MSU International Development Working Paper

Analyzing Trends in Herbicide Use in Sub-Saharan Africa

by

Philip Grabowski and Thom Jayne

MSU International Development Working Paper 142
April 2016

Department of Agricultural, Food, and Resource Economics
Department of Economics
MICHIGAN STATE UNIVERSITY
East Lansing, Michigan 48824

MSU Agricultural, Food, and Resource Economics Web Site: http://www.afre.msu.edu/
MSU Food Security Group Web Site: http://fsg.afre.msu.edu/index.htm

MSU INTERNATIONAL DEVELOPMENT PAPERS

The Michigan State University (MSU) International Development Paper series is designed to further the comparative analysis of international development activities in Africa, Latin America, Asia, and the Near East. The papers report research findings on historical, as well as contemporary, international development problems. The series includes papers on a wide range of topics, such as alternative rural development strategies; nonfarm employment and small scale industry; housing and construction; farming and marketing systems; food and nutrition policy analysis; economics of rice production in West Africa; technological change, employment, and income distribution; computer techniques for farm and marketing surveys; farming systems and food security research.

The papers are aimed at teachers, researchers, policy makers, donor agencies, and international development practitioners. Selected papers will be translated into French, Spanish, or other languages.

Copies of all MSU International Development Papers, Working Papers, and Policy Syntheses are freely downloadable in pdf format from the following Web sites:

MSU International Development Papers
- http://fsg.afre.msu.edu/papers/idp.htm
- http://ideas.repec.org/s/ags/mididp.html

MSU International Development Working Papers
- http://fsg.afre.msu.edu/papers/idwp.htm
- http://ideas.repec.org/s/ags/midiwp.html

MSU International Development Policy Syntheses
- http://fsg.afre.msu.edu/psynindx.htm
- http://ideas.repec.org/s/ags/midips.html

Copies of all MSU International Development publications are also submitted to the USAID Development Experience Clearing House (DEC) at: http://dec.usaid.gov/

ANALYZING TRENDS IN HERBICIDE USE IN SUB-SAHARAN AFRICA

by

Philip Grabowski and Thom Jayne

April 2016

Grabowski is Research Associate in the Department of Plant, Soil, and Microbial Sciences and part of the Center for Global Change and Earth Observation and Jayne is University Foundation Professor, Department of Agricultural, Food, and Resource Economics, both at Michigan State University.

ISSN 0731-3483

Published by the Department of Agricultural, Food, and Resource Economics and the Department of Economics, Michigan State University, East Lansing, Michigan 48824-1039, U.S.A.

ACKNOWLEDGMENTS

The authors would like to thank the following colleagues for their helpful support of this work: Stephen Kabwe (IAPRI Zambia) for facilitating the linkages with NWK and Cargill, Immanuel Mbewe at Cargill Zambia and Graham Chilimina at NWK-Agriservices for their willingness to share their data on herbicide sales and prices, and Ivy Lomotey from the Ministry of Agriculture in Ghana for hunting down historic herbicide prices. The authors would also like to thank the United States Agency for International Development mission in Lusaka, Zambia (USAID/Zambia) for providing funding for this research under Michigan State University's Food Security Research Project (FSRP) and Indaba Agricultural Policy Research Institute (IAPRI). Also the authors would like to thank Patricia Johannes for her editing and formatting assistance.

EXECUTIVE SUMMARY

Chemical weed control has been researched in Africa since the 1960s but adoption has been low or non-existent for decades. Recent evidence suggests that herbicide use in some parts of Africa is reaching significant levels and may be on the rise more generally. Little is known about which farmers are using herbicides in Africa and what factors drive their use. This study aims to document trends in herbicide use and analyze the drivers of those trends in Sub-Saharan Africa.

Herbicide use rates are generally increasing but vary widely by country, from 1% in Malawi to 55% in Ghana. Kenya and Tanzania both experienced a jump in herbicide use rates from less than 2% to about 10% in 2007 and 2009, respectively. Since then both countries have seen minor reductions in herbicide use. In contrast, in Ghana and Zambia herbicide use is increasing steadily. In Ghana there has been a dramatic rise from 4% in 1998 to 55% in 2013. In Zambia there has been a moderate increase over a shorter time: from 1% in 2009 to 5% in 2013.

