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Pesticide use in Sub-Saharan Africa: Estimates, Projections, and Implications in the Context of Food System Transformation

by

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Pesticide use in Sub-Saharan Africa: Estimates, Projections, and Implications in the Context of Food System Transformation

EXECUTIVE SUMMARY

Much of Sub-Saharan Africa (SSA) is urbanizing rapidly and the economy is growing at a robust pace. The overall demand for food is likely to increase dramatically over the next three decades and the composition of this demand is likely to shift away from staple grains and towards processed and fresh perishable foods, including horticultural products. Horticultural farmers will have increasing incentives to boost yields and minimize crop damage while also minimizing rising labor costs. Responding to these incentives in tropical/sub-tropical climates with high pest pressure will likely involve the substantial use of pesticides, herbicides, and fungicides, all in a lax regulatory environment where farmers may lack training in safe and effective pest control. While there have been a number of studies documenting the knowledge, attitude, and practice of pest control by farmers in SSA, we perceive two key gaps in the literature: (1) limited household level evidence on application rates and (2) little analysis on the determinants of use.

The purpose of this paper is to characterize pesticide use in developing Sub-Saharan Africa (d-SSA) in the context of urbanization, income growth, and food system change. To do this we (1) estimate some of the correlates of pesticide use worldwide and use them to predict trends in Sub-Saharan Africa through 2040, and (2) present new household survey results on pesticide purchase behavior by horticultural farmers supplying urban markets in Zambia and Mozambique. Our analysis shows that income per capita and population are positive and significant drivers of pesticide use, while surprisingly, urbanization, if controlling for other factors, is actually a negative driver, along with agricultural share of GDP. Our model predicts that total pesticide use in d-SSA will increase by a factor of 1.24 to 2.32 - depending on the income growth scenario - but will still be low compared to the rest of the world.

However our household surveys show that horticultural farmers are purchasing pesticides at much higher rates than what is suggested by the worldwide analysis, and are significantly exposed to health hazards due to high chemical toxicity and low levels of safety precaution. Part of this is driven by the fact that farmers perceive pests and diseases to be the greatest agricultural problem, much more than lack of access to inputs or access to irrigation. There is much variation across farmer types, with more technically advanced farmers purchasing a more diverse and targeted set

of pesticides. In Mozambique (where we have per-hectare application data), these farmers use a smaller amount of any given pesticide, and roughly half of the amount of methamidophos, which is a "highly toxic" pesticide.

Finally, we discuss the challenge of inducing behavioral change in what, despite the rapid influx of supermarkets and modern procurement practices, is still largely a traditional and informal food system. Verifying food safety through simple visual inspection and monitoring the behavior of the numerous supply chain actors (e.g. input dealers) is difficult. While consumers in d-SSA are still largely unaware of the dangers of toxic pesticide residue, evidence from other countries suggests that with a rising level of education and a rising middle class, consumer demand can be a potent driver of behavioral change in the medium to long run. In the short run, immediate action can be taken to ban the use of "highly toxic" pesticide. However this must be accompanied by the provision of less toxic pesticides and training in integrated pest management (IPM) strategies that are equally effective in pest control, while decreasing overall volumes.

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Pesticide use in Sub-Saharan Africa: Estimates, Projections, and Implications in the Context of Food System Transformation

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1 INTRODUCTION

Sub-Saharan Africa (SSA) has urbanized rapidly over the past six decades. According to official UN estimates, only 11% of the population lived in urban areas in 1950. Today this share is closer to 38% and is expected to reach 50% by 2040. Moreover, it has been broadly recognized that over the last 15 years, SSA has greatly improved its growth trajectory, averaging a robust 2.8% per capita real GDP annual growth from 2000 to 2013 (or 3.4% excluding South Africa). If this continues, it will spell fundamental changes at all levels of the food system.

A simulation exercise by Tschirley, et al. (2013) finds that overall demand for food in East and Southern Africa (ESA) is likely to increase by a factor of 3.3 to 9 times in the next 30 years, depending on economic conditions. The composition of demand is also likely to change dramatically. With increasing incomes, consumers are shifting away from purchasing primarily maize-based products or other cereal staples and towards purchasing processed and fresh perishable foods, including meats and horticultural products. Horticultural farmers, in order to meet the growing demand for consistent quantity and quality both locally and for export, have great incentives to increase yields and minimize crop damage due to insects, weeds, and fungi, all while dealing with rising labor costs.

Responding to these incentives in tropical/sub-tropical climates with high pest pressure involves substantial use of pesticides, including insecticides, herbicides, and fungicides. This pesticide use occurs in a lax regulatory environment (Karungi et al., 2011; Oluwole and Cheke, 2009), where many farmers do not possess adequate knowledge of optimal spray regimens (Abang et al., 2013; Karungi et al., 2011; Obopile et al., 2008), training in safety behavior (Mekonnen and Agonafir, 2002; Sosan and Akingbohungbe, 2009), or awareness of the environmental impact of indiscriminate use (Nonga et al., 2011).

Indeed, there is evidence at the local level that small scale farmers in SSA have become greatly reliant on synthetic pesticides, replacing more traditional methods of pest control (Cachomba et al., 2013; Nyirenda et al., 2011). However, most studies focus only on the proportion of farmers within a community using particular chemicals and the general circumstance and pattern of use (Ngowi et al., 2001; Ngowi et al., 2007; Nyirenda et al., 2011; Obopile et al., 2008; Oluwole and Cheke, 2009; Williamson et al., 2008). There are relatively few studies that report pesticide purchase or application rates in SSA.

Additionally, the correlates of pesticide use more generally are not well understood. Schreinemachers and Tipraqsa (2012) made a start to this by conducting a worldwide study of agricultural pesticide use using data from the Food and Agricultural Organization of the United Nations database on pesticide use in agricultural production from 1990-2011 (FAO: http://faostat3.fao.org/faostat-gateway/go/to/download/R/RP/E). They run two OLS bivariate regressions that show a strong positive correlation between crop productivity and pesticide use, and an increasing and concave relationship between country-wide per capita GDP and pesticide use. They find that the average country used 3.2 kgs of active ingredient per hectare of crops and estimate that a 1.0% increase in productivity (yield) correlates to a 1.8% increase in pesticide use per hectare, and to a 0.8% increase in pesticide use per unit of output. However they do not control for any other potential hidden variables such as urban share of total population and agricultural share of GDP.

To summarize, we perceive two key gaps in the literature regarding pesticide use in SSA: First, there is limited evidence collected from household-level datasets on pesticide purchase or application rates; and second, the determinants of pesticide use are not well understood. Work has been done to correlate pesticide use with income and yield separately, but there are other important factors that are not controlled for. We consider these gaps in the literature to be salient for a number of reasons.

First, it is well documented that smallholder farmers often do not take adequate safety precautions when dealing with chemical pesticides. There is considerable evidence that toxic pesticide use in SSA has contributed to chronic health problems in farmers such as acetylcholinesterase (AChE) inhibition in red blood cells (Ntow et al, 2009; Sosan et al, 2010), nervous and reproductive system damage (English et al, 2012; Taha and Gray, 1993), and has potentially contributed to a range of short term symptoms such as headache, general weakness, diarrhea, vomiting, abdominal cramps, excessive sweating, and nausea (Maumbe and Swinton, 2003; Ngowi et al., 2001; Oluwole and Cheke, 2009; Rama and Jaga, 1992; Sosan and Akingbohungbe, 2009).

Second, the accumulation of pesticide residues on and within fresh produce in SSA is a potential health concern for consumers. Multiple studies have sampled fresh produce on farms and in markets in countries such as Benin and Ghana and have found pesticide residues to be above the maximum residue limit (MRL), as defined by the European Union (Ahouangninou, 2012; Amoah et al., 2006; Pazou et al, 2013). This is concerning especially in light of the fact that most vendors and consumers of fresh produce are not very aware of the potential health problems due to pesticide residues (Deji, 2012; Probstet al., 2010).

And third, pesticides are known to be extremely harmful to animals, especially birds, bees, and aquatic organisms, and are known to bio-accumulate in soil and water (Manirakiza et al, 2003; Ntow et al, 2008; Sosan et al, 2008) Better understanding the nature of pesticide use is necessary for 1) promoting agricultural intensification while minimizing the use of toxic chemicals, and 2) promoting safe and efficacious forms of pest control.

The focus of this paper is to 1) **e**stimate the correlates of pesticide use on a global scale, 2) use these estimates to predict future trends in pesticide use in developing Sub-Saharan Africa (d-SSA, which excludes South Africa), given current and alternate growth trajectories, and 3) present new evidence, including pesticide purchase rates and respective toxicity levels from Zambia and Mozambique. We begin by presenting a brief literature review of pesticide use in SSA.

1.2 A brief review of the literature of pesticide use in SSA

In section 3 we will be referring to the World Health Organization (WHO) 2009 pesticide toxicity classifications. Pesticides are classified as “extremely hazardous” (WHO class Ia), “highly hazardous” (Ib), “moderately hazardous” (II), “slightly hazardous” (III), and “unlikely to present acute hazard” (U).

