farm size may represent the best way in the LSMS-ISA data to differentiate farmers by the intensity of their agricultural operations. In general, both in common parlance and in policy circles, a common conception exists that households with larger farms are more likely to apply modern inputs and are more likely to use inputs and in higher amounts.

We test this hypothesis using data from the LSMS-ISA countries. Using non-parametric local polynomial regressions, Figure 1 shows a mostly negative relationship between farm size, defined as total area under cultivation in the most recent main season, and household-averaged inorganic fertilizer application rates. Because we use imputed land size values, we avoid bias of self-reporting of the sort described by Carletto, Savastano, and Zezza (2013). Some of the most negative patterns occur in the countries that have larger average farm sizes, like Niger and Tanzania. On the other hand, in Malawi, where average farm sizes are the smallest, the relationship is less pronounced after an initial fairly small range of farm sizes. In Ethiopia, farm sizes need to approach nearly 7 hectares before a negative relationship sets in. Moreover, in Ethiopia and Uganda, there is a range over which the relationship is (mildly) positive before falling again. This same relationship is studied at the plot level in the next section of this report.

Figure 1: Local linear non-parametric regression of average total fertilizer use per hectare by total number of hectares cultivated by household in main season



Note: Farm size is defined as the total number of hectares under cultivation in the main season and does not include rented out or fallow land. Multiply imputed plot size variables, as described in Section 3, are used in the aggregation to the household level. Farm size observations above the 99th percentile in each country are excluded from these figures. Inorganic fertilizer application rates are representative of total inorganic fertilizer, not nutrients.

4.4. *Plot level input use*

In this section, we use the rich data on plot level characteristics to further explore input use variability at that level (recall footnote 4). Through both the household survey and geo-referencing, we now explore the association between modern agricultural input use and a range of biophysical, institutional, and governance variables at the plot level.

Crops on plot

Because nutrient needs, the incidence of pests, and the need for improved seeds will vary by plant type, we would expect farmers would allocate modern inputs differently across crops. In the LSMS-ISA data, we observe most input use, apart from seed type, at the plot (not crop) level. Instead of making assumptions about how inputs were distributed among the crops grown on a given plot, we lump plots into categories based on the types and portion of land under particular crops. While our categorization is rough, it attempts to isolate the “most important” crop on the plot, defined as comprising at least 50 percent of the plot area under cultivation (see note for Table 19 for more details). These categorizations offer an admittedly-imperfect attempt to categorize plots by the types of crops grown on them, but are arguably no more arbitrary than other classification schemes used in the literature.

A purposively chosen mix of crops for each country in the LSMS-ISA surveys can be found in Table 19 alongside the number of plots in each category and average input use values on those types of plots. Notice that in many countries the “other” category is the largest, pointing to the high degree of mixed and intercropping in these countries. Further, in Niger, most plots contained some mix of millet, sorghum, and cowpea on over half of the plot, so we created one category to lump those instances together.

One striking pattern is that plots with mostly maize are among those most likely to receive a modern input and with the highest application amounts. The two cases where maize plots are not always the most intensively cultivated – although still among the highest – are Ethiopia and Malawi where teff and tobacco plots, respectively, receive more inputs (Minten et al. 2013). Contrary to much prevailing prior belief, agro-chemicals do not appear confined to plots with horticultural or cash crops (which would fall into the “other” category), with relatively high percentages also on plots containing mostly grains. This finding is similar to Williamson, Ball, and Pretty (2008) who observed a very high rate of pesticide use not just on cash crops and vegetables, but also on staple crops. This observation in the LSMS-ISA data is especially important given the significance of maize as a food security crop for many households in Sub-Saharan Africa.

Table 19: Differences in input use between plots as categorized by portion of crops on plot

	No. of plots (weighted)	% using organic fertilizer	% using inorganic fertilizer	Avg total inorganic fertilizer (kg/ha)	% using improved seed	% using agro-chemicals	% using irrigation
Ethiopia							
Maize	3,681	31	46	88	34	14	2
Teff	4,047	7	63	66	2	45	1
Sorghum	2,875	12	8	5	<1	13	1
Coffee	746	12	4	3	1	<1	2
Other	10,823	19	32	41	4	18	1
Malawi (rainy season and permanent crop plots)							
Maize	13,838	15	77	135	-	1	<1
Tobacco	1,551	25	93	267	-	5	<1
Cassava	42	0	0	0	-	0	0
Other	3,335	2	12	22	-	7	1
Niger (rainy season)							
Maize	9	24	42	52	<1	11	40
Millet/sorghum/cowpea	5,606	35	11	1	1	6	1
Other	277	14	12	21	2	6	14
Nigeria							
Maize	817	2	51	123	-	50	4
Cassava	706	<1	13	32	-	18	1
Cowpea	542	2	33	63	-	40	1
Sorghum	617	3	43	89	-	43	2
Other	2,864	5	38	82	-	44	3
Tanzania (long rainy season and permanent crop plots)							
Maize	2,000	15	19	15	-	11	3
Rice	306	3	10	8	-	17	4
Cassava	808	6	9	6	-	7	<1
Other	1,947	9	12	6	-	12	1
Uganda (first season)							
Maize	872	7	4	3	-	20	3
Banana	513	32	1	1	-	6	4
Cassava	1,087	9	5	2	-	9	1
Other	1,815	7	3	1	-	9	5

Note: Plots are categorized based on the portion under a particular crop, as described by a respondent. Where one of the above crops takes up at least 50 percent of the plot, then it becomes a plot with that crop's name. All plots where no crop comprises more than 50 percent of a plot fall into the "other" category. Inorganic fertilizer application rates are unconditional and represent total, not nutrient, values.

One might also expect that monocropped and mixed crop plots would receive different levels of inputs, both as a signal of the degree of commercialization of the farmer and of the increased need to add nutrients to the soil where no other complementary crops are present.

Table 20 investigates this claim by looking specifically at monocropped versus mixed crop maize plots in all countries except Niger, where maize cultivation is marginal. In Malawi and Nigeria, the two major inorganic fertilizer consuming countries in our sample, monocropped maize plots receive statistically significantly more inorganic fertilizer per hectare than do mixed crop plots. At the same time, mixed crop plots are more likely to receive organic fertilizer in Ethiopia and Uganda and to receive agro-chemicals in Tanzania. However, these relationships do not hold across most other inputs.

Table 20: Differences in input use between monocropped and mixed crop maize plots

	No. of plots (weighted)	% using organic fertilizer	% using inorganic fertilizer	Avg total inorganic fertilizer (kg/ha)	% using any improved seed	% using agro- chemicals	% using irrigation
Ethiopia							
Monocropped	2,017	26	47	95	36	18	2
Mixed crop	688	46	45	66	30	1	2
<i>significance</i>		***				*	
Malawi (rainy season)							
Monocropped	7,821	15	78	140	-	1	<1
Mixed crop	5,237	14	77	128	-	1	<1
<i>significance</i>				***			
Nigeria							
Monocropped	290	2	61	151	-	51	4
Mixed crop	470	3	45	106	-	49	3
<i>significance</i>			**	**			
Tanzania (long rainy season)							
Monocropped	727	13	13	15	-	8	4
Mixed crop	1,369	16	22	16	-	12	2
<i>significance</i>			***			*	
Uganda (first season)							
Monocropped	72	1	6	15	-	13	1
Mixed crop	665	8	4	1	-	20	3
<i>significance</i>		***					**

Note: Inorganic fertilizer application rates are unconditional and represent total, not nutrient, values. *, **, and *** denote that difference in mean between groups is statistically significant using t-values of 1.645, 1.96, and 2.58 respectively.

Another common claim is that farmers who grow cash crops and, as an extension, plots with cash crops on them, are more likely to use modern inputs due to the fact that cash crops will generate cash income with which to pay for purchased inputs and may be associated with more extension advice promoting their use.

We selected a set of cash crops from the full list of available crops in the survey to determine whether or not a major cash crop is grown on a particular plot (see notes for Table 21). In addition to the fact that not more than 25 percent of plots have a cash crop cultivated on them, we do not find evidence that plots with cash crops are necessarily more likely to receive one of these modern inputs. In fact, plots without cash crops are more likely to receive inorganic fertilizer in Ethiopia, Malawi, and Nigeria. On the other hand, plots with cash crops are more likely to receive organic fertilizer application in Ethiopia, Niger, and Uganda and agro-chemicals in Nigeria, Tanzania, and Uganda. Perhaps due to the difference in importance in the chosen cash crop set across these six countries, or the inclusion of groundnuts which may be need less or no inorganic fertilizer, input use patterns with respect to cash crops do not appear as straightforward as might be expected.

Table 21: Differences in input use between plots with and without a cash crop in mix

	% of plots with cash crop	% using organic fertilizer			% using inorganic fertilizer			Average total inorganic fertilizer (kg/ha)			% using any improved seed			% using agro-chemicals			% using irrigation		
		No	Yes	sig	No	Yes	sig	No	Yes	sig	No	Yes	sig	No	Yes	sig	No	Yes	sig
Ethiopia	7	17	30	**	38	12	***	50	11	***	9	3	***	23	2	***	2	3	
Malawi	22	13	14		70	59	***	123	139	***	-	-		2	2		<1	<1	
Niger	8	32	50	***	11	10		2	1		1	3		6	6		1	<1	**
Nigeria	16	4	3		39	29	***	85	56	***	-	-		39	53	***	3	<1	***
Tanzania	20	11	13		11	31	***	9	16		-	-		9	24	***	2	<1	***
Uganda	36	7	16	***	2	5		2	2		-	-		8	16	***	3	4	
Average	18	14	21	-	29	24	-	45	38	-	5	3	-	15	17	-	2	4	-

Note: Cash crops are defined differently in each country, with the distinction made by the LSMS-ISA team at the World Bank. The cash crops included here are: Ethiopia-coffee, cotton, groundnuts; Malawi-tobacco, groundnuts; Niger-cotton, groundnuts; Nigeria-cocoa, groundnuts, cotton, palm oil; Tanzania-coffee, cotton, cashew nuts, tobacco, coconut, groundnuts; Uganda- coffee, cotton, groundnuts. *, **, and *** denote that difference in mean between groups is statistically significant using t-values of 1.645, 1.96, and 2.58 respectively. Inorganic fertilizer application rates are unconditional and represent total, not nutrient, values. The “average” row includes simple (unweighted) averages across the statistics reported at the country level.

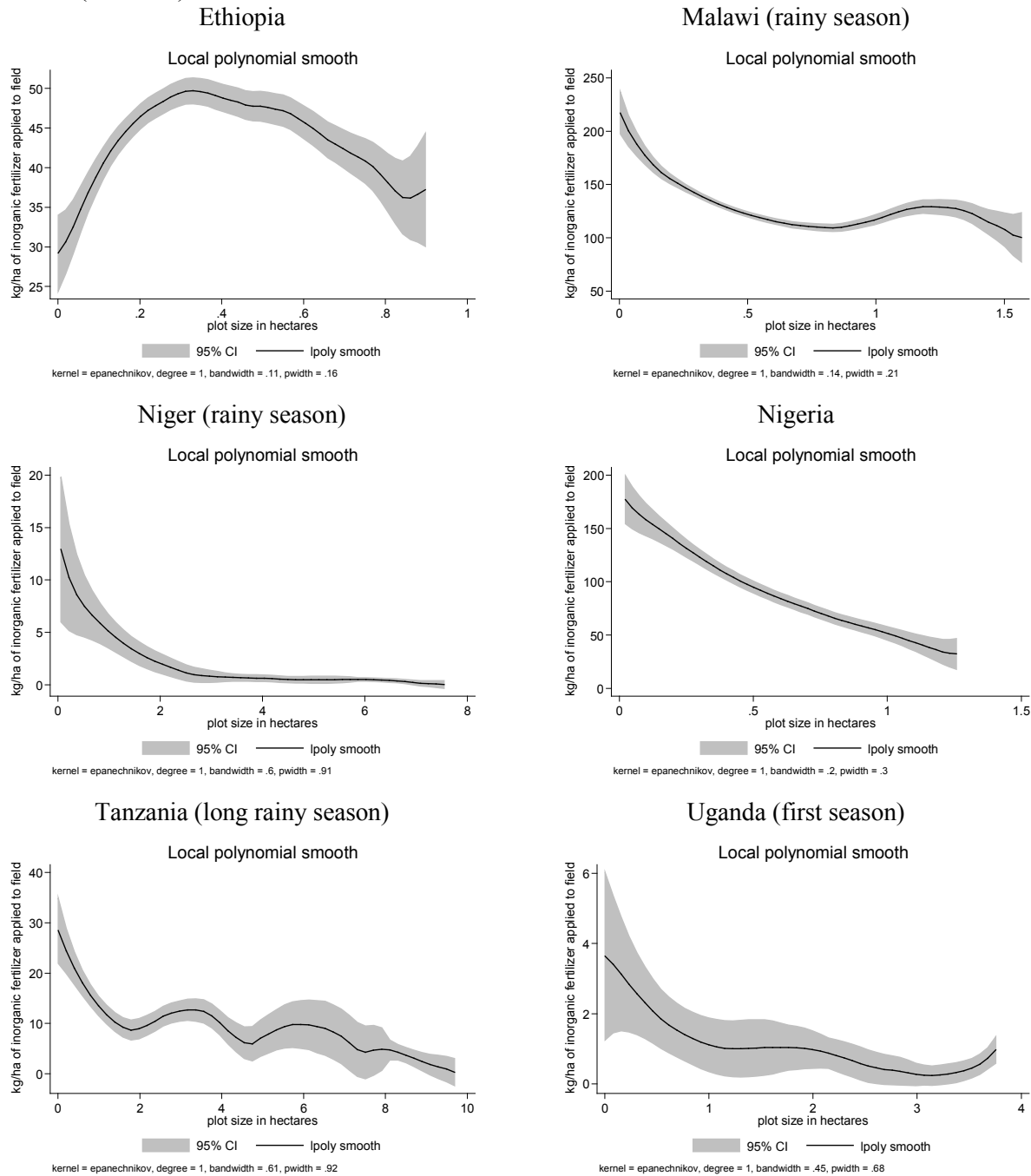
Plot size

Like common conceptions about the link between farm size and input use, it is likewise often believed that larger plots are typically maintained by wealthier or more commercialized farmers, and are therefore more likely to receive inputs due to lack of associated cash constraints. Contrary to that expectation, the local linear non-parametric regressions in Figure 2 show a mostly diminishing relationship between multiply imputed plot size (where household-reporting bias should be alleviated) and unconditional inorganic fertilizer application rates.

With Ethiopia as a notable exception and reminiscent of the total farm size relationship reported in Figure 1, we observe mostly a consistent, inverse (negative) relationships between plot size and inorganic fertilizer use intensity. In many cases, the relationship is even more pronounced at the plot level than at the household level, reinforcing prior findings that the inverse farm size-productivity relationship often found at household level is not wholly attributable to inter-household differences in the shadow prices of inputs, meaning some other, plot-level covariate must be driving within-household variation in input use decisions (Barrett et al. 2010). These within-household allocation decisions raise important and under-researched questions about farmer behavior and efficiency.

In Ethiopia, there is an upward arc at the start of the curve, implying that the smallest plots may receive less fertilizer than medium-sized plots, with a significant drop off after 4 hectares. Despite radically different levels of fertilizer application rates, the patterns are almost identical in Niger and Nigeria with almost logarithmic shapes to their curves. Plots in Uganda have the highest amount of variation within a given plot size, however the overall trend is still strongly negative. Malawi exhibits a flatter regression lines, perhaps due to the smaller range over which plot sizes are observed.

Figure 2: Local linear non-parametric regression of total fertilizer use per hectare at plot level by plot size (hectares)



Note: Plot sizes beyond the 99th percentile are excluded from these figures. Plot sizes are multiply imputed, following discussion in Section 3. Inorganic fertilizer application rates are unconditional and represent total, not nutrient, values.

Soil quality and erosion

One would expect that farm management practices would follow from the knowledge a farmer has about the environment in which they operate. One important characteristic of the operating

environment that should affect input use decisions is soil quality since, for example, it is well known that the responsiveness of crops to fertilizer application depends on the quality and fertility of the soil (e.g., Zingore et al. 2010; Zingore 2011). Even within a given farm, evidence suggests that productivity can differ immensely between plots (Tittonell et al. 2005), so too, then we would expect soil fertility status also to vary. Moreover, household perceptions of soil quality may influence fertilizer application rates (Marenya and Barrett 2009) and be influenced, in turn, by previously observed crop yields (Marenya, Barrett, Gulick 2008).

We can test these claims in three countries where the LSMS-ISA surveys elicited farmer perceptions of soil quality by plot: Malawi, Tanzania, and Uganda. Table 22 shows the input use differences between plots perceived to be of good, average, and bad quality.¹⁷ Unexpectedly, modern input use and rates – particularly for inorganic fertilizer, agro-chemicals, and irrigation – are virtually identical among the categories. Farmers do not appear to adjust input application rates to accommodate their perceptions of plot quality.

Table 22: Differences in input use between plots by household-reported soil quality

	No. of plots (weighted)	% using organic fertilizer	% using inorganic fertilizer	Avg total inorganic fertilizer (kg/ha)	% using agro- chemicals	% using irrigation
Malawi (rainy season and permanent crop plots)						
Good	8,686	12	65	130	3	<1
Fair	7,940	13	70	125	1	<1
Poor	1,967	19	70	117	1	<1
Tanzania (long rainy season and permanent crop plots)						
Good	2,276	10	15	10	12	2
Average	2,189	12	14	11	12	2
Bad	315	23	25	11	13	1
Uganda (first season)						
Good	2,635	11	4	2	12	3
Fair	1,496	9	1	1	8	5
Poor	141	11	2	<1	11	3

Note: Households do not report soil characteristics in Ethiopia and Nigeria; households in Niger do not report soil quality. Inorganic fertilizer application rates are unconditional and represent total, not nutrient, values.

Erosion is seen as one of the avenues through which soils degrade and lose their inherent productivity levels. Moreover, erosion is also the consequence of soil fertility depletion; it can act as a proxy for poor soil quality. Erosion control (e.g., through contour ridges, rock lines, vegetative bands, living hedges), then, is seen as a vehicle for maintaining soil fertility, particularly when paired with fertilizer use and legume intercropping (Morris et al. 2007).

In Table 23 we show the difference between inputs applied to plots characterized by the respondent as eroded or not, as observed in four of the LSMS-ISA countries. Analogous to the soil quality story, farmers do not appear to make tremendously different input use decisions across eroded and non-eroded plots. Only in Niger and Uganda, the two countries with the lowest inorganic fertilizer use rates, do we observe higher unconditional fertilizer application

¹⁷ One, perhaps unsurprising, side finding is the relatively low number of plots currently under cultivation that are characterized as “poor” or “bad” by the respondents. This implies that households are only cultivating plots that they consider of higher quality.

rates for non-eroded plots. Organic fertilizer decisions do not appear to be made based on the erosion status of a plot. That suggests that farmers view organic fertilizer application neither as an investment in improving soil health nor as a waste of scarce resources. Interestingly, outside of Malawi, where the differences are practically insignificant, eroded plots are slightly more likely to be irrigated than are non-eroded ones.