We used a probit model with pooled cross-sectional data from Ghana and Zambia to analyze the factors associated with household herbicide use. The results show that increased herbicide use is not associated with increased agricultural wage rates. Instead, in both Ghana and Zambia households that are male headed, have more adult workers, and own more land are more likely to use herbicides. In Ghana herbicide use is also higher among younger farmers and in communities that are farther from extension centers, where there are tractors, and where farming is the primary economic activity. In Zambia farmers were more likely to use herbicides if they had received subsidized fertilizer, if the cost of commercial fertilizer was lower, and if their previous maize price was higher. Also farmers in cotton growing areas of Zambia, and who use minimum tillage were more likely to use herbicides.

Together these results suggest that increased use of herbicides is driven by increased awareness, availability, and demand by better off, commercially oriented households. This often happens in areas where agricultural productivity is rising and where the opportunity cost of labor may be higher. This may explain why in Zambia there is a significant negative relationship between herbicide use and agricultural wages. In Ghana there was no significant relationship between wages and herbicide use. One way to interpret the insignificant effect of wages on herbicide use is that agricultural wages may always be high enough to make herbicides profitable. The use of herbicides, then, depends on their availability and farmers' ability to invest in a labor reducing technology.

Based on this analysis, herbicide use is expected to increase in areas where agriculture becomes more commercial. Policies to prepare for these changes should include training farmers on safe and effective herbicide application and monitoring for contamination in water supplies.

TABLE OF CONTENTS

LIST OF TABLES

TABLE **PAGE**

LIST OF FIGURES

FIGURE **PAGE**

ACRONYMS

AgRen	Agricultural Research and Extension Network
CA	Conservation agriculture
CFU	Conservation Farming Unit
CSO	Central Statistical Office
GLSS	Ghana Living Standards Survey
MSU	Michigan State University
IFPRI	International Food Policy Research Institute.
TAPRA	Tegemeo Agricultural Policy Research and Analysis

1. INTRODUCTION

Chemical weed control has been researched in Africa since the 1960s (e.g., Bouriquet 1961) but adoption has been low or non-existent for decades. It may be tempting to explain low herbicide use with the conventional wisdom that smallholder farmers in Africa largely do not use modern inputs because of poor infrastructure and market access. However, recent evidence from large scale surveys shows that modern input use is actually quite high in some countries in Africa (Sheahan and Barrett 2014).

In Africa, herbicide promotion increased in the mid-1990s with the rise of interest in conservation agriculture (CA). Reduced tillage under CA may result in improved soil quality, but it also makes weed control more difficult, thus making herbicides a key complementary technology (Wall 2007; Giller et al. 2009). The resulting dead layer of weeds after herbicide application may even be useful as a mulch if grazing and wildfires can be prevented (Lotter 2014). When used with conservation agriculture, herbicides have been shown to reduce labor days and reduce the risk of crop failure from weed take over (Muoni, Rusinamhodzi, and Thierfelder 2013).

Recent evidence suggests that herbicide use in some parts of Africa is reaching significant levels and may be on the rise more generally. In Ghana, recent studies have shown that herbicides were applied on 73% of maize plots (Ragasa et al. 2013), were used by 61% of yam farmers (Moro 2014), and represent 44% of all chemicals applied to vegetables (Ntow et al. 2006). Herbicide use rates are high in Ethiopia (27%) and Nigeria (21%), but less than 12% in Malawi, Tanzania, Niger, and Uganda (Sheahan and Barrett 2014). In peri-urban areas of Mali and Cote d'Ivoire, 38% of farmers used herbicides (Erenstein 2006). Industrial agriculture globally has shifted toward dependence on chemical weed control through the spraying of herbicides (Gianessi 2013).

Little is known about which farmers are using herbicides in Africa and what factors drive their use. One of the only socio-economic studies on herbicide uptake is based on a survey of 240 maize farmers in Kenya and Uganda, which found that the 3% of farmers who used herbicides were better educated, had larger farms and sold a larger proportion of their harvest (Overfield 2000).

In this paper we address this gap in the literature by documenting trends in herbicide use and analyzing the drivers of those trends. We present herbicide use rates over the past decade from five countries where we found available data from household surveys: Ghana, Zambia, Kenya, Tanzania, and Malawi. We also use pooled cross-sectional data from Zambia and Ghana to analyze the determinants of herbicide use over time.