Table A.1 in the appendix summarizes the literature reporting the proportion of farmers using various chemicals. Oluwole and Cheke (2009) observe eight distinct pesticide combinations (individual or mixed as a cocktail) used by at least 50% of the 150 farmers sampled in Nigeria. Among these is monocrotophos (Ib), in use by 78% of the farmers. Other individual pesticides include atrazine (III), metalachlor (III), lindane (II), copper sulfate (II), and paraquat (II). Obopile et al. (2008) observe two pesticides used by over 50% of farmers in Botswana: malathion (II) and cypermethrin (II), while Sosan and Akingbohungbe (2009) observe one (also in Nigeria): lindane

(II).

Overall there are five pesticides reported in the literature that are classified as WHO class Ib or class Ia. Some of these are very rarely used. For example, Obopile et al. (2008) found that only 2.7% of a sample of 112 brassica and tomato farmers in Botswana reportedly use demeton-S-methyl, 1.8% of farmers use dichlorvos, and 7.1% of farmers use methomyl, all of which are WHO class Ib pesticides. However, other studies have reported greater percentages of producers using dangerous pesticides. Monocrotophos (mentioned above) is reported by 41% of farmers sampled in Zambia, while parathian, an even more dangerous WHO class Ia pesticide, is used by just over 25% of farmers sampled in Malawi (Nyirenda et al., 2011).

There are a range of other studies that report pesticide use in a more general sense, for example, by listing the pesticides in use, or the timing and trend of application. Ngowi et al. (2007) find in Tanzania that 59% of the pesticides used are insecticides, and over three-quarters of farmers apply them regularly – with over 15% of farmers applying insecticides over 16 times per cropping season. In this study pesticide use appears to be a growing trend: it has increased for 53% of farmers surveyed and has decreased for only 14% in the last five years.

Williamson, Ball, and Pretty (2008) analyze smallholder pesticide management in four countries: Benin, Ethiopia, Ghana, and Senegal. Across all crops, a total of 47 different active ingredients are used by farmers, including 26 insecticides, 10 herbicides, and 5 fungicides. The most common are glyphosate (III), malathion (III), chlorpyrifos (II), cypermethrin (II), deltamethrin (II), dimethoate (II), endosulfan (II), fenitrothion (II), and profenofos (II). The lowest users of pesticides are the pineapple growers in Benin and Ghana. In Ghana, pineapple farmers apply insecticides 3-5 times per crop cycle and herbicides 2-3 times at planting, while in Benin pesticide use is rare, "with herbicides in regular use only by the better-off smallholders". In Senegal it is found that crops grown for export, such as green beans, are less pesticide-intensive than crops grown for the local market, including eggplant, cabbage, and tomato. The authors suggest this is due to strict EU regulatory standards. In general, vegetable growers have the highest application frequency. In Benin, some vegetable farmers spray insecticides every 3-5 days, while in Ethiopia, farmers are restricted to just 2-3 applications of insecticide in an entire season.

Table 1. Common pesticides used in the literature.

Active Ingredient	Study	Vegetables	Application rate range (kgs of a.i./ha/ application)	Manufacturer's recommended per-application dose*	Possible yearly range kgs/ha/ year***
Endosulfan (II)	Sibanda et al., (2000)	Tomatoes and Kale	0.20-0.67	0.70	
	Ntow (2008)	Mixed vegetables	0.04-1.00 and 0.02-0.80		0.12-12
Dimethoate (II)	Sibanda et al., (2000)	Tomatoes, cabbages, and fava beans	0.40-0.61	0.38	
	Ntow (2008)	Mixed vegetables	0.04-0.08		0.24-0.96
Mancozeb (U)	Sibanda et al., (2000)	Tomatoes	0.27	2.00	
	Ntow (2008)	Mixed vegetables	0.04-0.09		0.24-1.08
Lambda-cyhalothrin (II)	Sibanda et al., (2000)	Kale	0.06	0.012	
	Ntow (2008)	Varied	0.01-0.02		0.06-0.24
	(Ntow et al., 2006)	Tomatoes and peppers	0.004		
Chlorpyrifos (II)	Ntow (2008)	Varied	0.04-0.06	0.024	0.24-0.72
	Ntow (2006)	Tomatoes and peppers	0.02-0.04		0.12-0.48
Carbofuran (Ib)	Ntow (2008)	Varied	0.06-0.09	N/A	0.36-1.08
Cypermethrin (II)		Varied	0.02-0.6	N/A	0.12-0.72

*Manufacturer's recommended dose based on Sibanda et al., (2000) or Ntow et al., 2006. **Carbofuran included due to its high toxicity status. ***Refers to Ntow (2008) references, where there were 6-12 applications over the course of the year.

We have only found a few studies that report pesticide purchase or application rates per hectare. Most recently, Dabrowski (2015) published a series of GIS maps estimating a range of application rates for multiple pesticides by district in South Africa. Some other studies, that report application rates by crops, are reported in table 1. Sibanda et al. (2000) report that smallholder tomato and kale farmers in Zimbabwe use endosulfan (II) at rates ranging from 0.20 to 0.67 kgs per hectare per application, while Ntow (2008) reports that vegetable farmers in Ghana use it at widely varying rates of 0.02 to 1 kgs per hectare per application. Only in a few cases are the applications above the manufacturer's recommended dose of 0.70 kgs per hectare. The same author also reports carbofuran (Ib), a "highly hazardous" pesticide, being used by farmers at a rate of 0.06-0.09 kgs per hectare.

Sibanda et al. (2000) report dimethoate (II) is applied on tomatoes, cabbages, and fava beans at rates ranging from 0.40 – 0.61 kgs per hectare, above the manufacturer's recommended application dose of 0.38 kgs per hectare, while Ntow (2006, 2008) reports these rates to be much lower in Ghana, ranging from an acceptable 0.04 to 0.08. Sibanda et al. (2000) reports lambda cyhalothrin (II) used at a rate of 0.06 kgs per hectare in Zimbabwe – above the manufacturer's recommended dose of 0.01 kgs per hectare, while Ntow (2006, 2008) finds these rates to be much lower in Ghana, again, 0.004 kgs per hectare on tomatoes and peppers in 2006 and 0.01-0.02 kgs per hectare on various crops in 2008. Ntow (2006, 2008) reports chlorpyrifos (II) to be in use at a rate ranging from 0.02-0.04 kgs per hectare on tomatoes and peppers in 2006, and 0.04-0.06 kgs per hectare on various crops in Ghana in 2008. Mancozeb (U) is also used, a fungicide that is "unlikely to present acute hazard," but a carcinogen nonetheless.

Another study by Nonga et al. (2011) on agrochemical use by mainly maize, rice, banana, and vegetable farmers in the Manyara basin of Tanzania also reports pesticide use. Unfortunately, it cannot be directly compared with the other studies (or our results) because the units are given in average quantities of product used per year, but not by hectare. Nonetheless, the study is noteworthy due to the large number of pesticides reported in use, most of which contain WHO class II active ingredients. One exception is Furadan, a product containing carbofuran (Ib), which is reportedly used in average total yearly amounts of 254 kgs (of those using).

Abang et al. (2013) report the percentage of farmers in the tropical region of Cameroon purchasing different ranges of pesticide quantity each year - again not by hectare - finding that 32% of farmers buying liquid pesticide purchased 5 to 9 liters of pesticides each year, while 18% of farmers buying pesticide products in solid form purchased 10 to 49 kgs of product each year; 10% of farmers applied more than 49 kgs each year. They also separately list particular pesticides purchased in each region, and find that highly toxic pesticides are occasionally used (like carbofuran) but moderately toxic pesticides are the most commonly used.

2 DATA AND METHODS

2.1 Initial Data and Regressions

We build on the work of Schreinemachers and Tipraqsa (2012) to explore additional correlates of pesticide use, and to develop reasonable expectations of the trends of pesticide use in d-SSA over the next three decades under three income growth scenarios. We calculate pesticide use intensity by dividing total pesticide use (in quantity of active ingredient contained) by hectares of arable and permanent cropland. The data is incomplete or missing for some countries. For example, the data for China is missing completely, and the data for South Africa is missing after the year 2000.

We exclude a number of countries and years from the analysis due to problems in how the data is reported. For example, pesticide use is reported as formulated product instead of active ingredient in a number of cases, including in Bolivia, Mexico, Mali, Ghana after 2001, and Chile for all years except 1999 and 2004. In other cases, pesticide use does not include private use (Macedonia and Mauritania), or is only reported for non-agricultural purposes (Slovenia and Belgium). Unlike Schreinemachers and Tipraqsa (2012), we do not exclude small countries ("agricultural area below 10,000 hectares") because, in our estimation, they offer important variation in the data. We also do not exclude apparent outliers or data that appeared to represent a break from one year to the next. With no consistent way to differentiate data problems from actual shifts in pesticide use due to some exogenous shock, e.g. a policy shock banning a popular but dangerous pesticide, we cannot not justify excluding this information.