Table 23: Differences in input use between plots characterized as eroded or not

	% of plots eroded	% using organic fertilizer			% using inorganic fertilizer			Average total inorganic fertilizer (kg/ha)			% using any improved seed			% using agro-chemicals			% using irrigation		
		No	Yes	sig	No	Yes	sig	No	Yes	sig	No	Yes	sig	No	Yes	sig	No	Yes	sig
Malawi	35	13	14		67	68		126	126		-	-		2	3	*	<1	<1	
Niger	19	33	36		11	13		2	1	**	2	2		6	7		1	1	
Tanzania	17	11	15		15	17		10	13		-	-		12	12		2	2	
Uganda	24	9	15		4	1	***	2	1	**	-	-		11	9		2	7	*
Average	24	17	20	-	24	25	-	35	35	-	2	2	-	8	8	-	2	3	-

Note: In Malawi, the extent of erosion is broken down into several categories, of which we lump together here. *, **, and *** denote that difference in mean between groups is statistically significant using t-values of 1.645, 1.96, and 2.58 respectively. Inorganic fertilizer application rates are unconditional and represent total, not nutrient, values. The “average” row includes simple (unweighted) averages across the statistics reported at the country level.

To the extent that crop response rates to particular inputs will vary significantly by soil quality and erosion status, these findings suggest the need for more farmer education about how to tailor management practices to increase or deal with those conditions, as suggested by burgeoning recent research (e.g., Sheahan, Black, Jayne 2013). The use of organic inputs in particular may also increase the quality of the soil and productivity of the land over time, so the fact that “poor” plots are no more likely to receive organic fertilizer in Uganda and eroded plots are not statistically significantly more likely to receive organic fertilizer application in any of the four listed countries is cause for concern.

Land tenure/ownership

There is a large theoretical and empirical literature on the link between land tenure, agricultural productivity, and input intensification. Evidence from certain countries shows that land tenure does affect input intensification (e.g., Gavian and Fafchamps 1996; Holden and Yohannes 2002) while others find no connection (e.g., Fenske 2011; Pender et al. 2004; Place and Hazell 1993). In Madagascar, Bellemare (2013) found that formal land rights, manifested in possession of a certificate of title, are not associated with higher productivity. While saying nothing of the relationship to input use, this finding necessarily forces us to think more broadly about land ownership in the SSA context.

We define plot ownership rather loosely, meaning possession of a title or certificate is unnecessary, for the purposes of correlating input use with land ownership. The notes to Table 24 describe the conditions in each country under which we consider a plot “owned” by the household in each country. We find that an overwhelming majority of the plots operated in the main season are considered owned by the households, suggesting a slim land rental market in these countries. With percentages in the 80s and 90s, our findings mirror those from summaries of FAO agricultural census data in the 1960s across Africa (Otsuka, Chuma, Hayami 1992).

Table 24 also shows that owned plots are statistically significantly more likely to receive organic fertilizer than are unowned plots. One hypothesis might be that households operating owned

plots are more likely to make long term investments in the fertility of the soil than if the plot is going to be turned over in a season or two. Alternatively, unowned plots are often located further from the household and receive fewer inputs due to the higher transactions costs involved in fertilizing distant plots. On the other hand, no consistent pattern emerges with respect to inorganic fertilizer use. Beyond organic fertilizer and Nigeria, we find no consistent story across the inputs and countries, suggesting that land ownership is so prevalent that households do not make substantially different input use decisions between owned and unowned plots.

Table 24: Differences in input use between plots owned and not owned by the household

	% of plots owned	% using organic fertilizer			% using inorganic fertilizer			Average total inorganic fertilizer (kg/ha)			% using improved seed			% using agro-chemicals			% using irrigation		
		No	Yes	sig	No	Yes	sig	No	Yes	sig	No	Yes	sig	No	Yes	sig	No	Yes	sig
Ethiopia	75	8	20	***	36	35		51	45		9	8		22	19		1	2	***
Malawi	91	9	14	***	67	67		161	126	***	-	-		4	2	**	<1	<1	*
Niger	85	29	34		16	10	*	2	2		2	2		7	6		1	1	
Nigeria	78	2	4	***	27	40	***	51	89	***	-	-		42	41		2	3	
Tanzania	93	7	12	***	13	15		17	10	*	-	-		9	12		2	2	
Uganda	80	2	13	***	5	3		2	2		-	-		13	10		2	4	
Average	84	10	16	-	27	28	-	47	46	-	6	5	-	16	15		2	2	-

Note: A plot is classified as “owned” if categorized as follows: Ethiopia-granted by local leaders, inherited; Malawi-granted by local leaders, inherited, bride price, purchased with title, leasehold; Niger-own, mortgage; Nigeria-purchased, distributed by community or family; Tanzania-owned, owned but shared; Uganda-all parcels in section on “owned” plots. *, **, and *** denote that difference in mean between groups is statistically significant using t-values of 1.645, 1.96, and 2.58 respectively. Inorganic fertilizer application rates are unconditional and represent total, not nutrient, values. The “average” row includes simple (unweighted) averages across the statistics reported at the country level.

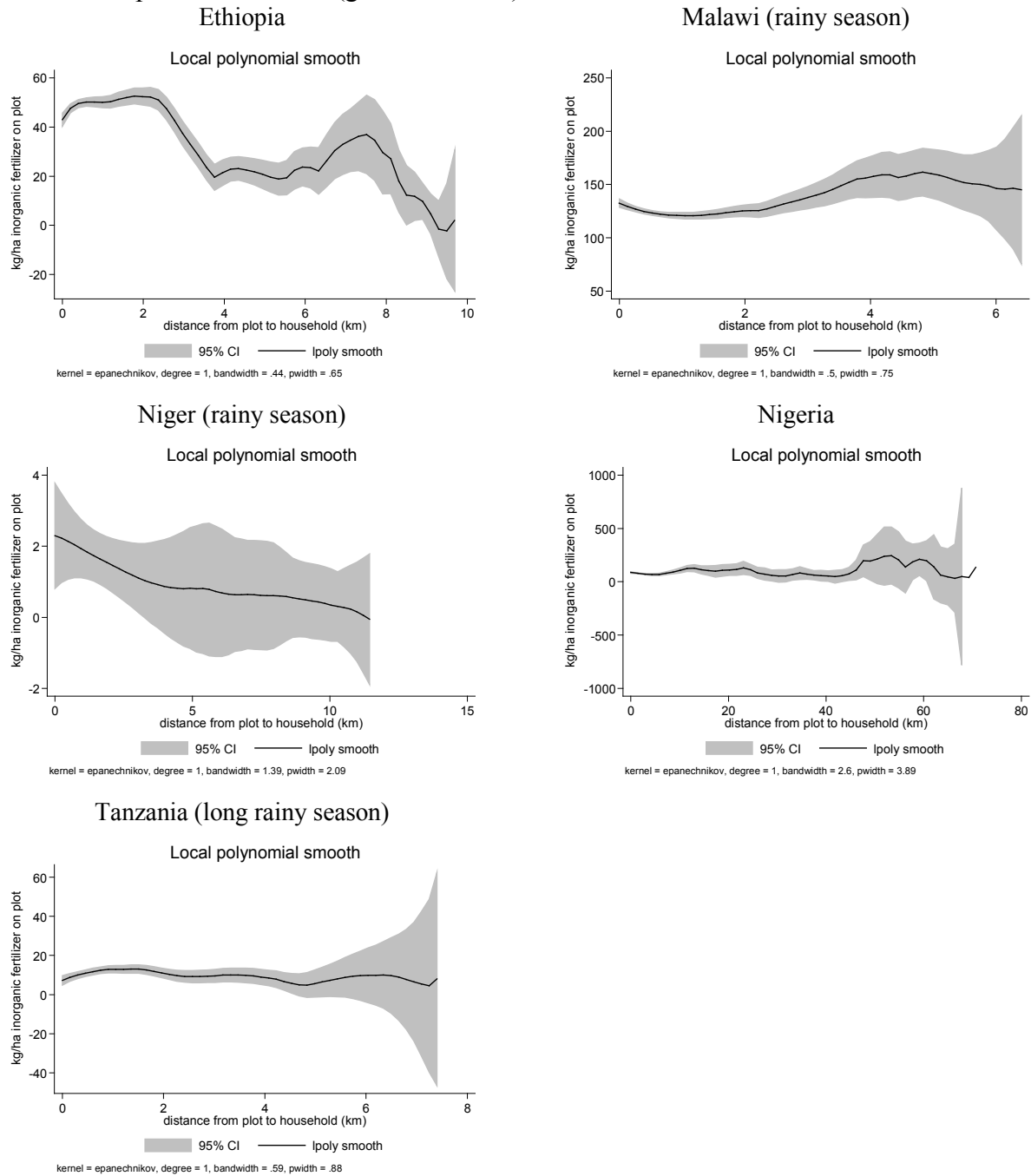
Distance from the household

A plot further from the household will require more transactions costs to manage. As such, we would expect that plots closer to the household would receive more attention and, as a result, more production-enhancing inputs. Where plots and households are geo-referenced, we observe the true (i.e., “as the crow flies”) distance from the household to the plot.¹⁸

Figure 3 shows the non-parametric regression results of inorganic fertilizer application rates associated with plot distance from the household. In general, there is no common pattern across the countries. In Niger, there is a negative relationship, as would be expected, however Malawi, Nigeria, and Tanzania exhibit mostly flat relationships, suggesting that farmers fertilize plots the same way not matter how close they are to the household. In Ethiopia, two different local maximum points occur, both at a low value of 2 and higher value of 8, suggesting there might be some areas of the country where households frequently manage plots further from the household with the same level of management and oversight. Because this distance measure is coarse and may not accurately encapsulate travel time, terrain, or road conditions, the relationships reported here are necessarily coarse but do suggest that plot distance from the household may not be as strong of a driver of input application rates as is sometimes believed.

¹⁸ In some surveys, we also observe the farmer-reported estimate of the distance. We do not attempt to rectify any difference in those values here.

Figure 3: Local linear non-parametric regression of total fertilizer use per hectare at plot level by distance from plot to household (geo-referenced)



Note: Distances beyond the 99th percentile are excluded from these figures due to the presence of certain plots that are situated very far from the household (i.e., the largest values were more than 1000 km from the household in Ethiopia and Nigeria, over 50 km in Niger, between 15-20 in Tanzania, and still within 10 km in Malawi). No plot level geovariabls exist for Uganda in 2010/11. Inorganic fertilizer application rates are unconditional and represent total, not nutrient, values.

Sex of plot manager or owner

As an extension of the relationship between the sex of the household head and input use, we also examine the patterns among plots managed by different members of respondent households. In the LSMS-ISA surveys, we observe the plot manager and/or owner (see notes to Table 25 for what is observed in each country). While managers and owners may be responsible for different types of management decisions, this classification represents the best means of comparison across countries. Table 25 shows that females manage or own generally less than a quarter of all plots cultivated in the main season.¹⁹ Plots managed or owned by men are statistically significantly more likely in most countries to receive inorganic fertilizer, and in higher amounts.²⁰ Men tend to use more agro-chemicals in certain countries (Malawi, Nigeria, Tanzania) and irrigation in others (Ethiopia, Niger, Nigeria). The sex of the plot manager or owner does not appear to be a major determinant of input use in Ethiopia, Tanzania or Uganda unlike in Malawi, Niger and Nigeria.

Table 25: Differences in input use between by sex of plot manager, owner, or operator

	% of plots managed or owned by female	% using organic fertilizer			% using inorganic fertilizer			Average total inorganic fertilizer (kg/ha)			% using improved seed			% using agro-chemicals			% using irrigation		
		M	F	sig	M	F	sig	M	F	sig	M	F	sig	M	F	sig	M	F	sig
Ethiopia	13	17	20		35	38		47	42		8	6		20	23		1	1	*
Malawi	24	13	13		68	66	*	131	112	***	-	-		3	1	***	<1	<1	
Niger	12	36	25	***	10	7		3	<1	***	1	1		7	2	***	2	<1	***
Nigeria	8	4	1	**	39	12	***	84	30	***	-	-		43	18	***	3	<1	***
Tanzania	17	11	13		16	11	*	11	11		-	-		13	9		2	2	
Uganda	33	10	11		2	4		1	2	**	-	-		9	12		6	3	
Average	18	15	14	-	28	23	-	46	39	-	5	4	-	16	11	-	3	2	-

Note: The following are how the gender of the operator is determined: Ethiopia-holder; Malawi-manager; Niger-owner; Nigeria-manger; Tanzania-manager; Uganda-manager. Inorganic fertilizer application rates are unconditional and represent total, not nutrient, values. *, **, and *** denote that difference in mean between groups is statistically significant using t-values of 1.645, 1.96, and 2.58 respectively. The “average” row includes simple (unweighted) averages across the statistics reported at the country level.

4.5. Joint use of inputs

It is commonly thought that modern inputs are seldom adopted in isolation since the complementarity between particular sets of inputs makes adopting them together advantageous for farmers, as well as the fact that inputs are generally sold alongside each other at input shops or provided together via government subsidy programs. If there are agronomic synergies among modern inputs, it is believed, then farmers will use them together, especially if farmers behave “efficiently.” For example, some modern seed varieties are bred to respond better when paired with inorganic fertilizer (Ellis 1992; Nyangena and Juma 2014). The entire integrated soil fertility management (ISFM) paradigm is built around the belief that inorganic and organic fertilizer should be used together to improve both the nutrient availability and absorption capacity of the soil (Place et al. 2003; Vanlauwe et al. 2010, 2011). Furthermore, the use of inorganic fertilizer may mean the presence of more weeds on the plot, necessitating the

¹⁹ For more on the gender dimensions of agriculture in the LSMS-ISA surveys, see Christiaensen, Kilic, Palacios-Lopez (in review).

²⁰ It is important to note, however, that most plots managed or owned by females are also found in female-headed households. When limiting our sample to only male-headed households, the statistical significance of these relationships disappears in Malawi (except in the case of agro-chemical use). The relationships remain unchanged in Ethiopia, Niger, Nigeria, Tanzania, and Uganda.

combined use of herbicide. Irrigation systems help to secure necessary soil moisture for efficient inorganic fertilizer use and improved seed varietal growth (Yilma and Berger 2006). Similarly, Rosegrant et al. (2014) use a crop model, incorporating climate change scenarios, to project massive gains to combining nitrogen at efficient levels with irrigated maize and rice in SSA.

We use two-way tables to explain the incidence of joint input use at both the household and plot level. Table 26 shows how household-level aggregated binary use decisions correlate across input pairs. In general, the levels of correlation are very mixed across countries and inputs. Conditional on using inorganic fertilizer, there is low correlation on use of other inputs in most cases. Moreover, inorganic fertilizer using households are highly likely to also use an organic fertilizer only in Ethiopia and Niger, suggesting that households in most other countries view the two as substitutes instead of complements, underscoring the ongoing challenge of promoting ISFM.

Table 26: Probability that a “paired” input would be used conditional on another input used at the household level

	Conditional on the observed use of these inputs (columns)					
	Organic fertilizer	Inorganic fertilizer	Improved seeds	Agro-chemicals	Irrigation	Own ag equipment
Ethiopia						
Organic fertilizer	-	75	73	68	72	68
Inorganic fertilizer	63	-	86	79	62	62
Improved seeds	24	34	-	33	34	25
Agro-chemicals	31	44	45	-	27	37
Irrigation	9	10	13	8	-	10
Own ag equipment	78	84	86	91	91	-
Malawi						
Organic fertilizer	-	19	-	16	21	25
Inorganic fertilizer	83	-	-	58	69	94
Agro-chemicals	3	2	-	-	4	7
Irrigation	<1	<1	-	<1	-	0
Own ag equipment	1	1	-	2	0	-
Niger						
Organic fertilizer	-	73	64	61	58	59
Inorganic fertilizer	22	-	27	34	40	18
Improved seeds	3	4	-	6	5	3
Agro-chemicals	9	16	19	-	17	8
Irrigation	7	17	12	15	-	7
Own ag equipment	84	84	78	80	77	-
Nigeria						
Organic fertilizer	-	3	-	4	9	7
Inorganic fertilizer	29	-	-	60	67	53
Agro-chemicals	30	48	-	-	64	51
Irrigation	9	7	-	8	-	6
Own ag equipment	17	12	-	14	14	-
Tanzania						
Organic fertilizer	-	35	-	44	37	44
Inorganic fertilizer	30	-	-	52	42	23
Agro-chemicals	27	38	-	-	36	30
Irrigation	7	9	-	10	-	8
Own ag equipment	36	23	-	39	36	-
Uganda						
Organic fertilizer	-	21	-	27	12	17
Inorganic fertilizer	5	-	-	19	7	6
Agro-chemicals	23	63	-	-	9	27
Irrigation	4	8	-	3	-	3
Own ag equipment	19	26	-	35	11	-

Note: This table should be read: “conditional on one of the inputs in a column being used, x% of households also use an input in the row.” All percentages are based on a binary input use decision and do not consider application rates or any other continuous measure. Arbitrarily chosen categories to help with overview: **low correlation** ≤ 25%, **high correlation** ≥ 50%.

Users of improved seed varieties are very likely also to use inorganic fertilizer in Ethiopia but not in Niger. Agro-chemicals and inorganic fertilizers are often used together at the household

level (except in Uganda and Niger), implying a relatively high amount of chemicals used in agriculture in these households. Owning agricultural equipment and having some fields under irrigation also are not consistently highly correlated across countries, and irrigation and machine ownership, separately, are only highly correlated with inorganic fertilizer use in half of the countries. Ethiopia seems to have the highest amount of joint correlation, and Uganda the least. Generally speaking, we find some areas of low correlation between “paired” input use patterns, suggesting that there are still yield gains to be exploited by using inputs together.

Because the hypothesized complementarities among inputs are primarily biophysical, we would expect that households use synergistic inputs together on the same plot, not just on the same farm. Table 27 explores this hypothesis using the same methodology as the household-level statistics found in Table 26. At the plot level, we find far less correlation than at the household level, with only a handful of instances where two inputs are used together in high percentages and with no noticeable patterns across countries. There are a few instances where chemicals – inorganic fertilizers and agro-chemicals like pesticides – are used together, providing further evidence that their use may be higher than expected by policy makers and analysts alike.