2. HERBICIDES AS A WEED CONTROL OPTION FOR SMALLHOLDER FARMERS

The use of chemical weed control methods has the potential to significantly reduce the labor requirements for weed control (Gianessi et al. 2009). For example, in Zambia farmers saved up to 30 labor days per hectare (Goeb 2013). Improved weed control may also improve yields by removing the competition for light, water, and nutrients. In experimental trials the method of weed control has little or no effect on yields as long as the timing and thoroughness of the weeding are similar (Muoni, Rusinamhodzi, and Thierfelder 2013; Tatenda and Stanford 2013; Ishaya, Tunku, and Kuchinda 2008). However, on farmers' fields the timeliness of weed control is made difficult by competing demands for household labor early in the season (Orr, Mwale, and Saiti 2002; Haggblade, Kabwe, and Plerhoples 2011).In some cases farmers may even abandon fields where weeds have taken over (Mavudzi et al. 2001). Evidence from Nigeria suggests that herbicide use by smallholder maize farmers can increase their labor productivity and fertilizer use efficiency by providing timely and effective weed control (Mutambara et al. 2013). Similarly, in Ghana significantly higher maize yields were observed on plots where herbicides were used (Ragasa et al. 2013).

2.1. Potential Drivers and Constraints of Herbicide Use

Agriculture in Sub-Saharan Africa is being affected by a variety of profound social, economic, and biophysical changes, many of which relate to weed control. Changes in wage rates, the availability of commercial inputs for agriculture and information about modern agricultural practices are likely to affect the relative advantage of herbicides over other weed control options Rapid rural population growth in Africa is associated with decreasing farm sizes in many countries (Jayne et al. 2003). Even where farm sizes may not yet have decreased, there may not be more land available for agriculture, and so fallows are reduced. For example, in Ghana impressive growth in the agricultural sector since the mid-1990s was driven by land expansion but that is no longer an option (Quiñones and Diao 2011).This has direct implications for weed control because shorter fallow periods result in increased pressure from annual weeds (Pingali, Bigot, and Binswanger 1988).

The induced innovation hypothesis (Hayami and Ruttan 1971) would suggest that increased agricultural wages would drive labor saving technologies, such as herbicides (Erenstein 2006). Increases in education have led to a cultural preference away from agriculture in many countries, causing many youth to look for employment in urban centers (White 2012).This and the potential for increasing urban wages associated with economic growth could result in increased labor shortages for agriculture, and thus increased agricultural wages. However, there are two hidden complications not reflected in the wage rate: the difficulty of recruiting laborers and the difficulty of supervising them.

A complementary approach to induced innovation is the Agricultural Innovation Systems perspective (Klerkx, Van Mierlo, and Leeuwis 2012) which brings attention to the need for coordinated action to remove bottlenecks across the value chain. This is crucial for new technologies where both supply and demand initially are nil. Herbicide adoption requires locally available products packaged in volumes desired by farmers as well as the equipment to apply it correctly. Lack of availability and large package sizes were key constraints found in a study in Kenya (Muthamia et al. 2004). The influence of market access had a strong effect on herbicide use patterns in peri-urban areas of West Africa (Erenstein 2006).

A third complementary perspective on agricultural change comes from the sociological literature on diffusion (Rogers 2003), which emphasizes the importance of opinion leaders in raising the awareness and social acceptability of changing to a new technology. This is important for herbicides whose chemical action is mysterious to the naked eye and can easily be associated with fears of permanently poisoning the soil. Another aspect of the diffusion literature is the importance of learning from trusted peers. Farmers' lack of use of herbicides may not be because they are not economically optimal but because of lack of knowledge or skill in how to use them effectively (Beltran et al. 2013). There are various types of herbicides (selective or non-selective, systemic or contact effects, seed dormancy inducing, etc.) each of which has its own application procedures for safe and effective use (e.g., CFU 2014).

2.2. Farmers' Decisions about How to Control Weeds

Farmers have a number of options for controlling weeds, though each has its own challenges (Table 1). Direct strategies for weed control actively eliminate weeds (or their seeds) such as through physical or chemical disturbance. Hoe farmers have developed a wide range of techniques to effectively control weeds at different stages of crop growth and for different rainfall patterns, though their timely use of these techniques depends on if they perceive it as the optimal use of their labor or cash, if hiring in laborers for weeding (Orr, Mwale, and Saiti 2002). Farmers with oxen can weed larger areas per day than hoe farmers, though with less precision. Various efforts have been made to develop improved animal drawn cultivators (Obuo et al. 2001; Shetto et al. 1993).