After dropping additional observations due to missing explanatory data (e.g. income); the total regression utilizes 1,342 country and year-specific observations, 218 from SSA, 163 from Asia, 142 from the Middle East and North Africa, 16 from North America, and 217 from Latin America. Europe (including Eastern and Western) is best represented with 586 observations. Table A.2 in the appendix reports the countries and years included in the regression and their income classification as of 2012. There are 19 countries in the dataset that are classified as low income in 2012, 15 of them from SSA. Ideally there would be more observations from other continents for low- income countries. Note, however, that a number of countries were reclassified from low-income to lower-middle-income since 1990, so over the entire period of analysis there have been more than 19 low-income countries, including others outside of SSA.

The dependent variable is pesticide use intensity (and sub-divided into insecticide, herbicide, and fungicide use intensity), while the independent variables are total population and urban share of population from the UN Urbanization Prospects -- 2014 revision, agricultural share of GDP, and GDP per capita in constant 2011 international dollars, both from the World Bank Development Indicators database. The dependent variable is pesticide use intensity (and sub-divided into insecticide, herbicide, and fungicide use intensity), while the independent variables are total population and urban share of population from the UN Urbanization Prospects – 2014 revision, agricultural share of GDP, and GDP per capita in constant 2011 international dollars, both from the World Bank website.

To control for continental level unobserved fixed effects, we include continental dummy variables (excluding the continent of Asia and, since we are interested in d-SSA, excluding South Africa). We also control for the time trend. We run four log-log regressions, one predicting total pesticide use per hectare of land under crops, and the other three separately predicting insecticide, herbicide, and fungicide/bactericide use per hectare. Our log-log specification has the added benefits of capturing non-linearities in the data and the coefficients can be interpreted as elasticities - the percentage change in pesticide use due to a 1% change in each variable, holding all other variables constant.

2.2 Pesticide Use Projections

We use the regressions' coefficients to project pesticide use in d-SSA and its composite regions (East Africa, West Africa, etc.) through 2040, using projected mean continental and regional values for each determining variable.

The baseline growth scenario assumes a purchasing power parity (PPP) per capita income growth equal to the compounded average growth rate from 2000-2013, reaching $7,034 by 2040. The high and low growth scenarios assume future growth rates of 50% more and 50% less than the baseline, reaching $10,959 and $4,481 by 2040, respectively. Agricultural share of GDP is projected using a global level-log model of agricultural share regressed against income, which seemed to provide a good fit within the d-SSA income range, and had an R-square of about 0.73, significant at the 1% level.

2.3 Household Survey Analysis

In addition to an analysis of the global correlates of pesticide use, we also summarize the literature of pesticide use in SSA and present and analyze new evidence from Zambia and Mozambique, which includes estimated annual pesticide purchase rates by type and toxicity classification, information that we do not find elsewhere. This evidence comes from recent agricultural household surveys conducted in Zambia and Mozambique in 2012 and 2013 respectively.

In Zambia, we sampled farming households growing horticultural products in areas supplying the capital city of Lusaka. Lists of such farmers were developed in three steps. First, we identified farmers visiting the Soweto wholesale market in Lusaka and obtained their contact information. Second, we interviewed traders working at the wholesale market to generate names of additional farmers with whom they dealt. Following consolidation of these lists, we visited known production areas, met with farmers who had been identified in the previous steps, and used their knowledge to add additional names of farmers selling into Lusaka. This procedure produced a total list of over 400 farmers, from which 263 were selected using systematic random sampling.

In Mozambique, we sampled farming households from the horticultural production areas primarily supplying the capital city of Maputo, composed of both the peri-urban areas normally referred to as the zonas verdes or “green zone” (GZ) and the nearby districts of Moamba and Boane (M/B). The sample frame for the zonas verdes was developed using lists of farmers’ associations operating in the zones, followed by visits to each association to develop a more complete list. In M/B, two processes were followed. First, farmers in the irrigation areas were identified through lists residing in the district agricultural offices. Second, production zones along the rivers were identified on maps followed by visits to those areas to complete the lists. In each case, farmers were selected using systematic random sampling. Due to the distinctly different production systems in each of these two areas, the sample was stratified to individually represent all small producers (those with less than 5 hectares of cultivated land with horticultural crops) in each area, with sample sizes of 344 for the GZ and 272 for M/B.

Clearly, smallholder farmers are not a homogenous group in either of these countries. Our data show considerable variation across households in most of our variables including production activities, market access, asset ownership, education, and household demographics. In order to further disaggregate the data, we employ a cluster analysis to create groups of farmers within each country that are statistically similar across several indicator variables. Table 2 shows the number of observations in each cluster, while the complete list of variables used to create clusters in each country can be found in table A.3 in the appendix along with definitions and summary statistics for Mozambique and Zambia separately.

Table 2. Cluster descriptives by country.

	Number of variables used in creation	Total observations used in clusters	# of observations in each cluster			
			Cluster 1	Cluster 2	Cluster 3	Cluster 4
Mozambique	32	616	62	209	228	117
Zambia	25	220	112	49	59	NA

Cairns et al., (2013) provide a description of the clustering methodology applied to the data from Mozambique and we follow a similar strategy in the case of Zambia, defining clusters across three main categories: 1) knowledge and access to information, 2) technology use, and 3) production and marketing behaviors. The same or similar variables are used to create clusters in both countries, but given that the data collection instruments were not identical in each survey, the variable sets also differ accordingly. Mozambique's larger sample of 616 horticultural producers is defined by four clusters, whereas Zambia's sample of 220 horticultural producers is defined by three. We order the clusters in each country so that cluster one represents the lowest average variable values (e.g., lowest access to extension services or least horticultural crop sales diversity) and cluster three in Zambia and cluster four in Mozambique represent the highest average variable values in each country. Thus we will refer to the higher cluster farmers as having "higher capacity" than lower cluster farmers. Note that as the clusters are created separately for each country, there is no direct comparability between clusters in Zambia and Mozambique. For illustration, cluster two in Zambia is not intended for comparison with cluster two in Mozambique, but, rather, for comparison with clusters one (generally less technologicially advanced than group two) and three (generally more technologically advanced than group two) in Zambia.

3 RESULTS

3.1 Global Determinants and Projected Trends in Pesticide Use

Table 3 presents the regression results estimating the correlates of pesticide application rates on a global scale. Income and population are positive and significantly correlated with pesticide use, while the agricultural share of GDP is negative and significantly correlated. These are mostly expected results: larger and more wealthy countries that experience higher yields tend to use more pesticides, while countries that have a higher share of their GDP devoted to agricultural production tend to use less pesticide (and less inputs overall).

Table 3. Global Determinants of Pesticide (active ingredient) Application Rates 1990-2012.

Log urban share	-0.369***	-0.259*	-0.141	-0.553***
Log population	0.140***	0.189***	0.184***	0.217***
Log income	0.474***	0.454***	0.909***	0.450***
Log ag share of GDP	-0.448***	-0.417***	-0.255***	-0.558***
d-SSA	-0.687***	-0.768***	-0.413**	-1.227***
North America	-0.302	-0.308	0.081	-1.308***
Latin America	2.231***	1.869***	2.800***	2.560***
Europe	0.333***	-1.193***	0.590***	1.010***
Middle East/North Africa	0.675***	0.815***	-0.083	1.038***
Log time	-0.067	-0.277***	-0.077	-0.105*
Constant	-3.706***	-5.267***	-11.092***	-5.005***
R-squared	0.555	0.3883	0.6267	0.4970

*Significance at 1% (***); 5% (**); 10% (*). Continental dummy variables – Asia is excluded, all other continental dummy variables are relative to Asia.

The regression results also show that after controlling for other factors, the level of urbanization is negative and significantly correlated with pesticide use (it is positively correlated if the other factors are not controlled for). This is perhaps surprising, but suggests that urbanization *per se* does not drive increasing pesticide use intensity – income per capita and total population have more explanatory value. There are significant and positive continental fixed effects for (relative to Asia) for Europe, Latin America and the Middle East/North Africa, while the effect for d-SSA is significant and negative (however it is significant for insecticide and fungicide/bacteriacide). This may seem counterintuitive, but it indicates that the significant drivers of increasing use have largely been accounted for in the model.

3.2 Future Trends in Pesticide Use

Figure 1 displays baseline insecticide, herbicide, fungicide/bactericide, *and* total pesticide use intensity, and total pesticide use under high and low growth scenarios.