Table 27: Probability that a “paired” input would be used conditional on another input used at the plot level in main season

	Conditional on the observed use of these inputs (columns)				
	Organic fertilizer	Inorganic fertilizer	Improved seeds	Agro-chemicals	Irrigation
Ethiopia					
Organic fertilizer	-	15	21	10	30
Inorganic fertilizer	30	-	83	64	23
Improved seeds	10	19	-	11	7
Agro-chemicals	11	37	29	-	8
Irrigation	2	1	1	<1	-
Malawi					
Organic fertilizer	-	15	-	10	4
Inorganic fertilizer	79	-	-	39	37
Agro-chemicals	2	1	-	-	1
Irrigation	<1	<1	-	<1	-
Niger					
Organic fertilizer	-	54	35	47	22
Inorganic fertilizer	18	-	12	25	27
Improved seeds	2	2	-	2	6
Agro-chemicals	9	14	10	-	18
Irrigation	1	3	5	4	-
Nigeria					
Organic fertilizer	-	1	-	2	8
Inorganic fertilizer	13	-	-	51	60
Agro-chemicals	20	56	-	-	71
Irrigation	6	4	-	4	-
Tanzania					
Organic fertilizer	-	14	-	18	23
Inorganic fertilizer	18	-	-	43	41
Agro-chemicals	28	33	-	-	36
Irrigation	4	5	-	6	-
Uganda					
Organic fertilizer	-	27	-	23	13
Inorganic fertilizer	8	-	-	22	4
Agro-chemicals	23	71	-	-	8
Irrigation	4	4	-	3	-

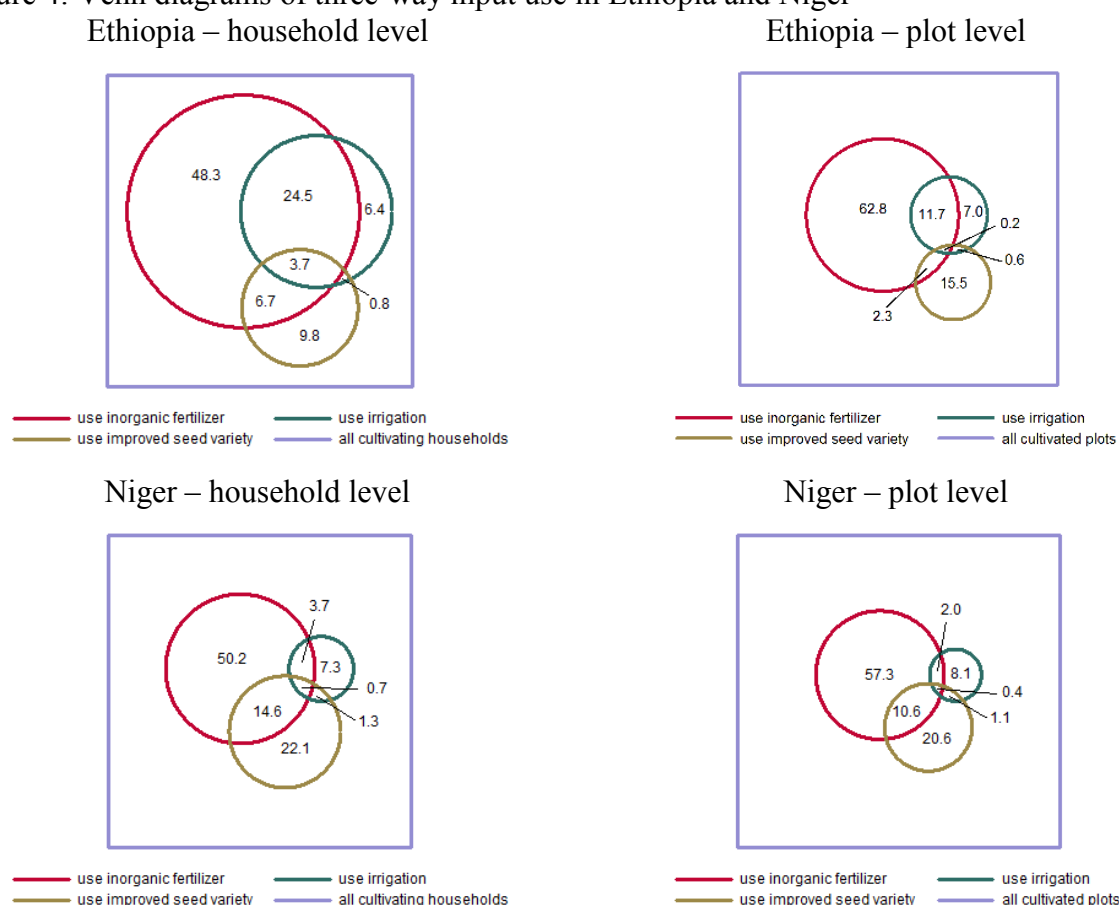
Note: This table should be read: “conditional on one of the inputs in a column being used, x% of plots in the main season also have an input in the row.” All percentages are based on a binary input use decision and do not consider application rates or any other continuous measure. Arbitrarily chosen categories to help with overview: **low correlation** ≤ 25%, **high correlation** ≥ 50%.

Because the “improved seed variety” category lumps all seeds together in Ethiopia and Niger, we separately explored the correlation between improved maize seed usage in Ethiopia and Malawi (maize production is very minor in Niger). We find that, of the plots with improved maize seeds

planted on them, 82 percent of plots in Malawi and 88 in Ethiopia have inorganic fertilizer also applied; those households are truly exploiting the gains from joint use of improved maize seed and inorganic fertilizer. At the same time, only 1 percent of those same plots have agro-chemicals applied in Malawi, 17 percent in Ethiopia. Apart from these instances, farmers do not seem to be combining modern inputs as much as is commonly believed.

We next plot Venn diagrams to explore the three-way intersection of input use for inorganic fertilizer, improved seed varieties, and irrigation at the household and plot level in Ethiopia and Niger, the two countries for which we observe complete data on seed use. These three inputs were chosen because they represent an interesting mix of short and potentially longer term investments and may provide the largest gains when paired.

Figure 4: Venn diagrams of three-way input use in Ethiopia and Niger



Note: These figures were created using the “pvenn” user-written command in Stata. The areas of the circles proportionally represent population size. The percentages in these figures are not weighted and are conditional on using any one of the three included inputs (i.e., exclude the population that does not use any of the three inputs).

In Figure 4, we graphically describe the full set of conditional probabilities over these three inputs. Like we observed in Table 26 and Table 27, the overlapping area, representative of the use of at least two of the three inputs, is relatively small at the household and plot level. When burrowing down to the intersection of all three inputs, less than 4 percent of households use all three inputs in Ethiopia and less than 1 percent use them together in Niger, conditional on using

at least one of the three. In each of the four scenarios, only fertilizer is used in over half of the sample where at least one of the three inputs is used. In Ethiopia, although not generally in Niger, we observe the same disconnect between household and plot level statistics; joint probabilities are always higher at the household level than the plot level. To the extent that yields could be further enhanced by combining more than two improved inputs, like the set of three described in Figure 6, it appears that households have even more to gain from coupling inputs together appropriately.

4.6. *Input use incentives and provisioning*

In this section, we look at characteristics of input provisioning within and across countries using household and community level information on relevant market transactions and stated accessibility. Using comparable variables, these descriptive statistics may help to illuminate differences in the supply systems of inputs which may help to further explain variation in the incidence and rate of input use.

Input/output price ratios

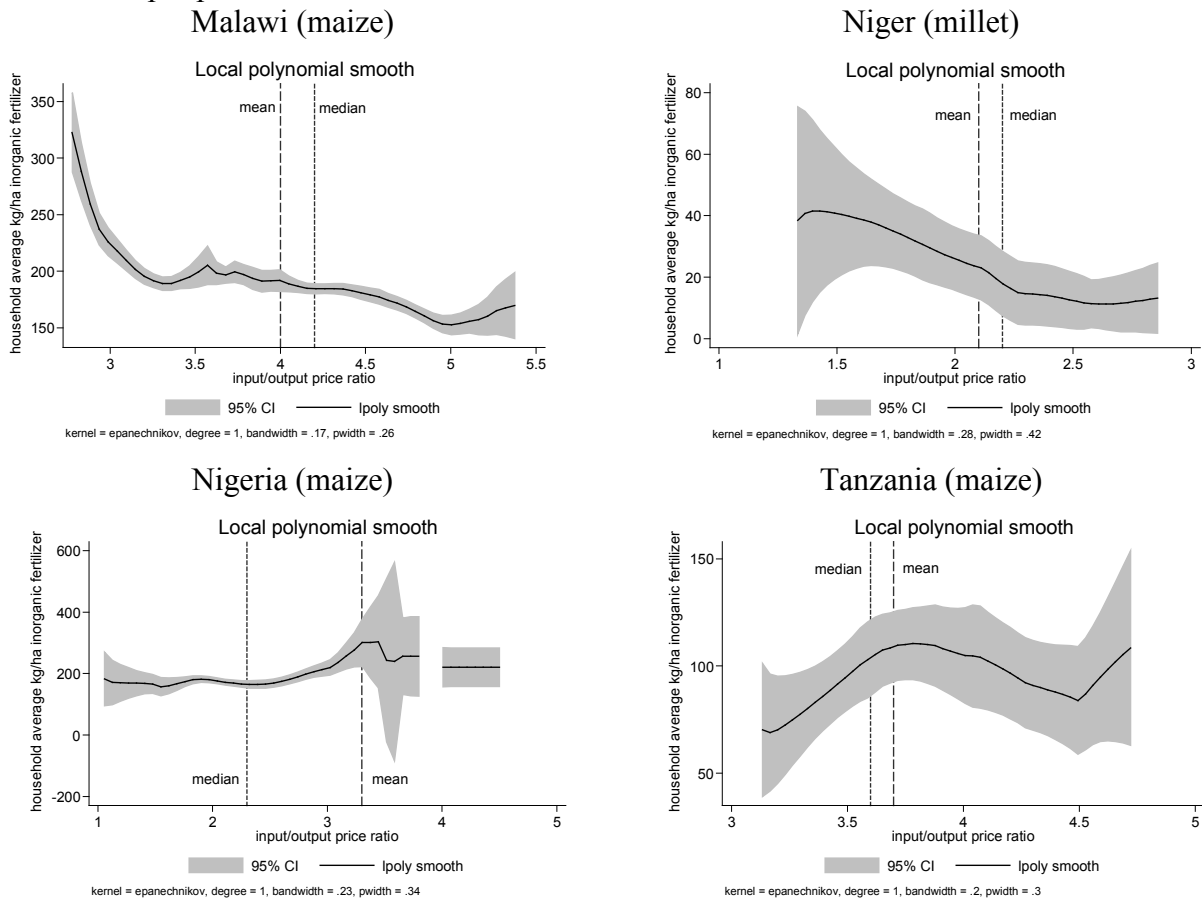
The incentive to use an input is best encapsulated in the ratio of the input to output prices. These values also represent the profit break-even point for application. If the marginal physical product (i.e., crop response rate) is higher than this price ratio, in principle (and ignoring risk aversion, financing costs, travel costs, etc.) it is profitable to use the input, making these variables valuable benchmarks for production analysis. One widespread belief about modern agricultural inputs in the SSA context is that they are too expensive for smallholders to afford on commercial terms, hence the need for government subsidies.

Where available, we create median input and output prices at different levels of geographic aggregation for inorganic fertilizer only. There are insufficient observations of prices for other inputs and heterogeneity among types of agro-chemicals and seed make aggregation unreliable. In the LSMS-ISA data, we generally only observe the prices paid by households that purchased fertilizer, so we may under-estimate price ratios in places where input prices are high and, therefore, households decide not to purchase. Household level prices that were specified in unconventional units for which we did not have conversion factors (e.g., heap, bag, cart) are left out of the median calculations. Fertilizer prices are calculated as total amount for the product (in kilograms), not specific to the amount of nutrients, and thus are not directly applicable to production and profitability analysis at this stage. Fertilizer prices are observed sometimes differently across surveys. In Ethiopia, no unit prices for inputs can be calculated at the household level. In Nigeria, we only use where the household did not purchase fertilizer from the government or a politician so as to not conflate commercial market prices with subsidized prices.

Figure 5 displays the relationship between the input/output price ratios assigned to households and their level of inorganic fertilizer use, for the major crop of each country. Because these price ratios act as one component of the incentive to use fertilizer, we expect a strong negative relationship, where higher price ratios are associated with lower application rates. Indeed, in Malawi and Niger, countries with very dissimilar average fertilizer application rates and a different crop chosen as most important, we observe the expected downward trend. The

relationship is mostly flat in Nigeria and is not monotonic in Tanzania. Because the per kilogram costs of fertilizer and price for which outputs can be sold are not necessarily indicative of the full incentive to use inputs, we expect that some part of these two anomalous relationships is a function of the missing portions of cost (e.g., transport cost) and crop response to fertilizer application. Moreover, the included prices are not household-specific, which are better correlated with household input use rates.

Figure 5: Local linear non-parametric regression of conditional fertilizer use per hectare by fertilizer/output price ratio



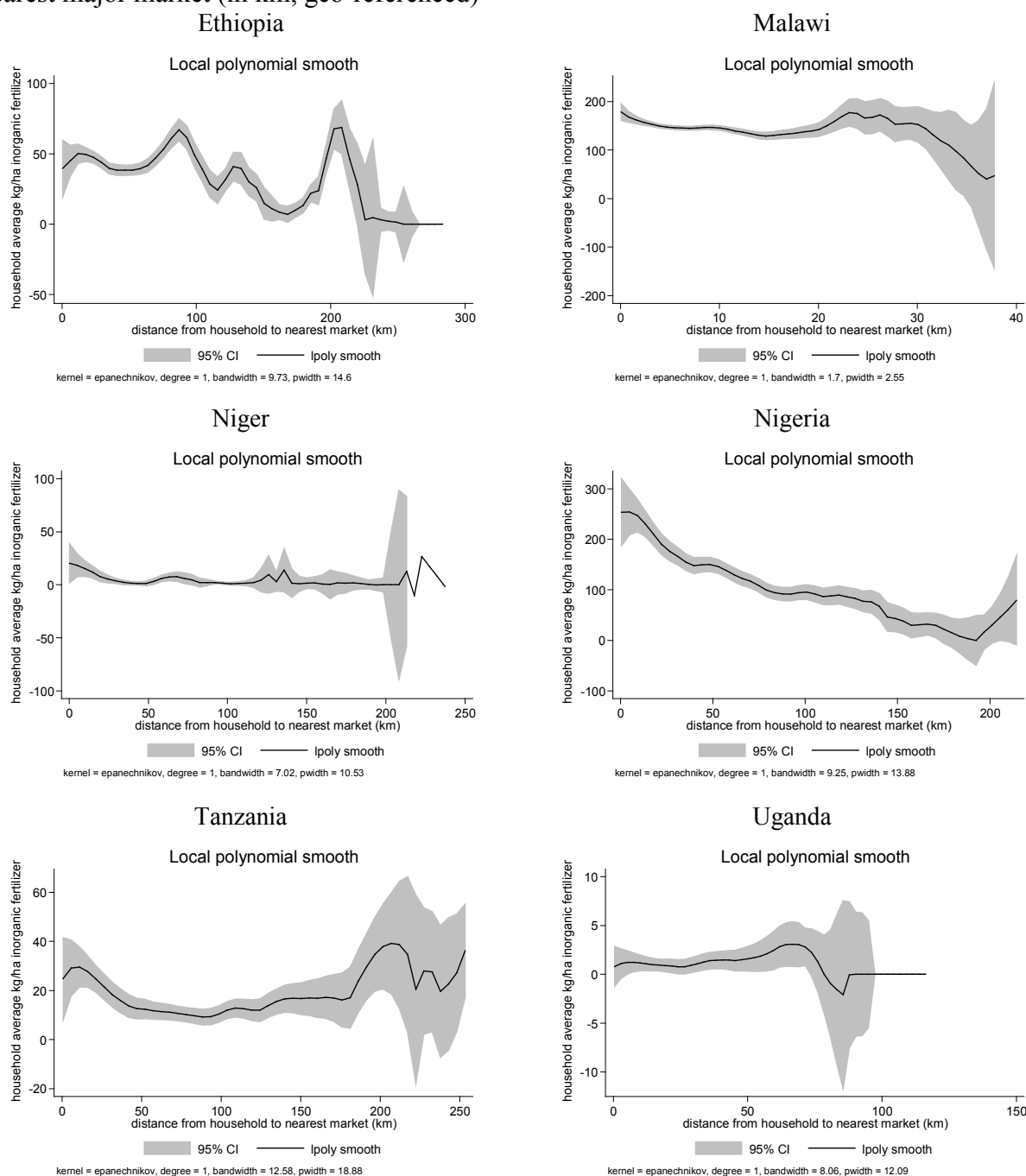
Note: Only households with fertilizer use included, and application rates are total, not nutrient, values. All prices are median prices at levels of geographic aggregation where at least 10 household-level observations exist. In Nigeria, we limit the fertilizer use rates to those below the 90th percentile and price ratios to those below 5 given a lot of noise in the data. Ethiopia is excluded because input prices are only observed in the community survey with mostly missing values. Uganda is excluded due to very little fertilizer use alongside very few observed prices of fertilizer.

Input market accessibility

Not only does the market price of the input matter, but so do the other costs associated with its procurement. Some of the costs can be observed, like transport costs, while others cannot, like the transactions costs associated with finding an input retailer and possibly negotiating prices. While many measures of market accessibility exist (Chamberlin and Jayne 2013), most research focuses on the transport cost and distance when considering input markets specifically. For

example, in Ethiopia, Zerfu and Larson (2010) found that high transport costs, among other factors, were instrumental in suppressing inorganic fertilizer use. Also in Ethiopia, Minten, Koru, and Stifel (2013) study the effects of the “last mile” in input markets access, finding that traveling 10 kilometers to procure inputs doubled the price of the input.

Figure 6: Local linear non-parametric regression of total fertilizer use per hectare by distance to nearest major market (in km, geo-referenced)



Note: In Malawi, the distance is to the nearest ADMARC (government parastatal) market, not market in general. In Uganda, the 2009/10 geovariables are used as a placeholder in the absence of an updated data set. Inorganic fertilizer application rates are unconditional and represent total, not nutrient, values.

Input market accessibility variables are not consistently collected across the LSMS-ISA countries. In some community surveys, like those in Tanzania and Uganda, we observe a community-level distance to the nearest market for seeds and fertilizer. When matching those community-level responses to the household level, the median distance to the nearest fertilizer market in Uganda is about 400 kilometers compared to 4 kilometers in Tanzania.

In addition to household reports of distance, we are also able to use household-level GPS coordinates to map the distance to the nearest major market center. While not necessarily an input market and likely not the closest available source of input purchases, we use this consistently observed variable as an indicator of remoteness and the magnitude of potential transport costs. Figure 6 shows the relationship between inorganic fertilizer application levels and this input market accessibility proxy. Nigeria and Malawi, after a point, may be the only countries with a noticeable negative relationship. The trend is mostly flat in Niger, Tanzania, and Uganda, with a huge amount of fluctuation in Ethiopia. We expect the fact that these relationships are not more pronounced is due, in part, to the fact that input dealers and traders may travel further into rural areas where road networks and incentives allow.

Incidence of credit

Because cash resources may be limited for smallholder farmers and/or cash inflows do not arrive when inputs need to be purchased, access to credit can be an important catalyst to input use and subsequent agricultural productivity gains. For example, Matsumoto and Yamano (2011b) find that having access to fertilizer credit increases teff yields by 37 percent in Ethiopia. Because of poorly developed financial markets and the high risks associated with providing credit to smallholder farmers, credit is widely thought to be used only minimally throughout SSA and, therefore, to act as a major constraint to input use (e.g., Croppenstedt, Demeke, Meschi 2003; Zerfu and Larson 2010).

Table 28: Percent of households receiving credit of different types

	Any type of credit (unspecified use)	Agricultural input purchases		
		Credit for inorganic fertilizer	Credit for improved seed	Credit for agrochemicals
Ethiopia	24.6	-	4.6	-
Malawi	-	0.5	-	<0.1
Niger	-	0.9	-	0.3
Nigeria	-	0.9	<0.1	-
Tanzania	-	0	0.6	-
Uganda	-	0.9	-	0.6

Note: See for text for more on how these variables are observed in each questionnaire.

Table 28 summarizes the credit use statistics we observe in the LSMS-ISA data, which should include both formal and informal sources. Credit use is not necessarily the opposite of credit constraints, however, as credit constraints are generally unobservable. In Ethiopia, nearly 25 percent of cultivating households claimed to receive some type of “credit service,” although whether for agriculture or other household purchases we cannot be sure. Apart from this generic question, we observe about 5 percent of households acquiring credit to pay for maize seed in particular, but do not observe similar statistics for other inputs. In Malawi, Niger, and Uganda,

we observe credit usage for inorganic fertilizer and agrochemicals. But for all three countries and both inputs, less than 1 percent of cultivating households claim to have received credit for the purchase of either of these inputs. In Nigeria, since we do not specifically observe improved seed purchases, we lump together all credit obtained for purchasing any seed type. Even then, the percent of farmers using credit to purchase seeds is less than 1 percent, just like inorganic fertilizer. In Tanzania, we also observe seed credit usage and find, again, less than 1 percent participation. Across these six countries, credit usage is incredibly low in all countries except Ethiopia where there exists widespread input credit guarantee schemes operated by cooperatives (Matsumoto and Yamano 2011b).