Evidence from studies in Ghana suggests that the profitability of chemical weed control is highly context specific. In the difficult to manage vertisols of the Accra plains, where the problematic weed *Cyperus rotundus* L. is prevalent, herbicide use was associated with an 85% yield improvement over hoe weeding (Darkwa et al. 2001).Another study found herbicide use with zero tillage to be 24% cheaper than clearing land with a tractor (Ngeleza et al. 2011). Herbicides have also been recommended as the best option for early weed control when establishing cacao plantations (Oppong, Osei-Bonsu, and Amoah 2008).In contrast, in northern Ghana herbicide use effectively controlled weeds but the high costs and the lower yields associated with zero tillage make ox-plowing the most profitable weed control measure (Kombiok and Alhassan 2007). Similarly, only 4% of peanut farmers used herbicides in Southern Ghana while 69% hired laborers (Bolfrey-Arku et al. 2006).

Chemical weed control has a relative advantage over manual methods where household labor has high opportunity cost and where recruitment and supervision of hired labor are problematic, as long as cash flow constraints and lack of training can be overcome. Families that have larger farms and/or high return non-agriculture income sources would have the highest opportunity costs of labor. Chemical weed control may be less important for households with effective animal traction weed control methods. Farmers who have oxen or a tractor can weed a larger area in a day and so are less likely to need herbicides. Farmers with animal power may still desire herbicides if the animals have alternative uses of similar value or if farmers aim to use herbicides to facilitate early planting with minimum tillage.

Some farmers may not choose to use herbicides even if they are the cheapest option for weed control. For example, female farmers in Zambia were concerned that herbicides would reduce food security by making it less likely to intercrop and by eliminating the wild vegetable weeds they rely on during the growing season (Nyanga, Johnsen, and Kalinda 2012).

Table 1. Strategies for Weed Control, Their Challenges, and How They Relate to Herbicide Use

Weed control strategy	Challenges for farmers in using that strategy	Relationship to the herbicide use option
Direct Strategies		
Hoeing or hand weeding (family labor)	Total household labor availability Opportunity cost of household labor	Herbicides can overcome family labor constraints if cash flow, access, and training needs can be met.
Hoeing or hand weeding (hired labor)	Cost of hiring laborers Difficulty of recruiting laborers Difficulty of supervising to ensure quality weeding	Herbicides have similar cash flow challenges but can overcome recruitment and supervision challenges.
Animal drawn or tractor drawn cultivators	Equipment costs Training Access to oxen/donkeys or tractors	As animals and cultivators are sunk costs, herbicides are likely more attractive to non-owners.
Herbicides	Training needs Capital to purchase at start of season Access to chemicals in remote areas	-
Indirect Strategies		
Timely planting (crop grows faster than weeds)	Labor bottleneck at planting Draft animal or tractor use bottlenecks at planting	Herbicides can facilitate early planting when combined with minimum tillage.
Increased planting density (less space and light for weeds)	Requires adequate soil fertility and moisture	No relationship
Mulching with crop residues (physical and light barrier to weed growth)	Producing sufficient biomass for a thick enough layer of mulch. Alternative uses for residues Free range grazing Uncontrolled fires	Sprayed weeds can provide a mulch layer that would otherwise be buried; if herbicides significantly improve production, more crop residues would be produced.

Source: Author.

Indirect strategies can also be used to prevent weed growth, such as through timely planting, dense spacing of crops or mulching. While these indirect methods are undoubtedly important strategies used by farmers to control weeds, research on these methods focuses on the more direct benefits to crop production such as increased water use efficiency and the direct yield effect of having more plants per hectare.

3. DATA AND METHODS

3.1. Data

We analyzed data from the following multi-purpose agricultural surveys for this analysis: Ghana Living Standards Survey (GLSS) Round 3 (1991), GLSS Round 4 (1998), GLSS Round 5 (2006), GLSS Round 6 (2013), Zambia Crop Forecast Surveys (2010, 2011, 2012, 2013, 2014), Kenya Tegemeo Panel Survey (2000, 2004, 2007, 2010), Tanzania Agricultural Census (2008), Tanzania New Panel Survey (2009, 2011, 2013), and the Malawi Integrated Household Survey (2010, 2013). These surveys were selected based on the availability of herbicide use information and essential explanatory variables such as agricultural wage rate information. Earlier household survey data from these countries did not include questions about herbicide use.