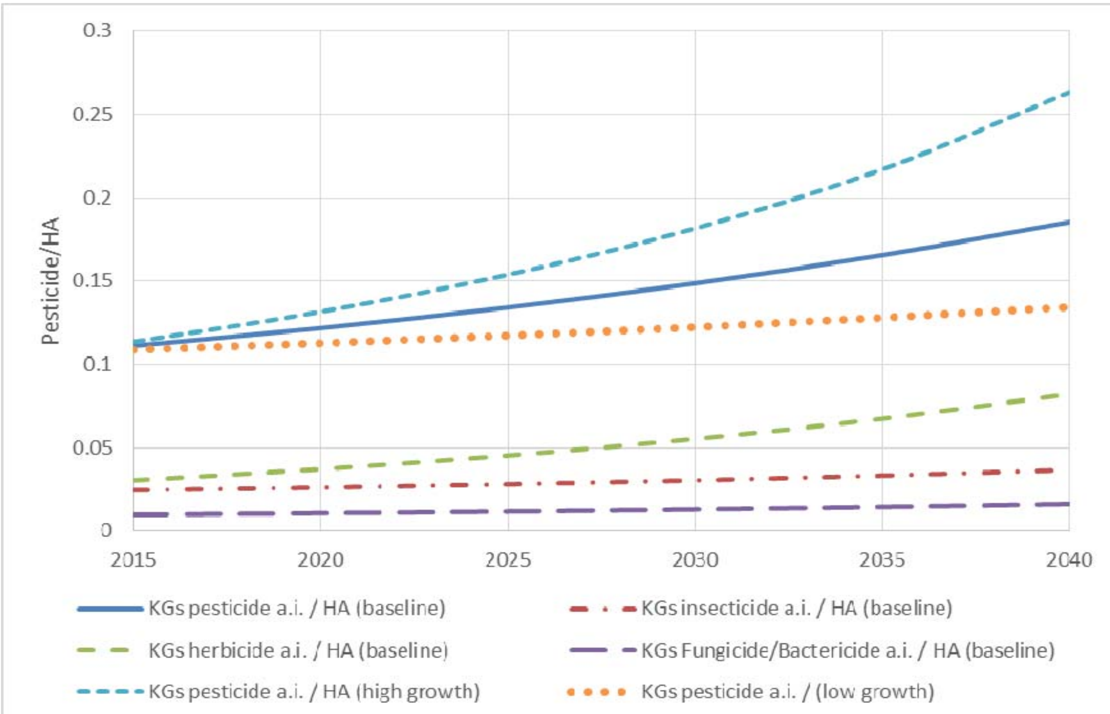

Figure 1. Predicted current and future average pesticide use in d-SSA

The predicted average pesticide application rate in 2015 is approximately 0.11 kgs/ha. Depending on the growth scenario, this is projected to increase by a factor of 1.2 to 2.3 from 2010 to 2040; it may reach up to 0.26 kgs/ha if high growth is realized, but will still be much lower than the recent middle income and high income rates of 0.8 and 2.4, respectively, reported by Schreinemachers and Tipraqsa. If baseline growth is realized (our estimate is 3.43% per year), it is projected to reach 0.19 kgs/ha.

Clearly there are major factors limiting pesticide use in d-SSA compared to the rest of the world. Some of this is captured by the d-SSA continental dummy; d-SSA uses less pesticide than what would be predicted, controlling for other variables in the model. As a thought experiment, if the continental effect is set to zero in the projection (but still controlled for in the model), pesticide use in the baseline scenario is expected to reach 0.37 kgs/ha by 2040, while pesticide use in the high growth scenario is expected to reach 0.52 kgs/ha. Another reason that d-SSA has low rates is due to the relatively high share of agricultural GDP. As a further thought experiment, if the agricultural share of GDP in 2040 is also set to the World Bank 2012 world average of 3.08% (instead of the projected d-SSA average of 16.11%), then the 2040 baseline projection for pesticide use in d-SSA is approximately 0.77 kgs/ha, very close to the average for middle income countries.

Another interesting implication from the graph is that while herbicide use intensity is currently just slightly higher than insecticide intensity, the gap will increase significantly by 2040. This may be an effect of both urbanization and income growth. The opportunity cost of labor becomes more valuable as rural inhabitants move to the city, necessitating the use of labor saving inputs like herbicide.

Figure 2 presents the projected average pesticide use (kgs a.i. / ha) for each region in d-SSA assuming the baseline growth scenario. Overall, the predicted levels in Southern and West Africa, mainly are expected to increase pesticide use the most. East Africa is expected to increase pesticide use the least, largely due the lowest projected income growth (2.62%).

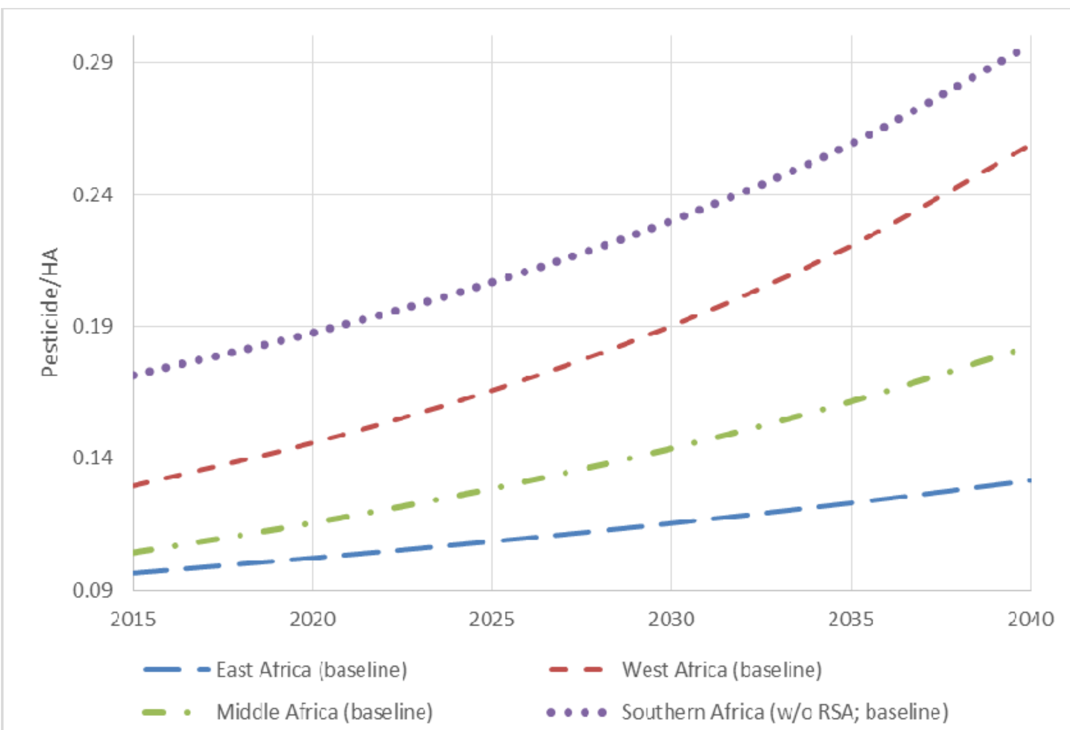

Figure 2. Projected average total pesticide use (Kgs a.i. /ha) for SSA and by region (baseline growth)

There are two important caveats and limitations to the above analysis. First, we based this analysis on total pesticide use and were not able to differentiate among toxicity levels. In developing countries, and d-SSA in particular, the toxicity of pesticides and potential for human exposure is perhaps the biggest cause for concern. Second, this is a continental and regional level analysis. Local pesticide use may differ significantly from national and continental averages, especially for certain types of crops. We will investigate this in the next section by presenting new evidence of farm-level pesticide purchase behavior among horticultural farmers in Mozambique and Zambia.

3.3 New evidence of use in Zambia and Mozambique

Smallholder horticulturalists face myriad challenges and risks in every stage of production, from input procurement to crop growth and harvesting. Table 4 highlights this point as Mozambican farmers cite multiple problems in horticulture production. They mention challenges with irrigation and several upstream input procurement issues including lack of access to inputs and low quality seed as main production problems. However, the leading response given, by a considerable margin, is pests and diseases (at 33%, over double the next major problem).

Table 4. Major factors listed as the most serious production problem by sampled farming households in Mozambique (weighted).

	Total (140 households)	Peri-urban "Green Zones" of Maputo (GZ) (80 households)	Districts of Moamba & Boane (M/B) (59 households)
Pests and Diseases	33%	34%	23%
Access to Irrigation Water	15%	15%	11%
Lack of Access to Inputs	14%	13%	16%
Theft	9%	10%	3%
Lack of Application Equipment	6%	5%	8%
Lack of Extension	5%	5%	8%
Low Quality Seeds	5%	5%	7%

Table 4 also shows a difference in responses between the GZ and the more rural M/B. For example, in the more rural M/B, access to inputs is the second-most cited problem and is only 8 percentage points below pests and diseases in relative importance, while in GZ, this difference is 19 percentage points.

Our data from Zambia corroborate our observations from Mozambique. Table 5 shows that an inability to control pests is the main reason for crop loss among Zambian farmers (46%). Farmers also cite lack of inputs and irrigation water as reasons for loss, but the gap between pests and the next major problem is even more exaggerated for crop failure in Zambia, a spread of 32 percentage points.

Table 5. Reasons for crop loss among farmers experiencing losses in Zambia.

Reason For Loss	Share of farmers
Inability to control pests	46%
Lack of fertilizer	14%
Poor quality seed	13%
Other reasons	10%
Lack of irrigation water	9%
Insufficient rainfall	9%

Pesticide use can be a very effective short-term pest control strategy, and may often be the difference between profits and losses. But pesticides also pose several risks to the health of applicators, consumers and the environment. Alarmingly, table 6 shows that large shares of farmers in each country use highly hazardous WHO Class Ib chemicals (76% and 87% in Zambia and Mozambique respectively) and moderately hazardous WHO Class II chemicals (77% and 48%, respectively). However, we observe a marked difference in the share of farmers using highly toxic chemicals across zones and countries: 76% of farmers in the rural M/B zone of Mozambique apply class Ib pesticides compared to 90% of farmers in the peri-urban GZ and 76% in Zambia. The latter may be partly attributable to the relatively higher intensity use of the land in the GZ, coupled with lower crop diversity, and hence the greater potential for evolving pest resistance and the felt need to apply a more toxic pesticide.