5. Explaining sources of variation in input use

In this section, we take what was motivated in a large number of descriptive tables a step further by attempting to identify the primary sources of the variation in observed input use. A huge literature exists that tends towards one set of variables as the most important reason for the “adoption” or use of a particular input, be it biophysical, infrastructure, market, socio-economic, or otherwise. Having so many observations across multiple countries with similar variables allows us the unique opportunity to test which of these variables or classes of variables is most strongly associated with variation in input utilization. In order to isolate the contribution of particular types of covariates to input use, we move to multivariate regression analysis. Because our analysis only includes one cross-section of observations in each country, the relationships we uncover are mere correlations and not causal, with a fair amount of unobserved heterogeneity unaccounted for. With this major caveat in mind, we proceed by estimating models at the household and plot level in attempt to understand the drivers of both between and within household-level variation in inorganic fertilizer and agro-chemical use.

5.1. *Between-household variation*

Using standard ordinary least squares (OLS) regression, we estimate separate binary linear probability models for inorganic fertilizer and agro-chemical use at the household level, pooling observations across all six LSMS-ISA countries. We then calculate Shapley values which decompose the explained variance (measured by R^2) of those regressions into contributions over particular groups of regressors (Huettner and Sunder 2012). In other words, we calculate the mean marginal contribution of each variable or group of variables to the overall regression model R^2 .

The variables we include represent biophysical (i.e., rainfall, elevation, soil nutrient availability, greenness index, and agro-ecological zones), socio-demographic (i.e., consumption quintiles, sex of the household head, household size, and household dependency ratio), farming operation (i.e., total hectares under cultivation, number of crops cultivated by household, maize production, cash crop production), market and infrastructure (i.e., distance to nearest market, distance to nearest road, price of fertilizer, price of the main grain) characteristics in addition to country-level dummy variables that identify overarching policy and institutional environment variability that transcends within-country biophysical, socio-demographic, farming, market and infrastructure variation.

Table 29: Decomposition of binary inorganic fertilizer use decision at household level

	Coef.		Std.Err.	P	Std.Coef.	Shapley
+ Annual precipitation (mm)	3.56E-05	***	0.000012	0.003	0.0294	0.99
+ Elevation (m)	0.000346	***	9.62E-06	0	0.4075	7.98
+ Nutrient availability of soil						2.40
Near ocean	0.179553	***	0.040535	0	0.0242	
No or slight constraint	omitted					
Moderate constraint	0.01627	**	0.0065502	0.013	0.0153	
Severe constraint	0.002641		0.0082263	0.748	0.002	
Very severe constraint	0.108112	*	0.0567305	0.057	0.0101	
Mainly non soil	-0.05706		0.0413699	0.168	-0.0074	
Near water	-0.00063		0.0178973	0.972	-0.0002	
+ Maximum greenness (EVI) in growing season	-0.05217		0.0562836	0.354	-0.0098	1.23
+ Agro-ecological zones						11.30
Tropic-warm/arid	-0.03376		0.0211127	0.11	-0.0096	
Tropic-warm/semiarid	omitted					
Tropic-warm/subhumid	-0.01206		0.0091855	0.189	-0.011	
Tropic-warm/humid	-0.07303	***	0.0205177	0	-0.0345	
Tropic-cool/semiarid	-0.16386	***	0.0122852	0	-0.0941	
Tropic-cool/subhumid	-0.13463	***	0.0133302	0	-0.0902	
Tropic-cool/humid	-0.18497	***	0.0199581	0	-0.0813	
Consumption (per AE) quintiles						2.55
1 (lowest)	-0.1129	***	0.0085298	0	-0.0883	
2	-0.07089	***	0.0082992	0	-0.0566	
3	-0.03299	***	0.0081485	0	-0.0267	
4	omitted					
5 (highest)	0.011294		0.0082742	0.172	0.009	
Sex of hh head (1=female)	-0.02466	***	0.0067751	0	-0.02	0.27
Household size	0.012796	***	0.0011004	0	0.0696	0.63
Household dependency ratio	-0.00387		0.0033838	0.253	-0.0065	0.18
Size of hh land under cultivation (ha)	-0.00052		0.0013721	0.704	-0.0025	1.02
Number of crops produced by hh	0.024381	***	0.0017476	0	0.1083	1.49
Cash crop produced by hh (1=yes)	0.043524	***	0.0065025	0	0.0398	2.09
Maize produced by hh (1=yes)	-0.10684	***	0.0079161	0	-0.0976	11.85
+ Distance to nearest market (km)	-0.00044	***	0.0000889	0	-0.0395	8.23
+ Distance to nearest major road (km)	-0.00048	**	0.0001854	0.01	-0.0154	1.06
Fertilizer price per kg (in USD)	0.000092		0.0003704	0.804	0.0026	0.45
Main grain price per kg (in USD)	0.50949	***	0.0736567	0	0.0674	0.89
Country						45.40
Ethiopia	-0.63434	***	0.0214342	0	-0.4208	
Malawi	omitted					
Niger	-0.4187	***	0.023601	0	-0.2496	
Nigeria	-0.18821	***	0.01401	0	-0.1258	
Tanzania	-0.53311	***	0.0122275	0	-0.3253	
Uganda	-0.78723	***	0.017311	0	-0.4509	

Notes: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. $n = 22,214$ households; overall $R^2 = 0.393$. Variables are grouped by categories described in text. Variables with a plus sign (+) are merged from a number of geo-referenced data sets publicly available on the LSMS-ISA website. Certain geo-referenced and aggregate variables are not currently available for Uganda 2010/11, so the same values for the 2009/10 round are used in their place. The main grain price is maize in all countries except Niger where the price of millet is used in its place. Household level weights are not used (meaning households from Malawi are over-weighted in these results). This table was created using the “rego” user-written command in Stata. See text for more details on the decomposition methodology and interpretation.

Table 30: Decomposition of binary agro-chemical use decision at household level

	Coef.		Std.Err.	P	Std.Coef.	Shapley
+ Annual precipitation (mm)	-0.00012	***	9.11E-06	0	-0.1572	2.38
+ Elevation (m)	1.64E-05	**	7.24E-06	0.024	0.0295	0.49
+ Nutrient availability of soil						4.88
Near ocean	-0.01571		0.0307009	0.609	-0.0032	
No or slight constraint	omitted					
Moderate constraint	-0.06329	***	0.0049554	0	-0.0908	
Severe constraint	-0.07707	***	0.0062243	0	-0.0883	
Very severe constraint	0.045592		0.0429411	0.288	0.0065	
Mainly non soil	-0.0568	*	0.031283	0.069	-0.0112	
Near water	-0.00149		0.0135571	0.912	-0.0007	
+ Maximum greenness (EVI) in growing season	0.553272	***	0.0420741	0	0.159	3.34
+ Agro-ecological zones						4.09
Tropic-warm/arid	0.032482	**	0.0159871	0.042	0.0141	
Tropic-warm/semiarid	omitted					
Tropic-warm/subhumid	-0.02379	***	0.0069571	0.001	-0.033	
Tropic-warm/humid	0.074277	***	0.0155417	0	0.0536	
Tropic-cool/semiarid	-0.05354	***	0.0093045	0	-0.0469	
Tropic-cool/subhumid	0.022071	**	0.0100845	0.029	0.0226	
Tropic-cool/humid	0.059155	***	0.0151118	0	0.0397	
Consumption (per AE) quintiles						2.20
1 (lowest)	-0.04939	***	0.0064587	0	-0.0589	
2	-0.02645	***	0.006285	0	-0.0322	
3	-0.01194	*	0.0061716	0.053	-0.0147	
4	omitted					
5 (highest)	0.023312	***	0.0062668	0	0.0283	
Sex of hh head (1=female)	-0.02292	***	0.0051321	0	-0.0284	1.73
Household size	0.006549	***	0.0008332	0	0.0543	3.11
Household dependency ratio	0.001824		0.0025628	0.477	0.0047	0.05
Size of hh land under cultivation (ha)	0.007742	***	0.0010393	0	0.0568	1.32
Number of crops produced by hh	0.025103	***	0.0013232	0	0.17	17.07
Cash crop produced by hh (1=yes)	-0.02152	***	0.0049183	0	-0.03	0.52
Maize produced by hh (1=yes)	-0.0258	***	0.0059845	0	-0.0359	0.98
+ Distance to nearest market (km)	-9.2E-05		0.0000673	0.173	-0.0124	6.10
+ Distance to nearest major road (km)	0.000352	**	0.0001405	0.012	0.0173	0.73
Main grain price per kg (in USD)	0.561882	***	0.0557924	0	0.1135	8.10
Country						42.91
Ethiopia	0.087462	***	0.0116976	0	0.0885	
Malawi	omitted					
Niger	-0.01037		1.78E-02	0.561	-0.0094	
Nigeria	0.327894	***	0.0106117	0	0.3343	
Tanzania	0.083967	***	0.0092623	0	0.0782	
Uganda	0.018		0.0131118	0.17	0.0157	

Notes: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. $n = 22,214$ households; overall $R^2 = 0.189$. Variables are grouped by categories described in text. Variables with a plus sign (+) are merged from a number of geo-referenced data sets publicly available on the LSMS-ISA website. Certain geo-referenced and aggregate variables are not currently available for Uganda 2010/11, so the same values for the 2009/10 round are used in their place. The main grain price is maize in all countries except Niger where the price of millet is used in its place. Agrochemical prices per kg are not observed in most countries, so we are unable to include a price variable here. Household level weights are not used (meaning households from Malawi are over-weighted in these results). This table was created using the “rego” user-written command in Stata. See text for more details on the decomposition methodology and interpretation.

Our regression estimates and estimated Shapley values for the binary inorganic fertilizer use decision can be found in Table 29. Quite surprisingly, the overwhelming amount of variation, indeed nearly half (45 percent), is accounted for by the country dummy variables. Even controlling for a wide range of important observable household-level variables, some combination of other policy, institutional, or macroeconomic variables explain most of the micro-scale variation in inorganic fertilizer use in this unprecedentedly large sample. Since our dependent variable is the binary input use decision, differences in survey design, which may lead to differences in measurement of continuous input volumes, cannot plausibly account for the importance of the country-level variables. This is an important finding, as clearly the policy and operating environments facilitated by governments matter.

Biophysical variables account for 24 percent of the explained variation in fertilizer use, followed by farm operation characteristics accounting for 16 percent, market and accessibility variables accounting for nearly 10 percent, and socio-economic variables less than 4 percent. The fact that geography and biophysical characteristics (accounting for a combined 70 percent of variation) matter so much to the fertilizer use decisions mirrors, to a large extent, findings by McCord and Sachs (2013) on the importance of the same factors in explaining variations in macroeconomic development conditions across countries. Together, these findings suggest the need to for broad-based policy reform at the country level, which are likely to have tangible impacts on spurring input use and staple grain productivity (e.g., Sheahan, Ariga, Jayne 2013).

When running this analysis with the same variables (apart from the fertilizer price) for agro-chemical use instead (Table 30), the same qualitative patterns emerge. Country-level variables account for 43 percent of the variation, farm operation variables account for 20 percent, biophysical variables account for 15 percent, market and accessibility variables account for 15 percent, and socio-economic variables account for 7 percent. Holding constant other factors, both cash crops and maize production are negative and statistically significantly related to agro-chemical use, while the number of crops cultivated is positively associated with input use and accounts for 17 percent of the variation alone, suggesting that diversified producers may be more likely to use agro-chemicals across these six countries.

5.2. *Within-household variation*

The richness of the LSMS-ISA data allows us to further explore the within-household variation, namely households' choice to apply inorganic fertilizer to one plot over another after controlling for characteristics of the household. To accomplish this, we first estimate a binary linear probability model at the plot level using household level fixed effects. Then, we “de-mean” the plot level values using household level averages to decompose the R^2 using the same technique just described.²¹ Because we explore within-household variation, it is important to note that these results apply only to the vast majority of households that cultivate more than one plot in the main season.

²¹ For categorical variables, like plot type and soil quality, we “de-mean” by treating the categories as continuous variables for the R^2 decomposition exercise. As such, the coefficient estimates on these resulting values have no economic meaning but the Shapley value provides an indication on the overall contribution of this category of variables to the fit of the model.

Table 31 shows the regression and R^2 decomposition results using the set of plot-level variables consistently observed across all six countries. Perhaps not surprisingly, most of the variation comes from what is grown on the plot—maize alone, maize interspersed with any other crop, another type of plot all together, and/or a cash crop included on the plot—which matches well with findings in Tables 19, 20, and 21. Indeed, plots that are mainly maize continue to emerge as those more likely to receive inorganic fertilizer applications. This appears to be in contrast with the household level results presented in Table 30 where households that cultivate maize anywhere on the farm are less likely to use inorganic fertilizer. That relationship, however, likely picks up on livelihood strategies in general, given that well over 70 percent of our (unweighted) full sample cultivates at least some maize. Results are largely the same when (i) dropping Niger from the sample given very low incidence of maize plots and (ii) dropping Uganda from the sample and adding the distance from the plot to the household (a variable not observed in Uganda). Otherwise, plot size relative to other plots cultivated by the household has a positive and statistically significant relationship explaining almost 10 percent of R^2 . This result does not necessarily run contrary to that described in Figure 2 which explores application rates rather than the propensity to apply any fertilizer.

Table 31: Decomposition of binary inorganic fertilizer use decision at plot level, part one

	Fixed effects model				Household “demeaned” model				
	Coef.	Std. Err.	P	Sig.	Coef.	Std. Err.	P	Sig.	Shapley
Sex of plot manager (1=female)	-0.0248184	0.013225	0.061	*	-0.0292	0.010567	0.006	***	0.38
Size of plot (hectares)	0.0478397	0.003172	0	***	0.048181	0.00249	0	***	9.73
Irrigated (1=yes)	-0.0153352	0.014509	0.291		-0.01022	0.011578	0.378		0.07
Cash crop grown on plot (1=yes)	-0.0763105	0.005549	0	***	-0.10189	0.004346	0	***	22.54
Plot owned by hh (1=yes)	-0.0541668	0.007275	0	***	-0.04467	0.005704	0	***	1.21
Number of crops on plot	0.0134958	0.002822	0	***	0.000118	0.002204	0.957		1.44
Type of plot					0.132505	0.002737	0	***	64.63
Non-maize plot	omitted								
Pure stand maize plot	0.2343585	0.005694	0	***					
Intercropped maize plot	0.1898541	0.007696	0	***					

Notes: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. $n = 57,665$ plots across 21,258 households in all six LSMS-ISA countries. Overall R^2 for the fixed effects model = 0.085. Overall R^2 for the demeaned model = 0.072. Average number of plots per household is 2.7. Plot level weights are not used. This table is created using the “rego” user-written command in Stata. Household level weights are not used (meaning households from Malawi are over-weighted in these results). See text for more details on the decomposition methodology and interpretation.

We estimate one final regression model with the subset of three countries where household-reported characteristics of the plot—namely soil qualities, the incidence of erosion, and slope—are observed (Malawi, Tanzania, and Uganda). Results in Table 32 show that while household-reported soil quality is a statistically significant predictor of the binary inorganic fertilizer use decision, it explains less than one percent of R^2 , with the plot type and cash crop variables remaining most important. The erosion status and slope of the plot are not important predictors of within-household fertilizer allocation decisions. These findings substantiate our original claims taken from evidence in Table 22 and Table 23 that understanding of the soil conditions necessary for efficient fertilizer response may be lacking, implying the need for improved extension programs around soil fertility.

Table 32: Decomposition of binary inorganic fertilizer use decision at plot level, part two

	Fixed effects model				Household “demeaned” model				
	Coef.	Std. Err.	P	Sig.	Coef.	Std. Err.	P	Sig.	Shapley
Sex of plot manager (1=female)	-0.0627898	0.023196	0.007	***	-0.08155	0.016154	0	***	0.51
Size of plot (hectares)	0.0367664	0.004143	0	***	0.040718	0.002883	0	***	4.86
Irrigated (1=yes)	0.2523292	0.046333	0	***	0.244164	0.032542	0	***	0.72
Cash crop grown on plot (1=yes)	-0.0040303	0.008979	0.654		-0.0978	0.00584	0	***	19.97
Plot owned by hh (1=yes)	0.0128825	0.01236	0.297		0.03394	0.008619	0	***	0.37
Number of crops on plot	0.0222392	0.004572	0	***	-0.00483	0.003134	0.123		3.1
Type of plot					0.192109	0.003733	0	***	69.67
Non-maize plot	omitted								
Pure stand maize plot	0.3868727	0.008902	0	***					
Intercropped maize plot	0.2905062	0.011408	0	***					
HH-reported soil quality					0.027676	0.006066	0	***	0.51
Good	omitted								
Fair	0.0273239	0.011684	0.019	**					
Poor	0.0345945	0.019959	0.083	*					
HH-reported erosion on plot (1=yes)	-0.0011885	0.012425	0.924		0.006294	0.008683	0.469		0.18
HH-reported slope of plot					0.001605	0.006332	0.8		0.11
Flat/valley	omitted								
Slight slope	0.0156812	0.011015	0.155						
Steep slope/hilly	-0.020706	0.022819	0.364						

Notes: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. $n = 26,440$ plots across 14,102 households in only Uganda, Malawi, and Tanzania. Overall R^2 for the fixed effects model = 0.214. Overall R^2 for the demeaned model = 0.164. Average number of plots per household is 1.9. Plot level weights are not used. This table is created using the “rego” user-written command in Stata. Household level weights are not used (meaning households from Malawi are over-weighted in these results). See text for more details on the decomposition methodology and interpretation.

6. Main findings and conclusions

While not designed as agronomic surveys, the newly collected and nationally-representative LSMS-ISA data sets in six major Sub-Saharan African countries allow us the unprecedented and hugely valuable opportunity to update understandings of the modern agricultural input landscape in the region, particularly following decades of structural change, external shocks, and a range of policy environments that may have influenced input adoption patterns in the 21st century. Overall, we find that input use across SSA is far more complex than stylized prior prevailing beliefs and often-quoted macro-scale statistics might suggest. Using mostly comparable covariates across the represented countries, we uncover a rich story of agricultural input use in African agriculture. Given the large volume of information presented in this paper, we summarize key descriptive results in ten important and/or surprising findings that may help to guide policy choices, serve as an empirical check on conventional wisdom about modern input use in SSA, and motivate a new wave of research to further our understanding.

1. Modern input use may be relatively low in aggregate, but is not uniformly low across these six countries, especially for inorganic fertilizer and agro-chemicals.

Many SSA smallholders still use rudimentary technologies on the farm and eschew the use of modern inputs. Nevertheless, modern agricultural input use has picked up to a significant level in some regions within some countries, especially in the case of inorganic fertilizer and agro-chemical use. In 3 of 6 countries with large-scale, nationally representative household farm input use data, average inorganic fertilizer use rates are well above the widely quoted 13 kg/ha statistic, with a simple cross-country average nutrient application rate of 26 kg/ha (equivalent to 57 kg/ha total fertilizer). Over three-quarters of all cultivating households in Malawi, half in

Ethiopia, and around 40 percent in Nigeria use inorganic fertilizer, which may be more widespread than common assumptions about smallholder agriculture posit.