Data on herbicide prices (a liter of glyphosate) were obtained from the Ministry of Agriculture in Ghana and from published reports listing prices (I. Lomotey, personal communication[1]; Ekboir, Boa, and Dankyi 2002; Akramov and Malek 2012; Ragasa et al. 2013).

In Zambia total herbicide total sales volumes were provided directly from NWK agri-services and Cargill-Zambia (S. Kabwe, personal communication[2]), the two largest cotton companies in Zambia and significant herbicide suppliers both through credit and retail. The price of glyphosate each year was obtained from NWK agri-services (A. Shamane, personal communication[3]). The NWK retail price was used for all years. NWK sells three types of glyphosate—small sachets of powder (the equivalent of 350 ml), one liter containers, and five liter containers. The cost per liter was lowest for larger packages. An average price per liter was estimated by using weighted averages where the weight was the proportion of total glyphosate sales pertaining to each type of glyphosate.

Population density data came from census information. The 2010 census was used for all years for Zambia. For Ghana, the 2000 census was used with the 1998 survey data, the 2010 census was used with the 2013 survey data, and the average of the two censuses was used with the 2006 data.

3.2. Methods

A basic model of farmer decision-making about weed control is to assume that farmers choose the cheapest option, given their context-specific challenges. The available data across time allows for an indirect analysis of how factors associated with the costs and benefits of chemical and physical weed control methods affect the probability of herbicide use. The data from Zambia and Ghana were used because they provide national cross sectional data collected with a similar methodology over time. For Ghana the 1991 data was not used for the pooled analysis due to a lack of key explanatory variables. For Zambia, the Crop Forecast Survey data collected before 2010 did not include questions about herbicide use.

[1] E-mail from Ghana's Ministry of Agriculture, Ivy Lomotey to Philip Grabowski on 7 May, 2015.
[2] E-mail from Stephen Kabwe to Philip Grabowski on 30 June, 2013, this included unpublished herbicide sales data from NWK (provided by Graham Chilimina) and Cargill (provided by Emmanuel Mbewe).
[3] E-mail from Alex Shamane of NWK Agri-services in Zambia to Philip Grabowski on 7 May, 2015.

We use a probit model to determine the partial effect of each variable on the probability that a household uses any amount of herbicides. Formally the probit model allows for estimating the probability of a binary variable as follows:

$$P\ (Y=1|X) = \Phi(X\beta) \qquad 1$$

Where Φ is the cumulative distribution function of the standard normal distribution. The results are presented as the average partial effect for each explanatory variable to facilitate interpretation. Tables 2-4 outline the variables used in the models and the expected correlation with herbicide use. The means and variance for these variables can be found in the appendix.

Sampling weights were used to account for the survey design. For Ghana, in 1998 the weights had a mean of 1 and were usable for the pooled analysis. For 2006 and 2013 the weights provided with the data for Ghana had values equal to the number of farmers represented by each observation. These weights were standardized to have a mean of 1 for the pooled analysis. In Zambia the same weighting system was used for all years so there was no need to adjust weights in the pooled analysis.

Observations were included only for farming households in districts where herbicides were used that year. This was done to exclude households where herbicides may have been completely unavailable as their inclusion could confound the results. Both rural and urban households were included from Ghana as long as they practiced some farming.

The dependent variable in the probit models has a value of one if the household spent anything on herbicides in the past 12 months and is zero otherwise. All prices were standardized each year to have a mean of zero and standard deviation of one to facilitate analysis across years without needing to make assumptions about inflation or devaluation.

To control for unobserved factors associated with each location regional dummy variables were included in the analysis. In Ghana a dummy variable for each region was used with Western Region as the base case. In Zambia provincial dummy variables were used with Central Province as the base case. For both countries, there were insufficient observations at the district level to be able to include district dummy variables.