Table 6. Share of producers using chemicals from each toxicity class.

	Mozambique			Zambia
	GZ	M/B	Total	
WHO Toxicity Class				
Ib - Highly hazardous	90%	59%	87%	76%
II - Moderately hazardous	48%	53%	48%	77%
III - Slightly hazardous	0%	3%	1%	16%
U - Not Hazardous	52%	56%	53%	75%

Interestingly, classes Ib, II and U pesticides are used by very similar shares of farmers within Zambia, approximately 75% of each, and within the M/B area in Mozambique, approximately 55% of each. Overall pesticide prevalence is lowest in the M/B area, which is characterized by dispersed plots where many producers grow their vegetables alongside the riverbanks and often without the aid of purchased productive inputs such as chemical pesticides or fertilizer (Cairns et al. 2013).

Analysis of specific chemicals used in each country refines these results. Table 7 shows that in Zambia, there are five chemicals that are in use by at least 30% of farmers, but only three in each Mozambique region. The most commonly applied active ingredient, methamidophos (we group methamidophos and monocrotophos in Zambia) is the only class Ib chemical used in each country, but it is used by a clear majority of farmers. Producers using pesticides in the M/B have the lowest relative share of farmers using methamidophos, but the highest shares using mancozeb and cypermethrin as well as several less commonly used pesticides..

Table 7. Most used pesticide active ingredients.

	Mozambique			Zambia	WHO Toxicity Class
	GZ	M/B	Total	Total	(toxicity to humans)
Active ingredient	---- percent of producers that used ----				
Methamidophos or Monocrotophos*	90.0%	58.2%	86.6%	74.5%	Ib - Highly hazardous
Cypermethrin	34.8%	43.9%	35.8%	7.3%	II - Moderately hazardous
Acetamiprid	6.3%	1.8%	5.9%	-	
Acephate	2.2%	4.5%	2.5%	13.4%	
Endosulphan	2.0%	2.4%	2.1%	5.4%	
Copper Oxycloride	0.6%	3.9%	1.0%	16.5%	
Imidacloprid	0.0%	4.2%	0.5%	36.0%	
Lambda-cyhalothrin	-	-	-	31.4%	
Mancozeb	40.3%	50.9%	41.4%	47.5%	U - Not Hazardous
Abemectin	20.6%	12.8%	19.7%	38.3%	

***Mozambique data show use of methamidophos exclusively and Zambia data show use of methamidophos as well as moncrotophos. Both pesticides are highly toxic, so we combined them to compare highly hazardous chemical usage across countries.

Table 8 shows the differences in toxicities used on major crops: tomatoes, kale, cabbage, and onions. In this analysis, chemical shares are not weighted by the volume of active ingredient used; we implicitly gave an equal weight to each chemical that a farmer applied. Furthermore, there is not much difference in the toxicity composition across crops. For example, in the GZ, which has the most toxic composition of chemicals, WHO class Ib chemicals are used 44% of the time on tomatoes (low) and 55% of the time on onions (high). In M/B and in Zambia, WHO class Ib chemicals are used most often on kale (38% and 39%, respectively), but not by a large margin. Class Ib chemicals are used on tomatoes 26% of the time in Zambia and used on onions 29% of the time in the M/B region of Mozambique.

Table 8. Toxicity shares of chemicals applied to each crop.

Country	Crop	WHO Pesticide Toxicity Classification				
		Ib	II	III	U	Could not identify
Zambia	Tomato	26%	35%	4%	34%	12%
	Kale	39%	39%	4%	18%	12%
	Cabbage	30%	36%	5%	28%	5%
	Onion	32%	36%	0%	32%	0%
Mozambique (M/B)	Tomato	33%	35%	1%	31%	N/A
	Kale	38%	32%	1%	29%	N/A
	Cabbage	31%	34%	2%	33%	N/A
	Onion	29%	41%	0%	30%	N/A
Mozambique	Tomato	44%	26%	0%	30%	N/A
	Kale	51%	24%	0%	25%	N/A
	Cabbage	46%	27%	1%	26%	N/A
	Onion	55%	28%	0%	17%	N/A

In table 9 we estimate the annual median purchase rate of pesticide per household. The most striking result is that the purchase rate of active ingredient is approximately 16 times higher in GZ compared to M/B in both the share of pesticides purchased for horticultural crops and for all crops more generally.

Table 9. Median annual PURCHASE amount of product and active ingredient per household, among those using.*

	Estimated pesticides applied to horticultural crops		Estimated pesticides applied to all crops	
	Median Product / Avg ha cultivated with horticulture	Median A.I. / Avg ha cultivated with horticulture	Median Product / Total Ha	Median A.I. / Total Ha
Moamba/Boane	2.00	0.32	0.89	0.15
Green Zones	47.00	5.08	25.35	2.44
Both	40.73	4.23	20.57	1.92

*Units are in either liters or kgs, these are used interchangably. Land cultivated with horticultural crop is the average between cool and hot seasons of the year.

We can also compare the total pesticide results to the projected results displayed earlier. The projected 2040 baseline level of pesticide use (in active ingredient) is 0.14 kgs/ha in East Africa and 0.32 kgs/ha in Southern Africa, both of which are much lower than the recent median purchase rate among horticultural farmers in the GZ, although in line with the amounts purchased by the producers in M/B. The pesticide purchase intensity represented by the producers in GZ would confirm the observation by Williamson et al. (2008) that horticultural production is the most pesticide intensive activity of all crops. However it is also important to note that the farmers selected for this study were chosen specifically because they farm in the areas within Mozambique that primarily supply the vegetable markets of Maputo city, and as such, we could expect these producers to use more pesticides than the average farmer in Mozambique or the broader region.

All of this points to the fact that, while pesticide use in d-SSA might be lower than in other parts of the world, there is significant regional and crop variation. In addition, the composition and toxicity of pesticide use matters. Table 10 displays the median quantities of specific chemical purchases per hectare on horticultural crops among those using each chemical in Mozambique.

Table 10. Median annual PURCHASE share of product applied to horticulture and active ingredient per average hectare cultivated with horticultural crops per chemical among those using the respective chemical in the Mozambique study.

Chemical	Observations	Median Annual Product	Median Annual Active Ingredient	Estimated Mean Annual Application Range (a.i.) in Ghana (Ntow 2008)
Methamidophos (L)	526	22.2	1.1	
Cypermethrin (L)	234	16.0	2.4	0.1-0.7
Mancozeb (kg)	268	14.5	11.6	0.2-1.1
Abamectin (L)	106	23.6	1.9	
Acetamiprid (L)	29	29.6	6.5	
Profenofos (L)	18	24.0	12.0	
Fipronil (L)	14	6.2	--	
Imidacloprid (L)	11	3.1	2.2	
Acephate (kg)	19	5.2	3.9	
Endosulphan (L)	14	22.9	8.0	0.1-12.0

*Units are in either liters or kgs, these are used interchangeably. Hectares represent the average land cultivated with horticultural crop between cool and hot seasons of the year.

The small relative volume of active ingredient per hectare used for methamidophos stands out immediately. Farmers purchase methamidophos almost twice as often as any other chemical, but the median application rate is only 1.1 units/ha. Three chemicals show much higher median volumes than the rest; endosulphan, profenofos and mancozeb. Endosulphan and profenofos have the two of the highest median purchase amounts per hectare and are both WHO class II, moderately hazardous, chemicals.

The results from table 10 can be selectively and cautiously compared to the results from table 1 summarizing the literature. Selectively, because only Ntow (2008) presents the results for three common pesticides used in Mozambique – cypermethrin, mancozeb, and endosulphan - and cautiously because the results are showing slightly different measures – mean annual application rate compared to median annual purchase rate in two different countries, Ghana and Mozambique. In each case the median level in Mozambique is above the mean range in Ghana. This is most pronounced for mancozeb (11.6 compared to 0.2-1.1 kgs/ha) and least pronounced for endosulphan (8.0 compared to 0.1-12.0 kgs/ha).

When we disaggregate our pesticide purchase data for Mozambique by clusters (shown in table 11, with 1 indicating "low technological capacity" and 4 indicating "high technological capacity") we see a general, though not consistent, trend of decreasing pesticide application rate from low to high clusters. In particular, cluster 4 farmers purchased less active ingredient than the farmers in all other clusters for each pesticide. Clusters 2 and 3 are primarily composed of producers in the GZ where smaller plots are farmed very intensively, explaining the sometimes higher averages in these two clusters (notably of mancozeb and cypermethrin) compared to cluster 1, which is primarily composed of producers in M/B.

Table 11. Pesticide A.I. per hectare - among those using - across clusters.