Significant proportions of farmers use agro-chemicals too, with over 30 percent of households in Ethiopia and Nigeria using some on their plots. Other studies using the same data find high rates of chemical use in storage of harvested farm output in the set of eastern and southern African LSMS-ISA countries (Kaminski and Christiaensen 2014), suggesting that the statistics we report represent lower bounds on total chemical use by farmers across agricultural operations. Because the use of pesticides, herbicides, and fungicides is perhaps more widespread than is widely recognized and because chemicals banned in other countries due to their toxicity are being used in SSA (Williamson et al. 2008), this descriptive finding in particular seems to invite further research to explore the prospective environmental and human health effects, as well as the productivity benefits, of non-trivial agro-chemicals use in African agriculture.

2. The incidence of irrigation and mechanization remains quite small.

While agro-chemical and inorganic fertilizer use appear greater, in some cases, than has been widely acknowledged to date, the prevalence of irrigation and tractor use is negligible, just as the conventional wisdom and macro-level statistics suggest. AQUASTAT/FAO and World Bank estimates report that less than 1 percent of land under cultivation in these countries is irrigated. The household level data we analyze suggest that 1-3 percent of land cultivated by smallholders is under irrigation, and that no more than 10 percent of households have any form of water control on agricultural plots. Of course, because the LSMS-ISA household data do not include large scale commercial farms run as firms rather than as households, these figures are likely somewhat downwardly biased as estimates of overall agricultural production in these countries. But given the modest extent of corporate farming in SSA, the core narrative of minimal levels of irrigation holds up in the most recent data. Tractor ownership is similarly miniscule, as also expressed by FAOSTAT, although actual utilization of tractors and oxen in the countries for which we observe this information (Ethiopia, Niger, Nigeria) is not as insignificant as simple ownership statistics suggest, implying that community level rental or sharing schemes help to facilitate mechanization.

3. Considerable variation exists within countries in the prevalence of input use and of input use intensity conditional on input use.

Within-country input use patterns vary strikingly, a fact necessarily masked by macro-level statistics of the sort that commonly inform discussions of African agriculture. The LSMS-ISA survey data allow us to disaggregate input use patterns to reveal a great deal of heterogeneity across sub-national regions, agro-ecological zones, and underlying soil types, as well as according to the characteristics of individual households and plots. For example, input use rates vary dramatically within large nations like Ethiopia and Nigeria where, in some regions, less than 10 percent of farmers use inorganic or organic fertilizers while well in excess of 70 percent do so elsewhere in the same country. It remains to be established whether such variation corresponds with differences in the profitability of input use. Analysis of the marginal costs and benefits of using modern inputs – infeasible in the descriptive, cross-sectional work undertaken here – would help determine whether this variation corresponds with efficient allocation of

inputs according to variation in prices and productivity impacts or if various constraints better explain the considerable heterogeneity we observe among and within regions intra-nationally.

4. *There is surprisingly low correlation between the use of commonly “paired” modern inputs at the household- and, especially, at plot-level.*

Since many of the modern inputs we study have positive interaction effects agronomically, are sold together at input retail shops, and/or are provided in bundles through government subsidy programs, one might reasonably expect farmers to use modern inputs together in packages. The LSMS-ISA data allow us, for the first time, to uncover to what extent a large sample of farmers exploits known complementarities. In general, we find that even when households pair modern agricultural inputs together on farm, at the plot level, there is very little correlation in modern inputs use. For example, only 4 percent of Ethiopian agricultural households use inorganic fertilizer use, improved seed, and irrigation on-farm, and far less than 1 percent use all three on the same plot. Because biophysical complementarities only arise when inputs designed to be used together are combined on the same plot, this implies that households are spreading inputs across plots rather than concentrating them on single plots. This behavior has gone largely unstudied to date and raises important questions about prospective untapped productivity gains from coordinated modern inputs use. This finding has implications for extension programs and policies aimed at promoting efficient input use.

5. *Maize-dominated plots exhibit higher rates of input use intensity, even relative to plots planted with cash crops.*

In general, modern input use rates are higher on plots where maize is the dominant crop than on plots dedicated primarily to other species. Moreover, plots that include a major cash crop – less than one quarter of the total observed – are generally no more likely to receive modern agricultural inputs of any sort. In particular, average fertilizer application rates are higher on plots where maize is grown than on ones where it is not, and the presence of maize accounts for nearly two-thirds of the explained intra-farm variation among plots in fertilizer application rates. And 25-40 percent of maize cultivating households purchased new maize seed in the last main agricultural season. In the few places where we observe full improved seed variety statistics, nearly one-quarter of maize cultivating households in Ethiopia and over half in Malawi used an improved variety in the main growing season. These findings suggest more widespread participation of African agricultural households in modern input distribution systems than has been widely recognized. The weight of the evidence suggests that maize may be “on the move” in Africa.

6. *There exists a consistent inverse relationship between farm or plot size and input use intensity.*

A longstanding agricultural development literature on the inverse relationship between farm size and crop yields suggests that input use falls off with farm size. We corroborate that latter pattern and find that it is robust even to controlling for farm-level effects and for possible self-reporting bias that can be corrected using GPS measurement of plots. Indeed, the inverse relationship is, perhaps surprisingly, stronger at the plot level than at household level in virtually all cases. The

powerful implication is that inter-household variation in the shadow price of inputs and outputs based on endowments, distance to market, etc. cannot explain the relationship, as much of the existing literature implies when suggesting that both equity and efficiency goals might be advanced by progressive land transfer programs that would redistribute land from larger land owners to those with smaller holdings. Consistent with the findings of Barrett, Bellemare, and Hou (2010), the striking within-household inverse relationship raises novel puzzles about farmers' behaviors that have yet to draw much research attention.

7. *Farmers do not significantly vary input application rates according to perceived soil quality.*

Yields and crop response to input use depend on the soil organic matter or soil carbon status of the plot. We might therefore expect that farmers would allocate inputs according to their beliefs about plot and soil quality. Instead, using simple descriptive statistics and not controlling for other factors, we find that input use is virtually the same across plots characterized by households in Uganda, Malawi, and Tanzania as “good,” “average,” and “poor” and based on the self-reported erosion status of plots. Regression analysis of within-farm variation on more than 26,000 plots on 14,000 farms holding constant observable and unobservable farm-level factors reveals that plots deemed “average” or “poor” in quality are statistically significantly more likely to receive inorganic fertilizer applications than are plots categorized as “good”, however these variables explain only a tiny amount of within-household fertilizer allocation decisions and this relationship does not hold over self-reported erosion status. If “poor” and eroded plots, in particular, have suffered serious nutrient mining and to the extent that plot quality matters, then this surprising finding may signal a knowledge gap among farmers and raises important questions about the accuracy and drivers of farmer perceptions of soil quality. This may signal a need for renewed efforts at extension programming around soil fertility and, possibly, the need to invest in simple soil quality tests.

8. *Few households use credit to purchase modern inputs.*

In all LSMS-ISA countries except Ethiopia, less than 1 percent of cultivating households used credit—either formal or informal—to purchase improved seed varieties, inorganic fertilizer, or agro-chemicals, signaling a dramatic breakdown in financial services that could help households invest in modern inputs. The cross-country, nationally representative data reinforce widespread perceptions of the weakness of agricultural input credit markets in the region. Much scope remains for deepening rural financial markets, despite recent advances in money transfer systems based on mobile phone platforms, the proliferation of microfinance institutions, etc.

9. *Gender differences in input use exist at the farm and plot level.*

Male headed households statistically significantly apply, use, and own more modern agricultural inputs than do female headed ones, consistent with the conventional wisdom. Similarly, plots owned or managed by women, who control less than a quarter of all cultivated plots, are less likely to receive modern agricultural inputs and receive lesser amounts when applied. Gender differences in modern agricultural input use, both among and within households, merit more attention as they may lead to needless productivity losses and food insecurity.

10. Although biophysical, demographic, and socioeconomic variables matter, national-level factors explain nearly half of the farm-level variation in inorganic fertilizer and agro-chemical use, underscoring the critical importance of the policy and institutional environment for ushering in a Green Revolution in Africa.

Most of the variation in binary patterns of inorganic fertilizer and agro-chemical use among over 22,000 LSMS-ISA households from six countries comes from the *country* level even after controlling for a range of important household-level and agro-ecological variables. This is an especially striking finding that signals the importance of the policy and market environment beyond those variables we observe and for which we can control statistically. Household socioeconomic status actually explains little of the observed inter-household variation in modern input use rates, far less than national-scale, biophysical, and market-related variables. Policy tools matter to increasing the use of modern inputs in SSA, underscoring the importance of processes such as the Comprehensive Africa Agriculture Development Programme initiated by the New Partnership for Africa's Development (<http://www.nepad-caadp.net/>).

References

- Abate, T., van Huis, A., & Ampofo, J. K. (2000). Pest management strategies in traditional agriculture: an African perspective. *Annual Review of Entomology*, 45, 631–659.
- Abdoulaye, I. D., & Sanders, J. H. (2013). “A Matching Approach to Analyze the Impact of New Agricultural Technologies: Productivity and Technical Efficiency in Niger.” Selected paper prepared for presentation at the Agricultural and Applied Economics Associations 2013 AAEA & CAES Joint Annual Meeting, Washington, DC, August 4-6, 2013.
- Abdoulaye, T., & Sanders, J. H. (2005). Stages and determinants of fertilizer use in semiarid African agriculture: the Niger experience. *Agricultural Economics*, 32, 167–179.
- Akramov, K. T. (2009). “Decentralization, Agricultural Services and Determinants of Input Use in Nigeria.” IFPRI discussion paper 00941. Washington, DC: International Food Policy Research Institute.
- Alem, Y., & Broussard, N. H. (2013). “Do Safety Nets Promote Technology Adoption? Panel data evidence from rural Ethiopia.” Working Papers in Economics No. 556. Goteborg, Sweden: University of Gothenburg, Department of Economics.
- Alemu, D., Mwangi, W., Nigussie, M., & Spielman, D. J. (2008). The maize seed system in Ethiopia: challenges and opportunities in drought prone areas. *African Journal of Agricultural Research*, 3(4), 305–314.
- Alene, A. D., & Hassan, R. M. (2006). The Efficiency of Traditional and Hybrid Maize Production in Eastern Ethiopia: An Extended Efficiency Decomposition Approach. *Journal of African Economies*, 15(1), 91–116.
- Alene, A., Yigezu, Y., Ndjeunga, J., Labarta, R., Andrade, R., Diagne, A., et al. (2011). Measuring the effectiveness of agricultural R&D in sub-Saharan Africa from the perspectives of varietal output and adoption. Prepared for the ASTI-IFPRI/FARA Conference, Accra, Ghana. International Food Policy Research Institute.
- Andersson Djurfeldt, A., Djurfeldt, G., & Bergman Lodin, J. (2013). Geography of Gender Gaps: Regional Patterns of Income and Farm–Nonfarm Interaction Among Male- and Female-Headed Households in Eight African Countries. *World Development*, 48, 32–47.
- Antle, J. M., & Pingali, P. L. (1994). Pesticides, Productivity, and Farmer Health: A Philippine Case Study. *American Journal of Agricultural Economics*, 76, 418–430.
- Asfaw, S., Shiferaw, B., Simtowe, F., & Haile, M. G. (2011). Agricultural technology adoption, seed access constraints and commercialization in Ethiopia. *Journal of Development and Agricultural Economics*, 3(9), 436–447.

- Ashburner, J., & Kienzle, J. (2011). "Investment in agricultural mechanization in Africa: Conclusions and recommendations of a Round Table Meeting of Experts." Rome, Italy: Food and Agriculture Organization of the United Nations.
- Aune, J. B., Bussa, M. T., Asfaw, F. G., & Ayele, A. A. (2001). The ox ploughing system in Ethiopia: can it be sustained? *Outlook on Agriculture*, 30(4), 275–280.
- Banjo, A. D., Aina, S. A., & Rije, O. I. (2010). Farmers' Knowledge and Perception Towards Herbicides and Pesticides Usage in Fadama Area of Okun-Owa, Ogun State of Nigeria. *African Journal of Basic and Applied Sciences*, 2(5-6), 188–194.
- Barrett, C.B., Bellemare, M.F. & Hou, J.Y. (2010). Reconsidering Conventional Explanations of the Inverse Productivity-Size Relationship. *World Development*, 38(1), 88-97.
- Bayite-Kasule, S. (2009). "Inorganic fertilizer in Uganda—Knowledge gaps, profitability, subsidy, and implications of a national policy." Uganda Strategy Support Program Brief No. 8. Washington, DC: International Food Policy Research Institute.
- Bellemare, M. F. (2013). The Productivity Impacts of Formal and Informal Land Rights: Evidence from Madagascar. *Land Economics*, 89(2), 272–290.
- Benson, T., Kirama, S. L., & Selejio, O. (2012). "The Supply of Inorganic Fertilizers to Smallholder Farmers in Tanzania: Evidence for Fertilizer Policy Development." IFPRI Discussion Paper 01230. Washington, DC: International Food Policy Research Institute.
- Benson, T., Lubega, P., Bayite-Kasule, S., Mogues, T., & Nyachwo, J. (2012). "The Supply of Inorganic Fertilizers to Smallholder Farmers in Uganda: Evidence for Fertilizer Policy Development." IFPRI Discussion Paper 01228. Washington, DC: International Food Policy Research Institute.
- Berazneva, J., Lee, D., Place, F. (2014). "Allocation and value of non-marketable crop residues in smallholder agriculture: the case of maize residues in western Kenya." Cornell working paper.
- Binswanger-Mkhize, H.P. & Savastano, S. (in review). "Agricultural Intensification: The Status in six African Countries." Mimeographed.
- Biswas, A. K. (1986). Irrigation in Africa. *Land Use Policy*, 3(4), 269–285.
- Burney, J. a., & Naylor, R. L. (2012). Smallholder Irrigation as a Poverty Alleviation Tool in Sub-Saharan Africa. *World Development*, 40(1), 110–123.
- Carletto, C., Savastano, S., & Zezza, A. (2013). Fact or artifact: The impact of measurement errors on the farm size–productivity relationship. *Journal of Development Economics*, 103, 254–261.

- Carter, M. R. (1984). Identification of the inverse relationship between farm size and productivity: An empirical analysis of peasant agricultural production. *Oxford Economic Papers*, 36, 131–145.
- Chamberlin, J., & Jayne, T. S. (2013). Unpacking the Meaning of “Market Access: Evidence from Rural Kenya.” *World Development*, 41: 245–264.
- Chidanti-Malunga, J. (2009). “Wetland farming and small-scale informal irrigation in Malawi: the case of Shire Valley.” PhD thesis. Cranfield University, School of Applied Sciences.
- Chirwa, E. W. (2005). Adoption of fertiliser and hybrid seeds by smallholder maize farmers in Southern Malawi. *Development Southern Africa*, 22(1), 1–12.
- Christiaensen, L., Kilic, T., & Palacios-Lopez, A. (in review). “Rhetoric and Reality: How Much Do Women in Africa Contribute to Agriculture?” Mimeographed.
- Clarke, L., & Bishop, C. (2002). “Farm Power - Present and Future Availability in Developing Countries.” Presented at the Special Session on Agricultural Engineering and International Development in the Third Millennium. ASAE Annual International Meeting/CIGR World Congress, July 30, 2002, Chicago, IL. USA.
- Croppenstedt, A., Demeke, M., & Meschi, M. M. (2003). Technology Adoption in the Presence of Constraints: the Case of Fertilizer Demand in Ethiopia. *Review of Development Economics*, 7(1), 58–70.
- Dercon, S., & Christiaensen, L. (2011). Consumption risk, technology adoption and poverty traps: Evidence from Ethiopia. *Journal of Development Economics*, 96(2), 159–173.
- Dillon, B. & Barrett, C.B. (in review). “Agricultural Factor Markets in Sub-Saharan Africa: An Updated View with Formal Tests for Market Failure.” Mimeographed.
- Doss, C. R. (2003). “Understanding Farm-level Technology Adoption: Lessons Learned from CIMMYT’s Micro Surveys in Eastern Africa.” CIMMYT Economics Working Paper 03-07. Mexico D.F., Mexico: International Maize and Wheat Improvement Center.
- Ellis, F. (1992). *Agricultural Policies in Developing Countries*. New York: Cambridge University Press.
- Evans, A. E. V, Giordano, M., & Clayton, T. (2012). “Investing in Agricultural Water Management to Benefit Smallholder Farmers in Tanzania.” IWMI Working Paper 146. Colombo, Sri Lanka: International Water Management Institute.
- Evenson, R E, & Gollin, D. (2003). Assessing the impact of the Green Revolution, 1960 to 2000. *Science*, 300, 758–762.

- Evenson, Robert E, Pray, C. E., & Rosegrant, M. W. (1999). "Agricultural Research and Productivity Growth in India." Research Report 109. Washington, DC: International Food Policy Research Institute.
- FAO. (2011). *Women in Agriculture: Closing the gender gap for development*. Rome, Italy.
- Feder, G, & Umali, D. L. (1993). The adoption of agricultural innovations: a review. *Technological Forecasting and Social Change*, 43(3-4), 215–239.
- Feder, Gershon. (1985). The relation between farm size and farm productivity. *Journal of Development Economics*, 18, 297–313.
- Feder, Gershon, Just, R. E., & Zilberman, D. (1985). Adoption of Agricultural Innovations in Developing Countries: A Survey. *Economic Development and Cultural Change*, 33(2), 255–298.
- Fenske, J. (2011). Land tenure and investment incentives: Evidence from West Africa. *Journal of Development Economics*, 95(2), 137–156.
- Fischer, T. R., Byerlee, D., & Edmeades, G. O. (2009). "Can Technology Deliver on the Yield Challenge to 2050?" Chapter 10 in *Looking Ahead in World Food and Agriculture*. pp. 389–462. Rome, Italy: Food and Agriculture Organization of the United Nations.
- Frenken, K. (2005). "Irrigation in Africa in figures: AQUASTAT Survey - 2005." FAO Water Reports 29. Rome, Italy: Food and Agriculture Organization of the United Nations.
- Fuglie, K. O. (2008). Is a slowdown in agricultural productivity growth contributing to the rise in commodity prices? *Agricultural Economics*, 39, 431–441.
- Fuglie, K. O., & Rada, N. E. (2013). "Resources, Policies, and Agricultural Productivity in Sub-Saharan Africa." Economic Research Report Number 145. Washington, DC: Economic Research Service, United States Department of Agriculture.
- Gavian, S., & Fafchamps, M. (1996). Land Tenure and Allocative Efficiency in Niger. *American Journal of Agricultural Economics*, 78(2), 460–471.
- Gianessi, L., & Williams, A. (2011). Overlooking the Obvious: The Opportunity for Herbicides in Africa. *Outlooks on Pest Management*, 22(5), 211–215.
- Grzywacz, D., Stevenson, P. C., Mushobozi, W. L., Belmain, S., & Wilson, K. (2013). The use of indigenous ecological resources for pest control in Africa. *Food Security*, 6, 71–86.
- Henao, J., & Baanante, C. (2006). "Agricultural Production and Soil Nutrient Mining in Africa." Muscle Shoals, Alabama: International Fertilizer Development Center.