Table 2. Description of Variables Used for both Ghana and Zambia to Model the Probability of Household Herbicide Use

Variable	Description	Hypothesized relationship	Justification
Male headed household	Binary	Positive	Better access to markets, more resources, and higher risk tolerance
Adult workers	People in household between age 13 and 65	Negative	Lower opportunity cost of labor
Age of head of household	Years	Negative	More resistant to change
Education of household head	Years	Positive	Better able to learn how to use herbicides
Land owned	10s of hectares	Positive	Higher opportunity cost of labor
Agricultural wage	Zambia: weed one acre. Ghana: clear for one day	Positive	Herbicides are more economical when wages are higher
Population density	Thousand people per square km	Negative	Where population densities are low it may be more difficult to find laborers
Herbicide price	The price of a liter of glyphosate	Negative	Lower prices make herbicide use more attractive

Source: Author.

Table 3. Description of Additional Variables Used For Ghana to Model the Probability of Household Herbicide Use

Variable	Description	Hypothesized relationship	Justification
Farming as primary economic activity	Binary	Negative	Higher opportunity cost of labor and greater liquidity
Tractors	Binary	Negative	In areas with tractors the cost of weeding may be low
Welfare	Total consumption adjusted for local prices	Positive	Farmers who are better off may be able to overcome cash constraints
Distance to road	km	Negative	Distance to paved road is another indicator of market access
Distance to extension center	km	Negative	Farmers farther from extension may have less information about herbicides

Source: Author.

Table 4. Description of Additional Variables Used For Zambia to Model the Probability of Household Herbicide Use

Variable	Description	Hypothesized relationship	Justification
Received fertilizer subsidy	Binary	Positive	Farmers who receive subsidies may have cash freed up to use on other inputs
Amount of subsidized fertilizer received	kg	Positive	Farmers who receive more fertilizer have more incentive to manage weeds
Cotton producing zone	Binary	Positive	In these areas more farmers have access to agricultural credit
Minimum tillage	Binary	Positive	Farmers who use minimum tillage may have more need for herbicides
Fertilizer price	Median ZMK per bag by district – standardized by year	Negative	Higher fertilizer prices may correlate with a general lack of agro-dealers
Fertilizer transport price	Median ZMK per bag by cluster – standardized by year	Negative	Fertilizer transport cost is one indicator of market access
Maize price	Median ZMK per kg by district – standardized by year	Positive	Higher maize price may encourage investment in inputs

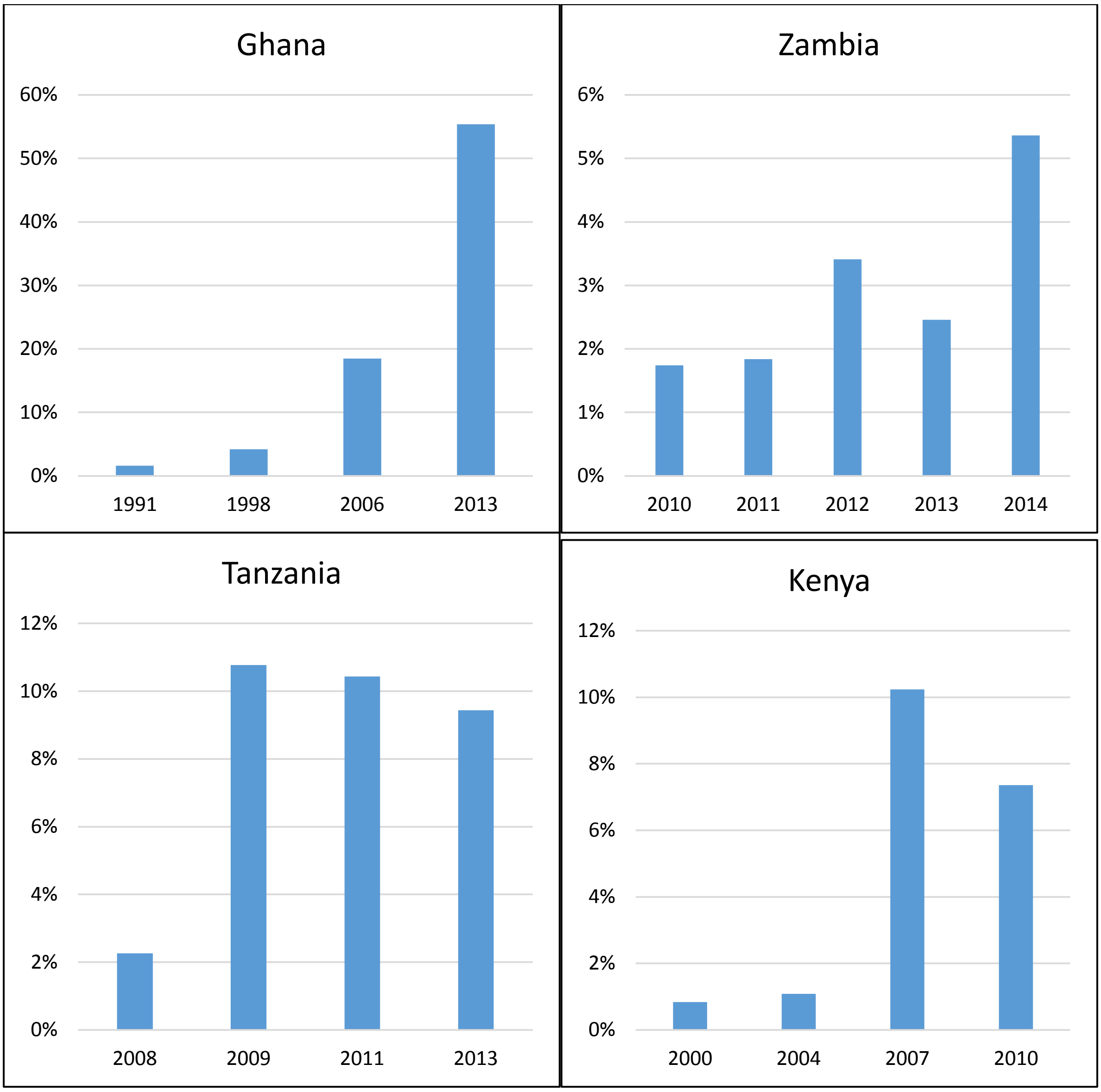
Source: Author.