Mozambique	Clusters			
	1	2	3	4
	A.I. purchased per hectare			
Methamidophos (L)	1.6	1.2	1.1	0.6
Cypermethrin (L)	2.0	2.6	2.6	1.1
Mancozeb (kg)	10.4	22.4	10.9	4.4
Abamectin (L)	7.2**	1.8	1.9	0.9

*Units are in either liters or kgs, these are used interchangeably. Hectares represent the average land cultivated with horticultural crop between cool and hot seasons of the year. **This median represents only 9 cases, and hence should be interpreted cautiously. ***Only four pesticides are shown due to very low numbers of observations per cluster for the other pesticides.

The general downward trend of pesticide purchases across increasing technological capacity clusters is related to the shift of higher capacity farmers towards a more diversified portfolio of chemicals, with the exception of those producing kale in both countries (see table 12). More advanced farmers are likely to be more discriminating in their pesticide purchases and apply a more diversified pesticide regimen, relying less on any single product.

Table 12. Average number of pesticides used on specific crops among those growing.

Crop	Mozambique					Zambia			
	Clusters					Clusters			
	1	2	3	4	All	1	2	3	All
	Mean number of pesticides used among those growing each crop								
Tomato	0.7	0.7	1.3	1.8	1.2	3.6	4.0	5.7	3.8
Kale	1.4	1.6	2.4	1.9	1.9	1.9	1.9	1.7	1.9
Cabbage	1.3	1.0	2.2	2.1	1.8	0.1	0.6	0.8	0.4
Total pesticides*	1.4	1.7	2.9	3.0	2.2	4.8	4.9	5.7	5.1

*Total pesticide numbers are averages across ALL households producing horticultural crops, not limited to those using pesticides.

We also observe a large difference across countries in the number of chemicals used – in Zambia they use, on average, 5.1 different chemicals, while in Mozambique the average is 2.2 different chemicals. Interestingly, the analysis shows a large difference in pesticide use across crops in Zambia, but not in Mozambique. In particular, Zambian producers used nearly two more pesticides on tomatoes than kale, while Mozambican producers use, on average, 0.7 more pesticides on kale than tomatoes.

4 CONCULSIONS AND IMPLICATIONS

While the FAO data indicates that d-SSA farmers, in general, use pesticide at a lower rate than the rest of the world, the devil is in the details. First, household level evidence from Mozambique suggests that commercialized horticultural farmers in the peri-urban GZ use 46 times the rate of active ingredient on horticultural crops than the predicted d-SSA average in 2015 (of all farmers across all crops), and more than double the rate that Schreinemachers and Tipraqsa report for high income countries across all crops. Second, horticultural farmers more generally, who will continue to grow in relative share due to the diet transformation, appear to use 20 times the active ingredient pesticide rates on their horticultural crop than the predicted continental average on all crops generally in d-SSA in 2040. Third, farmers in both countries used highly toxic chemicals (WHO class Ib) with astonishing regularity: 87% and 76% of farmers in Mozambique and Zambia, respectively, a point that should be qualified by pointing out that the absolute quantities of active ingredient in these chemicals were relatively lower than other pesticides. Fourth, there are considerable differences across farmer types and risk profiles. In both Zambia and Mozambique, we observe that more technologically advanced farmers generally purchase a more diverse set of pesticides, and in Mozambique, we can see that these producers use smaller per-hectare quantities of any given one. In addition, they use roughly half the rate of methamidophos - a “highly toxic” pesticide - than the least technologically advanced farmers. And finally, that d-SSA is projected to increase pesticide use by a factor of 1.24 to 2.32 by 2040 (from 2015) is worrisome given that the regulatory environment is weaker and smallholder farmers often do not take adequate safety precautions, and are thus vulnerable to associated short and long term illnesses. The extent of pesticide exposure and vulnerability to illness is currently being tested with further empirical evidence among Mozambican producers.

Clearly pesticide exposure, especially among horticultural farmers, is a growing concern in SSA. Addressing this concern will require better coordination in the horticultural supply chain and the food marketing system, which despite rapid modernization overall, still largely takes place within the traditional sector. There are a number of challenges making behavioral change difficult in the informal market, including the difficulty of verifying the safety of food sold at informal markets through simple visual inspection, and the difficulty of monitoring the behavior of the numerous actors involved in the food supply chain.

Achieving behavioral change is much more straightforward in modern supermarket chains, which emerged in South Africa and have started to spread throughout ESA. These large retailers depend on consistent quantity and quality of supply, which they tend to procure through imports and the use of long-term contracts with large and well-capitalized farms, where it is much easier to monitor farmer activity, streamline production processes, and control some of the inputs of production. Supermarket chains have also been known to complement this “preferred supplier” system by buying products from local wholesale markets (for an example in Kenya, see Neven and Reardon, 2004), but this is generally seen as a backup strategy, one that is not highly publicized due to safety concerns. Despite their rapid emergence in the last three decades, supermarket chains currently control a relatively small market share throughout ESA (Tschirley et al., 2013).

Consumer demand can also drive behavioral change in the food system, but evidence suggests that urban consumers in SSA are largely unaware of the dangers of pesticide residue (Probst et al., 2010), making it unlikely that they would be willing to pay a premium in the short run for certification schemes promising the absence or negligibility of harmful chemical residues. As evidence from developed countries suggests, this is likely to slowly change in the future as rising educational levels and incomes lead urban consumers to become more aware of food safety and more willing and able to pay for it. For example, Batte et al. (2007) find that consumers in Ohio are willing to pay an average premium of $0.33/box at traditional grocery stores and $0.50/box at specialty stores for pesticide-free breakfast cereals. Additional studies have shown that anywhere from 21-66% of consumers are willing to pay at least a 6% premium for pesticide-free produce (see table 13). Fu et al. (1999) find that, if consumers in Taiwan are explicitly informed that the risk of developing cancer over a lifetime from eating bok choy with pesticide residues is 0.01%, consumers are willing to pay a 46% premium to reduce the risk by 25%, a 56% premium for a 50% reduction, and a 75% premium for a 90% reduction.

Table 13. Willingness to pay (WTP) a price premium for pesticide-free produce in other countries

Study	Location	Product	Not WTP or not sure	WTP ≤ 5%	WTP 6-10%	WTP 11-20%	WTP > 20%
(Boccaletti and Nardella 2000)	Italy	Fresh fruit and vegetables	11%	23%	34%	21%	11%
(Cranfield and Magnusson 2003)	Canada	Food products	18%	38%	29%	10%	5%
(Misra, Huang, and Ott 1991)	USA	Fresh produce	55%	25%	15%	6%	0%

In the short run, immediate action can be taken by governments to ban the use of highly toxic pesticides. Some progress has been made on this front; Mozambique, for example, has recently officially banned the use of methamidophos, although it is taking some time for this ban to be fully enforced. Restricting access to dangerous pesticides, however, must be coupled with the provision of access to less harmful but equally effective pesticides and/or training in integrated pest management (IPM) strategies to reduce the pesticide application volumes overall.

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APPENDICES

Appendix A.1. Proportion of sample farmers using different active ingredients.