- Holden, S., & Lunduka, R. (2012). Do fertilizer subsidies crowd out organic manures? The case of Malawi. *Agricultural Economics*, 43, 303–314.
- Holden, S., & Yohannes, H. (2002). Land Redistribution, Tenure Insecurity, and Intensity of Production: A Study of Farm Households in Southern Ethiopia. *Land Economics*, 78(4), 573–590.
- Hopper, D. (1993). “Indian Agriculture and Fertilizer: An Outsider’s Observations.” Keynote address to the Fertiliser Association of India (FAI) seminar on Emerging Scenarios in Fertilizer and Agriculture: Global Dimensions in New Delhi, India.
- Houndekon, V. a., De Groote, H., & Lomer, C. (2006). Health costs and externalities of pesticide use in the Sahel. *Outlook on Agriculture*, 35(1), 25–31.
- Houssou, N., Diao, X., Cossar, F., Kolavalli, S., Jimah, K., & Aboagye, P. O. (2013). Agricultural mechanization in Ghana: Is specialized agricultural mechanization service provision a viable business model? *American Journal of Agricultural Economics*, 95(5), 1237–1244.
- Huettner, F., & Sunder, M. (2012). Axiomatic arguments for decomposing goodness of fit according to Shapley and Owen values. *Electronic Journal of Statistics*, 6, 1239–1250.
- Jayne, T. S., & Rashid, S. (2013). Input subsidy programs in sub-Saharan Africa: a synthesis of recent evidence. *Agricultural Economics*, 44 (6): 547-562.
- Jerven, M. (2013). *Poor Numbers: How We Are Misled by African Development Statistics and What to Do about It*. Cornell University Press.
- Johnson, M., Hazell, P., & Gulati, A. (2003). The Role of Intermediate Factor Markets in Asia’s Green Revolution: Lessons for Africa? *American Journal of Agricultural Economics*, 85(5), 1211–1216.
- Johnston, B. F., & Mellor, J. W. (1961). The Role of Agriculture in Economic Development. *The American Economic Review*, 51(4), 566–593.
- Kaliba, A. R. M., Verkuijl, H., & Mwangi, W. (2000). Factors Affecting Adoption of Improved Maize Seeds and Use of Inorganic Fertilizer for Maize Production in the Intermediate and Lowland Zones of Tanzania. *Journal of Agricultural and Applied Economics*, 32(1), 35–47.
- Kaminski, J., & Christiaensen, L. (2014). “Post-Harvest Loss in Sub-Saharan Africa: What Do Farmers Say?” World Bank Policy Research Working Paper No. 6831. Washington, DC: World Bank.
- Kassie, M., Jaleta, M., Shiferaw, B., Mmbando, F., & Mekuria, M. (2013). Adoption of interrelated sustainable agricultural practices in smallholder systems: Evidence from rural Tanzania. *Technological Forecasting and Social Change*, 80(3), 525–540.

- Kathage, J., Qaim, M., Kassie, M., & Shiferaw, B. (2012). "Seed market liberalization, hybrid maize adoption, and impacts on smallholder farmers in Tanzania." Global Food Discussion Papers No. 12. Gottingen, Germany: University of Gottingen.
- Kay, M. (2001). "Smallholder irrigation technology: prospects for sub-Saharan Africa." Knowledge Synthesis Report No. 3. Rome, Italy: Food and Agriculture Organization of the United Nations.
- Kuje Yohanna, J., Usman Fulani, A., & Aka'ama, W. (2011). A Survey of Mechanization Problems of the Small Scale (Peasant) Farmers in the Middle Belt of Nigeria. *Journal of Agricultural Science*, 3(2), 262–266.
- Larson, D. F., Otsuka, K., Matsumoto, T., & Kilic, T. (2012). "Should African Rural Development Strategies Depend on Smallholder Farms? An Exploration of the Inverse Productivity Hypothesis." Policy Research Working Paper 6190. Washington, DC: World Bank.
- Liverpool-Tasie, L. S., & Salau, S. (2013). "Spillover Effects of Targeted Subsidies: An Assessment of Fertilizer and Improved Seed Use in Nigeria." IFPRI Discussion Paper 01260. Washington, DC: International Food Policy Research Institute.
- Loiskandl, W., Ruffeis, D., Schönerklee, M., & Spendlingwimmer, R. (2008). "Case study review of investigated irrigation projects in Ethiopia." *Impact of Irrigation on Poverty and Environment in Ethiopia*, 357–369.
- Lunduka, R., Fisher, M., & Snapp, S. (2012). Could farmer interest in a diversity of seed attributes explain adoption plateaus for modern maize varieties in Malawi? *Food Policy*, 37(5), 504–510.
- Makombe, G., Namara, R., Hagos, F., Awulachew, S. B., Ayana, M., & Bossio, D. (2011). "A Comparative Analysis of the Technical Efficiency of Rain-fed and Smallholder Irrigation in Ethiopia." IWMI Working Paper 143. Colombo, Sri Lanka: International Water Management Institute.
- Mangisoni, J. H. (2008). Impact of treadle pump irrigation technology on smallholder poverty and food security in Malawi: a case study of Blantyre and Mchinji districts. *International Journal of Agricultural Sustainability*, 6(4), 248–266.
- Marennya, P., Barrett, C. B., & Gulick, T. (2008). "Farmers' perceptions of soil fertility and fertilizer yield response in Kenya." Working Paper. Ithaca, New York: Cornell University.
- Marennya, P. P., & Barrett, C. B. (2009). State-conditional Fertilizer Yield Response on Western Kenyan Farms. *American Journal of Agricultural Economics*, 91(4), 991–1006.

- Mason, N. M., & Ricker-Gilbert, J. (2013). Disrupting Demand for Commercial Seed: Input Subsidies in Malawi and Zambia. *World Development*, 45, 75–91.
- Matsumoto, T., & Yamano, T. (2011a). “Optimal Fertilizer Use on Maize Production in East Africa.” In Yamano, K. Otsuka, & F. Place (Eds.), *Emerging Development of Agriculture in East Africa: Markets, Soil and Innovations* (pp. 117–132). Dordrecht: Springer Netherlands.
- Matsumoto, T., & Yamano, T. (2011b). “The Impacts of Fertilizer Credit on Crop Production and Income in Ethiopia.” In T. Yamano, K. Otsuka, & F. Place (Eds.), *Emerging Development of Agriculture in East Africa* (pp. 58–72). Dordrecht: Springer Netherlands.
- McCord, G. C., & Sachs, J. D. (2013). “Development, Structure, and Transformation: Some Evidence on Comparative Economic Growth.” NBER Working Paper Series No. 19512. Cambridge, Massachusetts: National Bureau of Economic Research.
- McIntosh, C., Sarris, A., & Papadopoulos, F. (2013). Productivity, credit, risk, and the demand for weather index insurance in smallholder agriculture in Ethiopia. *Agricultural Economics*, 44(4-5), 399-417.
- Minot, N., & Benson, T. (2009). “Fertilizer Subsidies in Africa: Are Vouchers the Answer?” IFPRI Issue Brief No. 60. Washington, DC: International Food Policy Research Institute.
- Minten, B., Koru, B., & Stifel, D. (2013). The last mile(s) in modern input distribution: Pricing, profitability, and adoption. *Agricultural Economics*, 44(6), 629–646.
- Minten, B., Tamru, S., Engida, E., & Kuma, T. (2013). “Ethiopia’s Value Chains on the Move: The Case of Teff.” ESSP Working Paper 52. Washington, DC: International Food Policy Research Institute.
- Moris, J. R., Thom, D. J., & Humpal, D. S. (1987). “African irrigation overview: main report.” Logan, Utah: Utah State University.
- Morris, M., Kelly, V., Kopicki, R. J., & Byerlee, D. (2007). “Fertilizer Use in African Agriculture: Lessons Learned and Good Practice Guidelines.” Washington, DC: World Bank.
- Mrema, G. (2011). Public sector strategy development. In J. Ashburner & J. Kienzle (Eds.), *Investment in agricultural mechanization in Africa: Conclusions and recommendations of a Round Table Meeting of Experts* (pp. 23–36). Rome, Italy: Food and Agriculture Organization of the United Nations.
- Mrema, G. C., Baker, D., & Kahan, D. (2008). “Agricultural mechanization in sub-Saharan Africa: time for a new look.” Agricultural Management, Marketing, and Finance Occasional Paper 22. Rome, Italy: Food and Agriculture Organization of the United Nations.

- Mwakalila, S., & Noe, C. (2004). "The Use of Sustainable Irrigation for Poverty Alleviation in Tanzania: The Case of Smallholder Irrigation Schemes in Igurusi, Mbarali District." Dar es Salaam, Tanzania: Research on Poverty Alleviation.
- Mwendera, E., & Chilonda, P. (2013). Conceptual Framework for Revitalisation of Small-Scale Irrigation Schemes in Southern Africa. *Irrigation and Drainage*, 62(2), 208-220.
- Nakano, Y., & Kajisa, K. (2013). "The Determinants of Technology Adoption: The Case of the Rice Sector in Tanzania." Working Paper No. 58. Tokyo, Japan: Japan International Cooperation Agency Research Institute.
- Nathaniels, N. Q. R., & Mwijage, A. (2000). "Seed faris and the case of Marambo village, Nachingwea district, Tanzania: Implications of local informal seed supply and variety development for research and extension." AgREN Network Paper No. 101. London, UK: Overseas Development Institute.
- Nelson, Gerald C., Mark W. Rosegrant, Amanda Palazzo, Ian Gray, Christina Ingersoll, Richard Robertson, Simla Tokgoz, Tingju Zhu, Timothy B. Sulser, Claudia Ringler, Siwa Msangi, and Liangzhi You (2010). *Food security, farming, and climate change to 2050: Scenarios, results, policy options*. Washington, DC: International Food Policy Research Institute.
- Ngowi, A. V. F., Mbise, T. J., Ijani, A. S. N., London, L., & Ajayi, O. C. (2007). Pesticide use by smallholder farmers in vegetable production in northern Tanzania. *Crop Protection*, 26(11), 1617–1624.
- Njuki, J., Poole, J., Johnson, N., Baltenweck, I., Pali, P., & Mburu, S. (2011). "Gender, livestock, and livelihoods indicators." Nairobi, Kenya: International Livestock Research Institute.
- Nkonya, E., Pender, J., Kaizzi, K. C., Kato, E., Mugarura, S., Ssali, H., & Muwonge, J. (2008). "Linkages between Land Management, Land Degradation, and Poverty in Sub-Saharan Africa: The Case of Uganda." Research Report 159. Washington, DC: International Food Policy Research Institute.
- Nkonya, E., Pender, J., Kato, E., Phillip, D., & Ehui, S. (2010). "Options for Enhancing Agricultural Productivity in Nigeria." Background Paper No. NSSP 011. Abuja, Nigeria: International Food Policy Research Institute.
- Nonga, H. E., Mdegela, R. H., Lie, E., Sandvik, M., & Skaare, J. U. (2011). Assessment of farming practices and uses of agrochemicals in Lake Manyara basin, Tanzania. *African Journal of Agricultural Research*, 6(10), 2216–2230.
- Nyangena, W., & Juma, O. M. (2014). "Impact of Improved Farm Technologies on Yields: The Case of Improved Maize Varieties and Inorganic Fertilizer in Kenya." Discussion Paper Series 14-02. Environment for Development.

- Nyirenda, S. P., Sileshi, G. W., Belmain, S. R., Kamanula, J. F., Mvumi, B. M., Sola, P., et al. (2011). Farmers' ethno-ecological knowledge of vegetable pests and pesticidal plant use in Malawi and Zambia. *African Journal of Agricultural Research*, 6(6), 1525–1537.
- Oerke, E.C., & Dehne, H.W. (2004). Safeguarding production—losses in major crops and the role of crop protection. *Crop Protection*, 23(4), 275–285.
- Okoboi, G. (2010). “Of what merit is improved inputs use in Uganda’s maize productivity?” Contributed paper presented at the Joint 3rd African Association of Agricultural Economists (AAAAE) and 48th Agricultural Economists Association of South Africa (AEASA) Conference, Cape Town, South Africa, September 19-23, 2010.
- Okoboi, G., & Barungi, M. (2012). Constraints to Fertilizer Use in Uganda: Insights from Uganda Census of Agriculture 2008/9. *Journal of Sustainable Development*, 5(10), 99–113.
- Otsuka, K., Chuma, H., & Hayami, Y. (1992). Land and labor contracts in agrarian economics: theories and facts. *Journal of Economic Literature*, 30(4), 1965–2018.
- Palacios-Lopez, A., & Djima, I. Y. (2014). “Land Areas in the LSMS-ISA country datasets: An Application of Multiple Imputation (MI) methods.” Washington, DC: World Bank.
- Pan, L., & Christiaensen, L. (2012). Who is Vouching for the Input Voucher? Decentralized Targeting and Elite Capture in Tanzania. *World Development*, 40(8), 1619–1633.
- Pavelic, P., Villholth, K. G., Shu, Y., Rebelo, L.-M., & Smakhtin, V. (2013). Smallholder groundwater irrigation in Sub-Saharan Africa: country-level estimates of development potential. *Water International*, 38(4), 392–407.
- Pender, J., Abdoulaye, T., Ndjéunga, J., Gerard, B., & Kato, E. (2008). “Impacts of Inventory Credit, Input Supply Shops, and Fertilizer Microdosing in the Drylands of Niger.” IFPRI Discussion Paper 00763. Washington, DC: International Food Policy Research Institute.
- Pender, J., Nkonya, E., Jagger, P., Sserunkuuma, D., & Ssali, H. (2004). Strategies to increase agricultural productivity and reduce land degradation: evidence from Uganda. *Agricultural Economics*, 31, 181–195.
- Peterman, A., Quisumbing, A., Behrman, J., & Nkonya, E. (2011). Understanding the Complexities Surrounding Gender Differences in Agricultural Productivity in Nigeria and Uganda. *Journal of Development Studies*, 47(10), 1482–1509.
- Pingali, P. (2007). “Agricultural mechanization: adoption patterns and economic impact.” In R E Evenson & P. Pingali (Eds.), *Handbook of Agricultural Economics*, Volume 3 (pp. 2779–2805).

- Pingali, P. L., Bigot, Y., & Binswanger, H. P. (1987). *Agricultural Mechanization and the Evolution of Farming Systems in Sub-Saharan Africa*. Baltimore, MD: The Johns Hopkins University Press.
- Pingali, P. L., & Binswanger, H. P. (1984). "Population density and agricultural transformation: a study of the evolution of technologies in tropical agriculture." Research Unit Report ARU22. Washington, DC: World Bank.
- Place, F., Barrett, C. B., Freeman, H. A., Ramisch, J. J., & Vanlauwe, B. (2003). Prospects for integrated soil fertility management using organic and inorganic inputs: evidence from smallholder African agricultural systems. *Food Policy*, 28(4), 365–378.
- Place, F., & Hazell, P. (1993). Productivity Effects Of Indigenous Land Tenure Systems In Sub-Saharan Africa. *American Journal of Agricultural Economics*, 75, 10–19.
- Rashid, S., Tefera, N., Minot, N., & Ayele, G. (2013). Can modern input use be promoted without subsidies? An analysis of fertilizer in Ethiopia. *Agricultural Economics*, 44, 1–17.
- Reardon, T., Barrett, C. B., Berdegue, J. A., & Swinnen, J. F. (2009). Agrifood industry transformation and small farmers in developing countries. *World Development*, 37(11), 1717–1727.
- Ricker-Gilbert, Jacob. (2011). "Household-level Impacts of Fertilizer Subsidies in Malawi." PhD Dissertation. Michigan State University, Department of Agricultural, Food, and Resource Economics.
- Ricker-Gilbert, Jacob, Jayne, T. S., & Black, R. (2009). "Does Subsidizing Fertilizer Increase Yields? Evidence from Malawi." Selected Paper prepared for presentation at the Agricultural & Applied Economics Association 2009 AAEA & ACCI Joint Annual Meeting, Milwaukee, Wisconsin, July 26-29, 2009.
- Rosegrant, M W, & Perez, N. D. (1997). "Water Resources Development in Africa: A Review and Synthesis of Issues, Potential, and Strategies for the Future." EPTD Discussion Paper No. 28. Washington, DC: International Food Policy Research Institute.
- Rosegrant, M W, Ringler, C., & De Jong, I. (2009). "Irrigation: Tapping Potential." In V. Foster & C. Briceño-Garmendia (Eds.), *Africa Infrastructure: A Time for Transformation*. (pp. 287–298). Agence Française de Développement and the World Bank.
- Rosegrant, Mark W, Koo, J., Cenacchi, N., Ringler, C., Robertson, R., Fisher, M., ... Sabbagh, P. (2014). "Food Security in a World of Natural Resource Scarcity." Washington, DC: International Food Policy Research Institute.
- Rovere, R. La, Keulen van, H., Hiernaux, P., Szonyi, J., & A. Schipper, R. (2008). Intensification scenarios in south-western Niger: Implications for revisiting fertilizer policy. *Food Policy*, 33(2), 156–164.

- Sani, R. M., & Bagna, A. (2007). Adoption of improved seeds of millet and cowpea by farmers in Madarounfa district, Niger Republic. *Continental Journal of Agricultural Economics*, 1, 1–6.
- Schultz, T. W. (1964). *Transforming traditional agriculture*. New Haven, Connecticut: Yale University Press.
- Shah, T., van Koppen, B., Merrey, D., de Lange, M., & Samad, M. (2002). “Institutional alternatives in African smallholder irrigation.” Research Report 60. Colombo, Sri Lanka: International Water Management Institute.
- Sheahan, M., Ariga, J., & Jayne, T. S. (2013). “Modeling the Effects of Input Market Reforms on Fertilizer Demand and Maize Production: A Case Study of Kenya.” Selected Paper prepared for presentation at the Agricultural & Applied Economics Association’s 2013 AAEA & CAES Joint Annual Meeting, Washington, DC, August 4-6, 2013.
- Sheahan, M., Black, R., & Jayne, T. S. (2013). Are Kenyan farmers under-utilizing fertilizer? Implications for input intensification strategies and research. *Food Policy*, 41, 39–52.
- Sherlund, S. M., Barrett, C. B., & Adesina, A. a. (2002). Smallholder technical efficiency controlling for environmental production conditions. *Journal of Development Economics*, 69(1), 85–101.
- Sims, B., & Zienze, J. (2006). “Farm power and mechanization for small farms in sub-Saharan Africa.” Agricultural and Food Engineering Technical Report No. 3. Rome, Italy: Food and Agriculture Organization of the United Nations.
- Smale, M., Byerlee, D., & Jayne, T. S. (2011). “Maize Revolutions in Sub-Saharan Africa.” Policy Research Working Paper No. 5659. Washington, DC: World Bank.
- Spielman, D. J., Kelemwork, D., & Alemu, D. (2011). “Seed, Fertilizer, and Agricultural Extension in Ethiopia.” Ethiopia Strategy Support Program II Working Paper No. 20. Washington, DC: International Food Policy Research Institute.
- Sserunkuuma, D. (2005). The Adoption and Impact of Improved Maize and Land Management Technologies in Uganda. *eJournal of Agricultural and Development Economics*, 2(1), 67–84.
- Sunding, D., & Zilberman, D. (2001). The Agricultural Innovation Process: Research and Technology Adoption in a Changing Agricultural Sector. In B. L. Gardner & G. C. Rausser (Eds.), *Handbook of Agricultural Economics, Volume 1A* (pp. 207–261). Amsterdam: Elsevier.
- Svendsen, M., Ewing, M., & Msangi, S. (2009). “Measuring Irrigation Performance in Africa.” IFPRI Discussion Paper No. 00894. Washington, DC: International Food Policy Research Institute.

- Taffesse, A. S. (2008). "Decomposition of Growth in Cereal Production in Ethiopia." Working Paper. Ethiopian Economics Association.
- Takeshima, H., Adeoti, A., & Salau, S. (2010). "Measuring the Effect of Transaction Costs for Investment in Irrigation Pumps: Application of Unobserved Stochastic Threshold Model to the Case of Nigeria." NSSP Working Paper No. 0015. Abuja, Nigeria: International Food Policy Research Institute.
- Takeshima, H., Nin-Pratt, A., & Diao, X. (2013). Mechanization and agricultural technology evolution, agricultural intensification in sub-Saharan Africa: Typology of agricultural mechanization in Nigeria. *American Journal of Agricultural Economics*, 95(5), 1230–1236.
- Takeshima, H., & Salau, S. (2010). "Agricultural Mechanization and the Smallholder Farmers in Nigeria." Nigeria Strategy Support Program Policy Note No. 22. Washington, DC: International Food Policy Research Institute.
- Tambo, J. A., & Abdoulaye, T. (2012). Climate change and agricultural technology adoption: the case of drought tolerant maize in rural Nigeria. *Mitigation and Adaptation Strategies for Global Change*, 17, 277–292.
- Teklewold, H., Kassie, M., & Shiferaw, B. (2013). Adoption of Multiple Sustainable Agricultural Practices in Rural Ethiopia. *Journal of Agricultural Economics*, 64(3), 597–623.
- Tittonell, P., Vanlauwe, B., Leffelaar, P. A., Roe, E. C., & Giller, K. E. (2005). Exploring diversity in soil fertility management of smallholder farms in western Kenya: Heterogeneity at region and farm scale. *Agriculture, Ecosystems & Environment*, 110(3–4), 149–165.
- Tomich, T. P., Kilby, P., & Johnston, B. F. (1995). *Transforming Agrarian Economies: Opportunities Seized, Opportunities Missed*. New York: Cornell University Press.
- Van Koppen, B. (2003). Water reform in Sub-Saharan Africa: what is the difference? *Physics and Chemistry of the Earth*, 28(20–27), 1047–1053.
- Vanlauwe, B., Bationo, A., Chianu, J., Giller, K. E., Merckx, R., Mkwunye, U., et al. (2010). Integrated soil fertility management: Operational definition and consequences for implementation and dissemination. *Outlook on Agriculture*, 39(1), 17–24.
- Vanlauwe, B., Kihara, J., Chivenge, P., Pypers, P., Coe, R., & Six, J. (2011). Agronomic use efficiency of N fertilizer in maize-based systems in sub-Saharan Africa within the context of integrated soil fertility management. *Plant and Soil*, 339, 35–50.
- Weight, D., & Kelly, V. (1999). "Fertilizer Impacts on Soil and Crops of Sub-Saharan Africa." MSU International Development Working Paper No. 21. East Lansing, Michigan: Michigan State University.

- Williamson, S. (2003). "Pesticide Provision in Liberalized Africa: Out of Control?" Agricultural Research and Extension Network Paper No. 126. London, UK: Overseas Development Institute.
- Williamson, S., Ball, A., & Pretty, J. (2008). Trends in pesticide use and drivers for safer pest management in four African countries. *Crop Protection*, 27(10), 1327–1334.
- Wilson, C., & Tisdell, C. (2001). Why farmers continue to use pesticides despite environmental, health and sustainability costs. *Ecological Economics*, 39(3), 449–462.
- Yilma, T., & Berger, T. (2006). "Complementarity between Irrigation and Fertilizer Technologies – A justification for increased Irrigation Investment in the Less-Favored Areas of SSA." Contributed paper prepared for presentation at the International Association of Agricultural Economists Conference, Gold Coast, Australia, August 12-18, 2006.
- You, L., Ringler, C., Wood-Sichra, U., Robertson, R., Wood, S., Zhu, T., et al. (2011). What is the irrigation potential for Africa? A combined biophysical and socioeconomic approach. *Food Policy*, 36(6), 770–782.
- Zerfu, D., & Larson, D. F. (2010). "Incomplete Markets and Fertilizer Use: Evidence from Ethiopia." Policy Research Working Paper No. 5235. Washington, DC: World Bank.
- Zeza, A., Winters, P., Davis, B., Carletto, G., Covarrubias, K., Quinones, E., ... Bonomi, G. (2007). "Rural Household Access to Assets and Agrarian Institutions: A Cross Country Comparison." ESA Working Paper No. 07-17. Rome, Italy: Food and Agriculture Organization of the United Nations.
- Zhang, W., Jiang, F., & Ou, J. (2011). Global pesticide consumption and pollution: with China as a focus. *Proceedings of the International Academy of Ecology and Environmental Sciences*, 1(2), 125–144.
- Zingore, S. (2011). Maize Productivity and Response to Fertilizer Use as Affected by Soil Fertility Variability, Manure Application, and Cropping System. *Better Crops*, 95(1), 4–6.
- Zingore, S., Tittonell, P., Corbeels, M., Wijk, M. T., & Giller, K. E. (2010). Managing soil fertility diversity to enhance resource use efficiencies in smallholder farming systems: a case from Murewa District, Zimbabwe. *Nutrient Cycling in Agroecosystems*, 90(1), 87–103.1

Appendix 1: Recent studies on input use in LSMS-ISA countries

Study	F	S	P	I	M	Sample selected	Main findings	Input use statistics
Ethiopia								
Alene and Hassan (2006)	X	X				Survey of randomly selected farmers registered as participants in the new extension program including: 47 traditional maize producers and 51 hybrid maize producers in Meta district of eastern Ethiopia during the 2001/2 cropping season.	High levels of technical inefficiency among both traditional and hybrid maize producers. The adoption of a technology, like hybrid seeds, does not ensure productivity gains without complementary support services, like extension, credit, and input supply.	Hybrid maize producers apply fertilizer at an average rate of 108 kg/ha while traditional maize producers apply at an average rate of 41 kg/ha.
Spielman, Kelemwork, Alemu (2011)	X	X				Government MoARD data across various years, 2008 most recently, (nationally representative).	Provides a synthesis of policy focuses and changes surrounding modern input use over time in Ethiopia and proposes a way forward.	Fertilizer use intensity calculated to be 17 kg/ha of nutrients across all cropland, and 21 kg/ha across all grain production. About 20 percent of land under improved maize seed in 2008.
Teklewold, Kassie, Shiferaw (2013)	X	X				Farm household survey conducted in 2010 of 898 households with 1,616 maize plots from nine districts in three regional states (Amhara, Oromia, SNNRP)	Estimates probit models to predict the adoption of various sustainable agricultural practices (SAPs). Finds high degree of correlation between the adoption of SAP type and a range of household and market factors that limit uptake.	Manure was applied to 27 percent of plots. 67 percent of plots received fertilizer, with average application rates of 57 kg/ha of nitrogen and 18 kg/ha of potassium. Improved seed used on 37 percent of plots.
Asfaw et al. (2011)		X			X	Household survey of 700 farmers in major chickpea producing areas during the 2006/07 cropping season.	Estimate a double-hurdle model to determine the effects of adoption and intensity of use of improved seed varieties, finding that knowledge, perception of attributes, household wealth, and labor availability are major determinants of improved seed use.	32 percent of sample used improved chickpea varieties. For adopters, the area planted under improved seed is an average 0.6 hectares. Average non-oxen TLU of 0.89.
Williamson et al. (2008)			X			400 smallholder farmers from four SSA countries, including Ethiopia, which comprise five different farm cropping systems between 2002/03 <i>*Also includes analysis of Benin, Ghana, and Senegal.</i>	Identifies some of the drivers of increased pesticide use including choice of crop, increase pest incidence, lack of alternate methods, a growing informal market, and subsidies.	Farmers of mixed grains in Ethiopia used 5-7 types of insecticide, limited in comparison to other farm types
Alem and	X					Household panel survey data from	Use a difference-in-difference estimator and	37 percent of households used

Study	F	S	P	I	M	Sample selected	Main findings	Input use statistics
Broussard (2013)						456 of 1,477 total households in rural panel (only those peasant associations where a nontrivial number use fertilizer and receive food aid). Use available data between 1994 and 2004.	inverse probability weighting to find that participation in food-for-work program increased fertilizer adoption.	fertilizer in 1994 compared to 49 percent in 2004. Application rates per hectare for fertilizer users fell from 112 in 1994 to 94 in 2004.
Dercon and Christiaensen (2011)	X					Household panel survey data from 1,477 rural households between 1994 and 1999 that is broadly representative of farming systems throughout country.	The possibility of low consumption outcomes when a harvest fails (high risk) discourages the adoption of fertilizer which traps households in low risk/low return agriculture.	Application on cereals was 39 kg/ha, permanent crops was 18 kg/ha, and total was 32 kg/ha in 1999.
McIntosh, Sarris, Papadopoulos (2013)	X	X	X	X		Plot and household data from four zones in the Amhara region in 2011. Total of 2,399 households included.	Households with high marginal returns to inputs say they would purchase weather input insurance but only those with low marginal returns actually do. Demand for insurance is highly responsive to randomly allocated insurance vouchers.	30 percent of sample uses improved seed. 59 percent of sample uses organic fertilizer. 55 percent use Urea (42 kg/ha) and 53 percent use DAP (47 kg/ha), for an average inorganic fertilizer application of 89 kg/ha. 29 percent use insecticides and herbicides. 11 percent of area irrigated across sample, with over 20 percent in North Wello zone.
Taffesse (2008)	X	X	X	X		Author's calculations using 1997/98-2007/08 years of the Agricultural Survey Sample from the Central Statistics Agency of Ethiopia which includes the four main regions.	Barriers to commercializing Ethiopia's agricultural sector remain. A number of policy-relevant suggestions are described.	Fertilizer applied to 39 percent of area cultivated with cereals in 2007/08. Improved seed applied to 4.7 percent of cereal area. 1.1 percent of cereal crop area irrigated. 21 percent of cereal area used pesticides.
Alemu et al. (2008)		X				Focus group and household surveys with 60 farmers in 3 districts of the Rift Valley area in 2005.	Dissemination of improved maize seed varieties remains limited, likely due to low level of private sector provisioning and poor market access of farmers.	60 percent of farmers use only improved varieties; 22 percent use only local, and 18 percent use both.
Croppenstedt, Demeke, Meschi (2003)	X	X				Nationally representative survey of 6,147 households in 1994 from four regions with grain production.	By estimating a double-hurdle model of fertilizer adoption, find that access if the over-riding constraint.	Average of 39 kg/ha inorganic fertilizer bought. 44 percent of farmers use fertilizer. 6 percent of farmers frequently used improved seed.
Zerfu and	X					2,104 randomly selected households	Heterogeneous imperfect markets (high	68 percent of households used

Study	F	S	P	I	M	Sample selected	Main findings	Input use statistics
Larson (2010)						in 115 villages stratified by agro-ecological zone and region from 2004 and 2006.	transport costs, unfavorable climate, price risk, illiteracy) prohibit higher rates of fertilizer use. Better extension service may be a way to overcome hurdles.	fertilizer in 2004; 63 percent in 2006. Application rates increased from 42 kg/ha in 2004 to 55.7 kg/ha in 2006 (all households). Fertilized plots saw an average of 116 kg/ha in 2004 and 167 kg/ha in 2006.
Aune et al. (2001)					X	Survey results from Dodola district of Bale, Lay Armacheo Woreda of North Gondar, Tehulederie district of South Wollo, Central Zone of Tigray.	Households with oxen are generally the wealthiest. Those who pay to rent some from of ploughing device can pay up to 50 percent of harvest amount in rental cost.	Tractors are used in some areas of Ethiopia for ploughing, including Dodola district where 58 percent of households use a tractor.
Makombe et al. (2011)				X		Random sample of farmers who use 351 rainfed systems, 122 with traditional irrigated systems, and 281 with modern irrigated systems in 2005/06 from propositively chosen irrigation schemes throughout Ethiopia.	Used a stochastic frontier function to estimate technical efficiency of rain-fed versus smallholder irrigated sites. Traditional irrigating systems operate at lower technical efficiency than modern irrigating systems.	Five major grains account for 40-45 percent of irrigated land compared to 82 percent of the area under rainfed production.
Loiskandl et al. (2008)				X		Case study-based approach to analyzing the environmental social impact of chosen irrigation schemes and projects throughout the country.	Details some of the environmental and social impacts of existing irrigation schemes. Describes some of the irrigation plans of the government.	Awash, Blue Nile, and Rift Valley lakes areas are those with most irrigation development.
Malawi								
Ricker-Gilbert, Jayne, Chirwa (2011)	X					Nationally representative panel of 4,812 households from two rounds of survey data collected in 2003/06 and 2006/07.	By estimating a double hurdle model of commercial fertilizer demand, find that a 1 kg increase in subsidized fertilizer crowds out 0.22 kg of commercial fertilizer.	31 percent of farmers in 2003/04 received subsidized fertilizer compared to 57 percent in 2006/07.
Ricker-Gilbert (2011)	X					Nationally representative panel of 4,812 households from two rounds of survey data collected in 2003/06 and 2006/07.	Large-scale government fertilizer subsidy program is having large but heterogeneous effects on (i) household commercial fertilizer purchases and (ii) the labor market, while little impact on various measures of household well-being.	Average commercial fertilizer use was 63 kg/household in 2002/03-2003/04 versus 4.3 kg/household of subsidized fertilizer. In 2006/06, average commercial fertilizer purchases were 19.7 kg/household while subsidized fertilizer was 55 kg/household.
Ricker-Gilbert, Jayne, Black (2009)	X					Nationally representative panel of households in 2002/03, 2003/04, and 2006/07.	Descriptive results show that households who paid commercial prices for inorganic fertilizer achieved higher maize yields than those who received subsidized fertilizer.	Average fertilizer use rate was 55.7 kg/ha across survey years, with median at 0.

Study	F	S	P	I	M	Sample selected	Main findings	Input use statistics
Holden and Lunduka (2012)	X					Household and plot level data from 2006, 2007, 2009 of 450 households and over 3,000 plots in two districts in Central Malawi and four districts in Southern Malawi.	A 1 percent increase in fertilizer use intensity led to a 0.62-1.66 percent and 1.9 percent increase in the intensity of manure used by fertilizer subsidy recipients and non-recipients respectively.	48 percent of households applied organic manure to plots in 2009. Mean fertilizer use level on maize plots was 237 kg/ha and non-maize plots was 125 kg/ha in 2009.
Mason and Ricker-Gilbert (2013)		X				Two nationally representative surveys of rural smallholder farmers in 2006/07 and 2008/09 to form a data set of 2,750 households. <i>**Also includes analysis of Zambia.</i>	An additional kg of subsidized maize seed decreased household commercial maize seed purchases by 0.58 kg. Households in areas where the ruling part won last major election were significantly more likely to acquired subsidized seeds.	Average household purchased 3.6 kgs of commercial seed and received 2.2 kgs of subsidized improved seed. 56 percent and 64 percent of households planted at least some improved maize variety in 2006/07 and 2008/09 respectively.
Lunduka, Fisher, Snapp (2012)		X				179 households from Mulanje District.	Farmers are interested in a variety of characteristics of seeds, including taste and poundability, not just yield potential.	76 percent of households cultivated modern varieties of maize seed.
Zezza et al. (2007)	X		X		X	Nationally-representative samples using data from 15 LSMS/RIGA countries, including Malawi and Nigeria. Both data sets from 2004. <i>*See also Nigeria section.</i>	Household access to assets and institutions remains low, with heterogeneous affects between and within countries.	Average TLU of 0.32 across full sample and 0.51 among livestock owners. 67 percent of the sample used fertilizer. 3 percent used pesticide. 3 percent said to engage in mechanization.
Chirwa (2005)	X	X				156 households surveyed in Machinga district in southern Malawi.	Using probit models, finds that fertilizer adoption is positively associated with higher levels of education, larger plot sizes, higher non-farm income. Hybrid seed adoption is positively associated with land tenure and fertile soils.	54 percent of plots were fertilized. 41 percent of maize fields were planted with hybrid seeds.
Nyirenda et al. (2011)			X			168 vegetable farmers (mostly tomatoes, brassicas, onions) interviewed in Northern Malawi. <i>**Also includes analysis of Zambia.</i>	Over 75 percent of sampled farmers used pesticides while few were aware of pesticidal plants, cultural practices, and the use of resistant varieties.	75 percent of sampled farmers used synthetic pesticides.
Mangisoni (2008)				X		50 treadle pump and 50 non-treadle pump farmers were interviewed in two districts (Blantyre in the Southern Region and Mchinji in the Central Region) where treadle pump	Through gross margins analysis, finds that treadle pump users have higher net farm incomes per hectare than non-adopters. Poverty measures were lower for treadle pump users as well.	Malawi has developed only 62,000 hectares of estimated irrigation potential of 400,000 hectares.

Study	F	S	P	I	M	Sample selected	Main findings	Input use statistics
						usage is high		
Chidanti-Malunga (2009)				X		200 key informant interviews with households in irrigated Shire Valley at southern tip of Malawi	Farmers prefer flood recession agriculture, river diversion, and treadle pumps. Motorized pumps were too costly. Estimated gross margins for a number of irrigation scenarios.	80 percent used river diversion, 15 percent used treadle pumps, and 4 percent used flood recession.
Niger								
Abdoulaye and Sanders (2013)	X					Household survey in Maradi of 694 households in 2010, 2011, 2012 who participate in a program aimed at increasing sorghum productivity	Assesses productivity differences between adopters and non-adopters of a package of improved sorghum technologies. Finds that producers are becoming more efficient over time.	Farmers in the “improved technology” category apply an average of 92 kg/ha of inorganic fertilizer compared to households in the “traditional technology” category who apply 28 kg/ha
Pender et al. (2008)	X		X			Household surveys in 2004/05 in Dosso, Maradi, Tillabery, and Zinder regions where fertilizer micro-dosing had been promoted via on farm trials.	Investigate the impacts of various interventions (e.g., micro-dosing demonstrations) and institutional environments (e.g., access to input supply store) in the decision to use inorganic fertilizer.	39 percent, 7 percent, 36 percent, and 13 percent bought inorganic fertilizer in Dosso, Maradi, Tillabery, and Zinder respectively. 2 percent and 30 percent bought pesticides in Dosso and Zinder respectively (others were zero). 7 percent bought insecticides in Zinder (others were zero).
Abdoulaye and Sanders (2005)	X					100 households in Fakara Plateau in the administrative regions of Boboye and Kollo in western Niger	Probit and tobit models used to jointly estimate inorganic and organic fertilizer adoption which shows the importance of price ratios and use of demonstration plots in the farmer decision to use	88 percent of households had used organic fertilizer in the previous cropping season, 90 percent of which came from on-farm animal manure. Households used less than 8 kg/ha of inorganic fertilizer.
Sani and Bagna (2007)		X				120 farmers randomly selected from 12 villages of Madarounfa district in southern part of Maradi region	Decreasing rate of adoption of improved millet and cowpea seeds over time. Low adoption rates are explained by high cost of improved seeds, high cost and unavailability of fertilizer, and inadequate supply of input. Farming experience, all else equal, influenced the adoption of improved seeds of millet significantly, while membership of cooperatives influenced the adoption of improved seeds	48 percent and 47 percent of sample used improved millet and cowpea seeds respectively in 2002.