Active Ingredient	WHO Toxicity Class	Proportion of farmers using this product (sample size)***	Country	Crops	Citation
Alpha-cypermethrin	II	.188 (112)	Botswana	tomato, brassicae	Obopile et al., 2008
Anilazine	O	.03	Tanzania	coffee	Ngowi et al., 2001
Atrazine	III	.647 (150)	Nigeria	varied	Oluwole & Cheke, 2009
Atrazine + gramoxone	--	.253 (150)	Nigeria	varied	Oluwole & Cheke, 2009
Atrazine, primextra	--	.227 (150)	Nigeria	varied	Oluwole & Cheke, 2009
Avermetin	--	.036 (112)	Botswana	tomato	Obopile et al., 2008
Apron Star*	III	.473 (150	Nigeria	varied	Oluwole & Cheke, 2009
Azodrin	--	.136 (168)	Malawi	varied	Nyirenda et al., 2011
Carbaryl	II	.062 (168)	Malawi	varied	Nyirenda et al., 2011
		.054 (112)	Botswana	tomato, cabbage	Obopile et al., 2008
Copper hydroxide	II	.06	Tanzania	coffee	Ngowi et al., 2001
Copper oxide	II	.05	Tanzania	coffee	Ngowi et al., 2001
Copper oxychloride	II	.044 (168)	Malawi	varied	Nyirenda et al., 2011
		.091 (91)	Zambia	varied	
		.018 (112)	Botswana	cabbage	Obopile et al., 2008
		.08	Tanzania	coffee	Ngowi et al., 2001
Copper sulfate	II	.907 (150)	Nigeria	varied	Oluwole & Cheke, 2009
Copper sulfate, ridomil, lime	--	.867 (150)	Nigeria	varied	Oluwole & Cheke, 2009
Chlorfenapyr	II	.045 (112)	Botswana	tomato, cabbage	Obopile et al., 2008
Chlorothalonil	U	.039 (168)	Malawi	varied	Nyirenda et al., 2011
		.06	Tanzania	coffee	Ngowi et al., 2001
Chlorpyrifos	II	.125 (112)	Botswana	tomato, cabbage	Obopile et al., 2008
		.21	Tanzania	coffee	Ngowi et al., 2001
		.02 (50)	Uganda	hot peppers	IPM CRSP, 2007**
Cypermethrin	II	.227 (168)	Malawi	varied	Nyirenda et al., 2011
		.536 (112)	Botswana	tomato, onion, brassicae	Obopile et al., 2008
		.36 (50)	Uganda	hot peppers	IPM CRSP, 2007
Deltamethrin	II	.018 (112)	Botswana	brassicae, onion	Obopile et al., 2008
Demeton-s-methyl	Ib	.027 (112)	Botswana	brassicae	Obopile et al., 2008
Diazinon	II	.027 (112)	Botswana	butternut, onion	Obopile et al., 2008
		.367 (150)	Nigeria	cacao	Sosan & Akingbohungbe 2009
Dichlorvos	Ib	.018 (112)	Botswana	brassicae	Obopile et al., 2008
Dicofol	II	.063 (112)	Botswana	tomato	Obopile et al., 2008
Dimethoate	II	.029 (168)	Malawi	varied	Nyirenda et al., 2011
		.170 (112)	Botswana	brassicae, onion	Obopile et al., 2008
		.52 (50)	Uganda	hot peppers	IPM CRSP, 2007
Endosulfan	II	.018 (112)	Botswana	tomato, onion, cabbage	Obopile et al., 2008
		.03	Tanzania	coffee	Ngowi et al., 2001
		.14 (150)	Nigeria	cacao	Sosan & Akingbohungbe 2009
Fenitrothion	II	.25	Tanzania	coffee	Ngowi et al., 2001
Fenthion	II	.027 (112)	Botswana	butternuts	Obopile et al., 2008
Fenvalerate	II	.045 (91)	Zambia	varied	Nyirenda et al., 2011
		.54 (50)	Uganda	hot peppers	IPM CRSP, 2007**
Glyphosate	III	.28 (150)	Nigeria	varied	Oluwole & Cheke, 2009
Gramoxone, primextra	--	.693 (150)	Nigeria	varied	Oluwole & Cheke, 2009
Lambda cyhalothrin	II	.109 (168)	Malawi	varied	Nyirenda et al., 2011
		.035 (91)	Zambia	varied	
Lindane	II	.227 (150)	Nigeria	varied	Oluwole & Cheke, 2009
		.693 (150)	Nigeria	cacao	Sosan & Akingbohungbe 2009
Malathion	III	.024 (91)	Zambia	varied	Nyirenda et al., 2011
		.500 (112)	Botswana	butternuts, brassicae, onion	Obopile et al., 2008
Mancozeb	U	.056 (168)	Malawi	varied	Nyirenda et al., 2011
		.042 (91)	Zambia	varied	

		.098 (112)	Botswana	swiss chard	Obopile et al., 2008
		.06 (50)	Uganda	hot peppers	IPM CRSP, 2007**
Methomyl	Ib	.071 (112)	Botswana	brassicae, tomato	Obopile et al., 2008
Metolachlor	III	.867 (150)	Nigeria	varied	Oluwole & Cheke, 2009
Monocrotophos	Ib	.414 (91)	Zambia	varied	Nyirenda et al., 2011
		.78 (150)	Nigeria	varied	Oluwole & Cheke, 2009
Paraquat	II	.987 (150)	Nigeria	varied	Oluwole & Cheke, 2009
Parathian	Ia	.252 (168)	Malawi	varied	Nyirenda et al., 2011
		.018 (112)	Botswana	cabbage, onion	Obopile et al., 2008
Profenofos	II	.18	Tanzania	coffee	Ngowi et al., 2001
Propiconazole	II	.03	Tanzania	coffee	Ngowi et al., 2001
Propoxur	II	.027 (150)	Nigeria	cacao	Sosan & Akingbohungbe 2009
Resmethrin	III	.017 (91)	Zambia	varied	Nyirenda et al., 2011
Ridomil, mancozeb,metaxyl	II	.873 (150)	Nigeria	varied	Oluwole & Cheke, 2009
Roundup, primextra	--	.06 (150)	Nigeria	varied	Oluwole & Cheke, 2009
Sulfur	III	.1 (50)	Uganda	hot peppers	IPM CRSP, 2007**
Triadimefon	II	.04	Tanzania	coffee	Ngowi et al., 2001
Trichlorfon	II	.018 (112)	Botswana	tomato	Obopile et al., 2008
Vakanona	--	.08 (91)	Zambia	varied	Nyirenda et al., 2011
2,4-D amine	II	.267 (150)	Nigeria	varied	Oluwole & Cheke, 2009

*Apron star is composed of (metalaxy+ difenoconazone+ thiamethoxam); **the source IPM CRSP, 2007 as cited and adapted by Karungi et al; ***proportions less than .015 were excluded.

Appendix A.2. Countries, continents, and years included in the regression, by World Bank income classification for 2012.

Country	Continent	Years available	Income Classification
Bangladesh	Asia	1990-2000, 2009-2010	Low Income
Nepal	Asia	1995, 2004-2009	Low Income
Kyrgyzstan	Middle East	1992, 2000-2011	Low Income
Tajikistan	Middle East	1993-1996, 2004-2011	Low Income
Burundi	D-SSA	1992-2005	Low Income
Central African Republic	D-SSA	1994-1995	Low Income
Democratic Republic of the Congo	D-SSA	1990, 1993-1996	Low Income
Ethiopia	D-SSA	1995-1996, 1998, 2000-2001, 2005-2010	Low Income
Gambia	D-SSA	1992-1993, 1996, 2004-2005, 2007	Low Income
Guinea	D-SSA	1992-1997, 2009	Low Income
Kenya	D-SSA	1994-1997	Low Income
Madagascar	D-SSA	1990-2009	Low Income
Malawi	D-SSA	2007-2009	Low Income
Mozambique	D-SSA	1994-1997, 2002-2011	Low Income
Rwanda	D-SSA	1992, 1997-1998, 2000-2001, 2003-2004, 2007-20011	Low Income
Tanzania	D-SSA	1994-1995, 1997	Low Income
Togo	D-SSA	1990-1996, 2003-2010	Low Income
Uganda	D-SSA	1992-1995	Low Income
Zimbabwe	D-SSA	1990-1992, 1995-1998	Low Income
India	Asia	1990-1999, 2003-2010	Lower-Middle Income
Indonesia	Asia	1990-1993	Lower-Middle Income
Lao PDR	Asia	1997-1998, 2000, 2007, 2009	Lower-Middle Income
Papua New Guinea	Asia	1992-1995	Lower-Middle Income
Sri Lanka	Asia	1990-2000, 2006-2011	Lower-Middle Income
Timor-Leste	Asia	2002, 2005, 2007, 2009	Lower-Middle Income
Vietnam	Asia	1994-2001	Lower-Middle Income
Armenia	Europe	1993-1996, 2003-2010	Lower-Middle Income
Moldova	Europe	1992-1993, 2000-2011	Lower-Middle Income
Ukraine	Europe	1992, 2003-2011	Lower-Middle Income
El Salvador	Latin America	1990-2010	Lower-Middle Income
Guyana	Latin America	2004-2011	Lower-Middle Income
Honduras	Latin America	1995-2011	Lower-Middle Income
Nicaragua	Latin America	1994-2010	Lower-Middle Income
Paraguay	Latin America	1992, 1997-2001	Lower-Middle Income
Samoa	Latin America	1994-2000	Lower-Middle Income
Egypt	Middle East	1990-1993	Lower-Middle Income
Morocco	Middle East	1990, 2004-2006	Lower-Middle Income
Pakistan	Middle East	1990-2001	Lower-Middle Income
Yemen	Middle East	2002-2008	Lower-Middle Income