Study	F	S	P	I	M	Sample selected	Main findings	Input use statistics
							of cowpea significantly.	
Rovere et al. (2008)	X				X	Data from the International Livestock Research Institute (ILRI) of nearly 500 households in the Fakara area.	Analyzes scenarios for intensification in the Sahel. Nitrogen as an external input will be required which can be accomplished partially by owning livestock but also synthetic fertilizer.	TLU of between 0.96 and 15.48. No specific fertilizer rates provided.
Houndekon, De Groote, Lomer (2006)			X			111 farmers from 17 villages in the departments of Tahour and Zinder in southern Niger (where locust problems are frequent and pesticides are regularly used)	Clear link between chemical pesticide use and health problems with cost to human health of \$1.70/ha and to livestock losses of \$0.33/ha.	Portion of sample receiving free pesticide from the government decreased from 47 to 25 percent between 1993 and 1996. Portion of sample purchasing pesticide increased from 19 to 26 percent over the same period.
Nigeria								
Liverpool-Tasie and Salau (2013)	X	X			X	640 households randomly chosen from 10 local government areas (LGAs) were interviewed in Kano (northwest Nigeria)	Uses a control function approach to find that receiving subsidized fertilizer increases the likelihood that a farmer will use improved seed.	55 percent of sample used improved seeds in 2009. Households received an average of 142.5 kgs of subsidized fertilizer. Average TLU of 6.9.
Akramov (2009)	X	X	X			Nationally representative study covering 75,000 households in 7,700 communities; 53,694 households who participated in agriculture included in this study	Government involvement in agricultural service provision positively effects household-level input use, with wealthier farmers more likely to benefit. Impact of good roads on input use is heterogeneous across states.	43 percent used fertilizer across full sample with ranges of nearly 80 percent in northwestern areas and about 10 percent in the south; 7 percent use improved seed; 10.5 percent used pesticides
Zezza et al. (2007)					X	Nationally-representative samples using data from 15 LSMS/RIGA countries, including Malawi and Nigeria. Both data sets from 2004. <i>*See also Malawi section.</i>	Household access to assets and institutions remains low, with heterogeneous affects between and within countries.	Average TLU of 0.71 across full sample and 1.54 among livestock owners.
Banjo et al. (2010)			X			Use of questionnaires and interviews with 52 farmers in Odogbolu Local Government Area of Ogun state	High rates of dangerous pesticide types and low use of protective measures by vegetable and maize farmers.	87 percent of farmers applied pesticides and herbicides at prescribed rates while 13 percent applied indiscriminately and frequently. All farmers agreed that usage of pesticides and herbicides is increasing and that application rates are high.

Study	F	S	P	I	M	Sample selected	Main findings	Input use statistics
Tambo and Abdoulaye (2012)		X				Household survey of 200 farming households in Borno State of northeastern Nigeria during 2009/10	Key determinants of using drought tolerant maize seeds are access, use of complementary inputs, extension service, and knowledge of climate change information.	50 percent of households used drought tolerant maize seeds which accounted for 58 percent of the total area planted under maize
Nkonya et al. (2010)	X		X	X		3,750 households in low-lying areas of Nigeria conducted in 2006/07 across 12 states that participate in the Fadama II project. Supplemented with data from the National Bureau of Statistics socioeconomic data from 2006.	Examines the profitability of production of specific crops types based on government recommendations and household food preferences. Fertilizer adoption is low, even on crops where it is estimated to be profitable.	34 percent of farmers used fertilizer (52 percent in dry savannahs versus 11 percent in the humid forest). 6 percent used herbicides while 4 percent used pesticides. (compiled from National Bureau of Statistics data) 10 percent of households irrigate in the humid forest zone versus 26 percent in the dry savannah (Fadama II survey)
Takeshima, Adeoti, Salau (2010)				X		3,750 households in low-lying areas of Nigeria conducted in 2006/07 across 12 states that participate in the Fadama II project	Small-scale irrigation schemes are driving increases in irrigation throughout Nigeria, however utilization remains suboptimal, likely due to the transactions costs of the initial investment.	7 percent of farmers in sample had invested in irrigation pumps in 2006. Another 14 percent invested once receiving financing from the project.
Yohanna et al. (2011)					X	130 respondents to questionnaires administered by extension agents throughout the middle belt of Nigeria	Mechanization remains limited among households with less than 5 hectares of land.	21 percent of respondents used mechanized equipment for land clearing. 25 percent used for tilling. 40 percent used for harvesting.
Takeshima and Salau (2010)					X	Combined statistics from a number of different studies	Agricultural mechanization remains low for smallholder farmers in Nigeria	86 percent of households in northern Nigeria use hand tools in agricultural production (data from 1980) 5 percent of households used animal power in farming (data from National Living Standards Survey in 2004)
Tanzania								
Pan and Christiaensen	X	X				Vulnerability Household Panel from the Kilimanjaro region in 2003,	Evidence of elite capture in distribution of input vouchers despite detailed targeting	Between 50 and 69 percent of households used improved seed in

Study	F	S	P	I	M	Sample selected	Main findings	Input use statistics
(2012)						2004, and 2009 of 772 households. Input subsidies were administered in 39 of the 45 villages sampled.	criteria, especially in unequal and remote communities.	2004. Between 30 and 50 percent of households used inorganic fertilizer in 2004.
Benson et al. (2012)	X					Two surveys in three farming areas where fertilizer is used (Kilimanjaro, Iringa, and Ruvuma regions) for a total of 193 households and 31 traders.	Study the supply of inorganic fertilizer and find that the government has taken some actions to improve access although several suggestions are made on how to further improve the supply, particularly through the private sector.	95 percent of farmers in the sample use fertilizer, mostly on maize but some on rice. Median application rate of 220 kg/ha on maize, 124 on rice, 247 on vegetables.
Kaliba, Verkuijl, Mwangi (2000)	X	X				30 percent of the farmers from a 1,000 nationwide sample from 1994; specifically focused on Central, Easter, Southern, and Western zones (intermediate and lowlands areas)	Availability of extension service, on-farm field trials, variety characteristics, and rainfall were the more important and significant factors affecting adoption of modern inputs for maize production	56 percent adopted at least one improved maize seed variety, equivalent to 40 percent of the total area under maize; 23 percent used inorganic fertilizer on maize
Nakano and Kajisa (2013)	X	X		X		672 households that produce rice surveyed in 2009/10 from three major agro-ecological zones, which can be considered nationally representative for rice cultivation.	Find that credit increases the use of fertilizer, fertilizer is used more in irrigated areas, and that small-scale farmers are not disadvantaged in modern input adoption.	23 percent of rice plots were irrigated. Irrigated fields have an average of 32 kg/ha of fertilizer with 29 percent using modern seed varieties. Rainfed plots have an average of 7 kg/ha of fertilizer with 7 percent of rainfed rice fields have modern varieties.
Ngowi et al., (2007)			X			Interviews with 61 small-scale farmers from 4 districts in northern Tanzania in 2005 where vegetable crops are often sprayed with pesticides.	Trends in pesticide use among these farmers was high and increasing. Well over half of the sample reported sickness from pesticide use and little knowledge of how to protect oneself.	59 percent use insecticide, 29 percent use fungicide, 10 percent use herbicide, 2 percent use rodenticide. 53 percent reported an increase in pesticide use over time.
Kathage et al. (2012)	X	X		X		Household survey of 695 maize producing households in the northern and eastern zones, representative of the two main agro-ecological zones in Tanzania, conducted in 2010.	Average net gain to using hybrids is estimated between 50-60 percent, with more gains in the north than the east.	Hybrid maize seed adoption is at 48 percent in the northern zone and 13 percent in the eastern zone. 3-4 percent of plots were fertilized. 1 percent of plots were irrigated.
Nathaniels and Mwijage (2000)		X				194 seed fair attendees and 9 local farmer seed experts with follow-up household visits in 1997/98 in small area of southeastern Tanzania.	Through a seed fair network, piloted a process for testing new varieties of seeds through farmers then allowing them to sell. Successes could be a useful model for replication in other areas.	Of 50 farmers mentioning source of maize seed, all had saved at least some from previous season with only 6 purchasing at a local shop.

Study	F	S	P	I	M	Sample selected	Main findings	Input use statistics
Nonga et al. (2011)	X		X			Survey of 80 households in villages surrounding Lake Manyara in northern Tanzania in 2008.	High and indiscriminate use and poor disposal methods of pesticides with negative public and environmental health effects.	78 percent of the sample used inorganic fertilizers while 43 percent applied animal manure. 50 percent used insecticide, 38 percent used fungicide, and 13 percent used herbicide.
Kassie et al. (2013)	X	X				Survey of 681 households with 1,539 plots from 60 villages and 4 districts in rural Tanzania in 2010.	Uses a probit model to estimate factors contributing to simultaneous adoption sustainable agricultural production techniques. These include rainfall, insect and disease, extension service, land tenure, social capital, plot location, and household assets.	23 percent of plots received animal manure; 67 used improved seeds; 4 percent used inorganic fertilizer.
Evans, Giordano, Clayton (2012)				X		200 total farmers interviewed via rapid rural appraisals in five administrative regions and in-depth interviews with three representative communal irrigation schemes in Morogoro.	To achieve government short-term irrigation goals, significant progress will need to be made in infrastructure, institutions, and human resources. Examine the role of conservation agriculture techniques within these efforts.	Estimated that between 2-8 percent of rural household benefit from community managed river diversion schemes and that 85 percent of irrigators use buckets and watering cans only.
Mwakalila and Noe (2004)				X		Interviews with households in 5 villages from Mbarali district where various forms of irrigation are practiced.	Returns to irrigation depend on how well the systems are maintained. Provides suggestions for policies and institutional arrangements to make irrigation schemes work better for small-scale farmers.	79 percent practiced irrigated agriculture for rice paddy production. Rice is more likely to be irrigated than maize in the sample.
Uganda								
Matsumoto and Yamano (2011)	X	X				Panel survey of 895 households from 94 rural local councils across all areas of Uganda, except insecure areas of the north, interviewed for the second time in 2005 <i>**Also includes analysis of Kenya.</i>	Low application of inorganic fertilizer is not profitable due to high relative price.	3 percent of sample used inorganic fertilizer on maize for an average use rate of 2.4 kg/ha; 6 percent used organic manure on maize at an average use rate of 86 kg/ha; 21 percent use hybrid maize seeds
Sserunkuuma (2005)	X	X				451 households with 1,677 plots from some randomly section and some purposively selected lowest administrative units in 2000/01/	Finds that farmers do not manage their soil fertility, which acts as a major barrier to increasing maize yields.	62 percent of plots planted with maize were planted with improved varieties. Of those that use improved varieties, 7 percent use inorganic fertilizer compared to only 1 percent of those who use traditional/local seeds.

Study	F	S	P	I	M	Sample selected	Main findings	Input use statistics
Benson et al. (2012)	X		X			Household surveys of 272 farmers in four areas where a set number of fertilizer users and non-users were targeted for inclusion. Areas surveyed include coffee growing regions, vegetable producers in peri-urban areas, and staple maize producers.	Study the supply of inorganic fertilizer and find that the government has taken some actions to improve access although several suggestions are made on how to further improve the supply, particularly through the private sector.	59 percent of the sample used fertilizer, ranging from about 40 percent in Masaka to over 80 percent in Kampala. 34 percent use organic fertilizer in maize, 66 percent on vegetables. 34 percent use pesticides on maize, 79 percent use on vegetables.
Nkonya et al. (2008)	X				X	851 households with 3,625 plots interviewed in 2005 as identified using a portion of the sampling frame from the Ugandan National Household Survey (same sample as Peterman et al. 2011).	Used several measures to demonstrate the strong linkage between poverty and sustainable land management, providing evidence that a land degradation 'poverty trap' exists.	2 percent used organic fertilizer/residues. Another 2 percent used inorganic fertilizers. Average TLU of 2.9.
Okoboi and Barungi (2012)	X			X		Uganda Census of Agriculture data from 2008/09 of 29,355 households	Isolate a number of extension, knowledge, market, and household characteristics leading to low use of inorganic fertilizer.	8 percent of sample used inorganic fertilizer while 26 percent used organic fertilizer. 1 percent had irrigation equipment.
Okoboi (2010)	X	X	X		X	Uganda National Household Survey 2005/06 of 1,888 farms.	Yield and gross profit functions were estimated. Found that improved inputs had a significant positive gain to yield, but not gross profit.	1 percent used inorganic fertilizer, 3 percent used herbicide or fungicide; 11 percent used traction/power; 3 percent used organic fertilizer (manure); 11 percent purchased improved seed.
Peterman et al. (2011)	X			X		851 households with 3,625 plots interviewed in 2005 as identified using a portion of the sampling frame from the Ugandan National Household Survey. <i>*Also includes analysis of Nigeria, although no input use statistics reported.</i>	Explore the gender differences in agricultural productivity and find that female-headed households have significantly lower productivity levels even when controlling for household-level observable and unobservable characteristics.	Less than 2 percent of sample use fertilizer and/or irrigation.
Larson, et al. (2012)	X					Household survey of 825 rural households with 3,200 maize plots visited in 2003 and 2005 by REPEAT project. <i>*Also includes analysis of Kenya and</i>	Using a model of endogeneous technology choice, they find that the inverse productivity hypothesis holds even in highly heterogeneous data where geography-specific variables are accounted for.	Inorganic and organic fertilizer used on only 2 and 4 percent, respectively, of maize plots. Inorganic fertilizer users apply an average 32.4 kg/ha to maize plots.

Study	F	S	P	I	M	Sample selected	Main findings	Input use statistics
						<i>some of the same data used in this analysis (Malawi and Tanzania).</i>		
Bayite-Kasule (2009)	X	X				Uganda National Household Survey from 2005/06 of 1,888 farms.	To drive fertilizer use and productivity in Uganda will require a holistic strategy of integrating public and private sector partners.	1 percent of farmers use fertilizer (ranging from 0.6 percent in the western region to 1.3 percent in the central region); 6.3 percent use improved seed (ranging from 2.2 percent in the western region to 12 percent in the eastern region).

Note: F=fertilizer, S=seed, P=pesticides, I=irrigation, M=mechanization

Appendix 2: Disaggregated input types observed in the questionnaires for each country

In this appendix, we describe how the input variables were calculated using the unique questionnaire design for each country.

Types of organic fertilizer enumerated in surveys by country

Organic fertilizer type	Ethiopia	Malawi	Niger ¹	Nigeria	Tanzania	Uganda
Manure	X		X			
Composite manure				X		
Compost	X		X			
Organic fertilizer	X	X ²			X	X

¹ Note: In Niger, we also observe whether or not a household applies crop residues to a plot although we did not include that in the overall organic fertilizer tabulation since it was not observed in other countries.

² Note: While only “organic fertilizer” appears in the Malawi questionnaire, it is defined as “animal manure, compost, or green manure.”

Types of inorganic fertilizer enumerated in surveys by country

Inorganic fertilizer type	Ethiopia	Malawi	Niger	Nigeria	Tanzania	Uganda
UREA (46:0:0)	X	X	X	X	X	
DAP (18:46:0)	X	X	X		X	
CAN (26:0:0)		X			X	
TSP (0:46:0)					X	
SA (21:0:0)					X	
NPK (23:23:0+48/Chitowe)		X				
NPK (15:15:0)			X			
generic NPK				X ¹	X ²	
Minjingu Rock Phosphate (MRP) ³					X	
D compound (8:18:15) ⁴		X				
Nitrate ⁵						X
Phosphate ⁶						X
Potash ⁷						X
Other ⁸		X		X		
Mixture/mixed			X ⁹			X ¹⁰

¹ Note: We assume NPK (27:13:13) per most common type on page 12 of this document:

http://www.nigeriamarkets.org/files/NPK%20Fertilizer%20Rationalization%20Study_Nigeria.pdf

² Note: We assume NPK (17:17:17).

³ Note: We assume a phosphate component of 28.6 percent per the company website:

<http://minjingu mines.com/link5.htm>

⁴ Source: <http://www.moafsmw.org/ocean/docs/Policy%20Documents/D%20Fertiliser%20Policy%2025.09.07.pdf>

⁵ Note: We assume urea.

⁶ Note: We assume DAP.

⁷ Note: We assume muriate of potash (MOP).

⁸ Note: Other category generally accompanied by a “specify” variable which was manually coded.

⁹ Note: Mixture is assumed to be an equal mix of the three other fertilizer types contained in survey (urea, DAP, NPK).

¹⁰ Note: Mixed is assumed to be an equal mix of the urea and DAP.

Types of seed enumerated in surveys by country

Seed type	Ethiopia	Malawi	Niger	Nigeria	Tanzania	Uganda
Local/traditional	X	X	X		X	X
Composite/OPV		X				
Hybrid		X				
Hybrid recycled		X				
Unspecified			X			
Improved	X		X		X ¹	X ¹
Mixed			X			
Free				X		
Saved				X		
Commercial				X		

¹ In Tanzania and Uganda, improved seeds are further defined as certified or quality declared.

Note: Seed types in gray assumed to be or include “improved” varieties.

Types of agrochemicals enumerated in surveys by country

Pesticide type	Ethiopia	Malawi	Niger	Nigeria	Tanzania	Uganda
Pesticide	X		X	X	X	
Herbicide	X	X	X	X	X	
Fungicide	X	X	X		X	
Fumigant		X				
Insecticide		X				X
Miticides and acaricides						X
Growth regulators and harvest aids						X
Rodenticides						X
Nematicides and molluscicides						X
Other		X	X		X	X

Types of irrigation systems enumerated in surveys by country

Irrigation type	Ethiopia ¹	Malawi	Niger ²	Nigeria ¹	Tanzania	Uganda ¹
Irrigation system type						
Divert stream		X		X		
Bucket		X		X		
Hand pump		X		X		
Treadle pump		X		X		
Motor pump		X		X		
Bucket					X	
Hose					X	
Sprinkler				X	X	
Flooding					X	
Gravity		X		X		
Water source for irrigation						
Waterway (river, lake, etc.)	X	X	X	X	X	

Well		X	X	X	X	
Drilling			X			
Dam, water retention			X			
Borehole		X		X	X	
Other	X	X		X		
Harvested	X				X	

¹ In Ethiopia, Nigeria, and Uganda, we only have a binary variable for whether or not the plot was irrigated. In Uganda, we also know nothing about the source of water for irrigation.

² In Niger, we can only infer the plot was irrigated based on the responses to the source of water.

Types of animal power and mechanized equipment in surveys by country

	Ethiopia	Malawi	Niger	Nigeria	Tanzania	Uganda
Animal power/traction						
Bulls	X	X	X	X	X	X
Cows	X		X	X	X	X
Steers	X		X	X	X	
Heifers	X		X	X	X	X
Donkey	X		X	X		X
Ox		X	X	X		X
Horse/mule	X	X	X	X		X
Tractor						
Tractor		X	X	X	X	X
Other mechanized equipment						
Plough	X	X	X	X	X	
Cart			X	X		
Harrow					X	
Other tractor related				X		
Yoke			X			
Ox cart		X			X	X
Ox plough		X			X	X
Ox seed planter					X	
Other animal related				X		
Motorized pump		X	X			
Thresher			X		X	
Generator		X	X			
Sheller			X		X	X
Seeder			X			
Ridger		X		X		
Planter				X		X
Harvester				X		
Pick-up				X		
Water pump	X			X		
Sprinkler				X		
Cultivator/harrow		X				X
Mofer and kember	X					

Grain mill		X				
Weeder						X
Sprayer					X	X
Hilaire			X			
Lames sarcleuses			X			
Poudreuse			X			

Note: In Ethiopia, we do not observe the value of agricultural equipment, only the types of agricultural assets owned.