Cameroon	D-SSA	1995-2001	Lower-Middle Income
Cote d'Ivoire	D-SSA	1994-1996	Lower-Middle Income
Ghana	D-SSA	1995-2001	Lower-Middle Income
Senegal	D-SSA	1992-1998, 2000-2001	Lower-Middle Income
Sudan	D-SSA	1992-1997	Lower-Middle Income
Zambia	D-SSA	1994-1996	Lower-Middle Income
Malaysia	Asia	2006-2010	Upper-Middle income
Thailand	Asia	1993-2000, 2003-2011	Upper-Middle income
Albania	Europe	1993-1995	Upper-Middle income
Azerbaijan	Europe	2007-2011	Upper-Middle income
Bulgaria	Europe	1992	Upper-Middle income
Hungary	Europe	1990-2010	Upper-Middle income
Montenegro	Europe	2010-2011	Upper-Middle income
Romania	Europe	1990-2011	Upper-Middle income
Belize	Latin America	1990-1992, 1998-2001, 2006-2009	Upper-Middle income
Brazil	Latin America	1991-2001	Upper-Middle income
Columbia	Latin America	1990-2011	Upper-Middle income
Costa Rica	Latin America	1998-2011	Upper-Middle income
Dominican Republic	Latin America	1994-2010	Upper-Middle income
Ecuador	Latin America	1990-2011	Upper-Middle income
Panama	Latin America	2011	Upper-Middle income
Peru	Latin America	1995-2011	Upper-Middle income
Saint Lucia	Latin America	1997-1999	Upper-Middle income
Suriname	Latin America	1990-1991, 1995-1997, 2000, 2011	Upper-Middle income
Venezuela	Latin America	1990-1992	Upper-Middle income
Iran	Middle East	1990-1996	Upper-Middle income
Jordan	Middle East	1990-2000, 2008-2011	Upper-Middle income
Kazakhstan	Middle East	1994-1997, 2000-2007	Upper-Middle income
Lebanon	Middle East	1996-1997	Upper-Middle income
Tunisia	Middle East	1997	Upper-Middle income
Turkey	Middle East	1990-2010	Upper-Middle income
Turkmenistan	Middle East	1992-1993	Upper-Middle income
Angola	D-SSA	1992-1996	Upper-Middle income
Botswana	D-SSA	1990-1992	Upper-Middle income
Mauritius	D-SSA	1990	Upper-Middle income
Namibia	D-SSA	1990-1993	Upper-Middle income
Seychelles	D-SSA	1990-1998	Upper-Middle income
South Africa	D-SSA	1994-2000	Upper-Middle income
Australia	Asia	1990-2006	High Income
Japan	Asia	2000-2011	High Income
Austria	Europe	1990-2010	High Income
Belgium-Luxembourg	Europe	1993-1999	High Income
Croatia	Europe	1995-1996	High Income
Cyprus	Europe	1990-1997	High Income
Czech Republic	Europe	1993-2007	High Income

Denmark	Europe	1990-2011	High Income
Estonia	Europe	1995-2011	High Income
Finland	Europe	1990-2011	High Income
France	Europe	1990-2010	High Income
Germany	Europe	1990-2011	High Income
Greece	Europe	2005-2006	High Income
Iceland	Europe	1999-2009	High Income
Ireland	Europe	1994-2011	High Income
Italy	Europe	1990-2011	High Income
Latvia	Europe	1992-1998, 2000-2010	High Income
Lithuania	Europe	1992-2010	High Income
Malta	Europe	1993-2001, 2007	High Income
Netherlands	Europe	1990-2010	High Income
New Zealand	Europe	1990-2009	High Income
Norway	Europe	1990-2011	High Income
Poland	Europe	1991-2010	High Income
Portugal	Europe	1991-2011	High Income
Russia	Europe	1997	High Income
Slovakia	Europe	1993-2010	High Income
Spain	Europe	1990-2010	High Income
Sweden	Europe	1990-2011	High Income
Switzerland	Europe	1990-2011	High Income
UK	Europe	1990-2011	High Income
Antigua and Barbuda	Latin America	2010-2011	High Income
Barbados	Latin America	1993-1997	High Income
Chile	Latin America	1999, 2004	High Income
Saint Kitts and Nevis	Latin America	2000-2011	High Income
The Bahamas	Latin America	2000-2006	High Income
Uruguay	Latin America	1991-2011	High Income
Bahrain	Middle East	1993-1995	High Income
Kuwait	Middle East	1995-1996, 1998	High Income
Oman	Middle East	1990-2000	High Income
Saudi Arabia	Middle East	1996-1997, 2007	High Income
Canada	North America	1990, 1994, 1999-2006, 2008	High Income
United States	North America	1990-2007	High Income

*The World Bank defines country income classifications as follows: Low Income (<$1035); Lower-Middle Income ($1035 - $4,085); Upper-Middle Income ($4,085-$12,616); High Income (>$12,616)

Appendix A.3. Indicator variables included in cluster creations.

		Mozambique						Zambia	
		All		*Zonas Verdes*		Moamba/ Boane		All	
Mozambique Definitions	**Zambia Definitions**	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
Indicators of Experience, Training and Agricultural Information									
A family member received information from an extension agent concerning horticulture	Same	28%	0.55	29%	0.46	25%	0.42	22%	0.42
A family member received information about horticultural prices	Dummy for whether or not the HH always sells through a broker	20%	0.49	20%	0.41	21%	0.41	86%	0.35
A family member received credit for horticulture in the last 12 months. Top sources: Bank (33%), Relatives (17%), Government (14%), Association (14%)	Same	7%	0.31	7%	0.26	11%	0.31	4%	0.19
A family member participated in a training of at least three months in duration	A family member participated in a training in the past 5 years	9%	0.35	9%	0.29	11%	0.31	4%	0.20
Percent of literate adults in the family	X	70%	0.27	71%	0.22	57%	0.29		
Years of experience cultivating horticulture of the family member with the most experience in horticulture > 23 (median)	Years since first cultivated horticulture on own >median (15)	48%	0.62	50%	0.51	37%	0.49	48%	0.50
The number of years of education of the most educated adult in the family > 9 (median)	Head education > median	48%	0.61	49%	0.51	32%	0.46	42%	0.49
Diversification of Production and Sales									
Total number of horticultural crops produced > 3	Same	67%	0.57	68%	0.48	63%	0.49	17%	0.38
Total number of horticultural crops produced > 5	Same	28%	0.55	28%	0.45	33%	0.48	4%	0.19
The family sold tomato	Same	11%	0.33	7%	0.26	37%	0.47	80%	0.40
The family sold tomato in both seasons of the year	X	4%	0.21	3%	0.17	13%	0.34		
Total number of horticultural crops sold > 2	Same	72%	0.54	73%	0.45	56%	0.49	27%	0.44
Total number of horticultural crops sold > 4	Same	28%	0.55	28%	0.45	29%	0.45	9%	0.29
Input Expenditures and Farm Management Practices									
Index of seed purchase source formality (0 informal, 1 formal)	Same	0.35	0.49	0.31	0.4	0.65	0.42	91%	0.29
Percent of seed varieties used for which the producer could give the name	X	18%	0.17	18%	0.14	16%	0.17		
Pump irrigation was used in at least one horticultural field	Pump ownership dummy	7%	0.16	1%	0.09	58%	0.42	69%	0.46

Appendix A.3 cont. Indicator variables included in cluster creations.

		Mozambique						Zambia	
		All		*Zonas Verdes*		Moamba/ Boane		All	
Input Expenditures and Farm Management Practices cont.	**Zambia Definitions cont.**	Mean	Std Dev	Mea n	Std Dev	Mea n	Std Dev	Mea n	Std Dev
Value of fertilizer used > 500 MZN (median)	Travel time to reach supplier> median (90 minutes)	50%	0.61	55%	0.51	10%	0.29	50%	0.50
Value of pesticide used > 1,000 MZN (median)	Travel time to reach supplier> median (90 minutes)	52%	0.61	53%	0.51	45%	0.47	49%	0.50
Value of seed used > 2,500 MZN (median)	Travel time to reach supplier> median (90 minutes)	49%	0.07	49%	0.51	45%	0.47	51%	0.50
Employed part-time hired labor	X	90%	0.38	90%	0.32	95%	0.22		
Employed full-time hired labor	Hired labor dummy	20%	0.49	20%	0.41	24%	0.43	71%	0.46
Post-harvest activities and Crop Loss									
Selected the product before sale	X	7%	0.31	6%	0.25	12%	0.33		
Washed the product before sale	# of days waited after pesticide application prior to harvest > median (7)	9%	0.34	9%	0.29	7%	0.25	39%	0.49
Used a personal car to transport produce to sell in a market	Vehicle ownership dummy	1%	0.11	1%	0.09	4%	0.19	25%	0.44
Sold all the produce that was brought to the market (applicable in the case of tomato, cabbage, lettuce or kale)	X	15%	0.43	14%	0.36	21%	0.41		
Pesticide Management and Toxicity Awareness									
Percent of total pesticides for which respondent gave a verified correct assessment of true EPA **human** toxicity level	Same, but used WHO toxicity	44%	0.4	46%	0.33	28%	0.32	25%	0.25
Percent of total pesticides for which respondent gave a verified correct assessment of true EPA **bird** toxicity level	Same	38%	0.43	40%	0.36	25%	0.3	33%	0.24
Percent of total pesticides for which respondent gave a verified correct assessment of true EPA **fish** toxicity level	Same	21%	0.35	21%	0.29	23%	0.31	40%	0.3
Percent of total pesticides for which respondent gave a verified correct assessment of true EPA **bee** toxicity level	same	12%	0.29	12%	0.24	13%	0.23	36%	0.32

Appendix A.3 cont. Indicator variables included in cluster creations.

		Mozambique						Zambia	
		All		*Zonas Verdes*		Moamba/ Boane		All	
Pesticide Management and Toxicity Awareness cont.	**Zambia Definitions cont.**	Mean	Std Dev	Mea n	Std Dev	Mea n	Std Dev	Mea n	Std Dev
The person who applied the pesticide(s) could read the label	X	53%	0.61	54%	0.51	46%	0.49		
The person who applied the pesticide(s) used protective clothing beyond just boots (plastic overalls, mask/glasses, gloves, other)	same	48%	0.62	50%	0.51	36%	0.48	60%	0.49
Pesticides were applied in the early morning or after sunset	same	56%	0.61	58%	0.5	39%	0.48	20%	0.40