4. RESULTS

4.1. Trends over Time

Herbicide use has increased dramatically in Ghana from less than 2% in 1998 to over 50% of farming households in 2013. Zambia also has a generally upward trend over the past five years. In other African countries where data is available the trend is less clear. In Tanzania and Kenya there are significant increases in herbicide use rates in 2009 and 2007 respectively but then later decreases in herbicide use (Figure 1). In contrast herbicide use is low in Malawi has remained low at 1.0% in 2010 and 1.3% in 2013 (not shown in Figure 1). For the remainder of this study we focus on understanding the upward trends in herbicide use in Ghana and Zambia.

Figure 1. Trends in Household Herbicide Use over Time in Ghana, Zambia, Tanzania, and Kenya



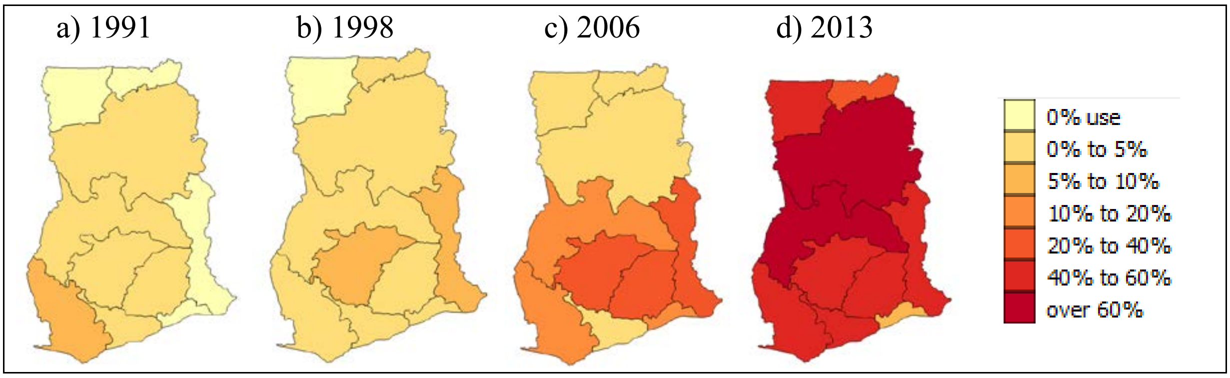
Notes: Ghana data is from Ghana Living Standards Surveys rounds 3-6; Zambia data is from CSO Crop Forecast Surveys; Data from Tanzania is from the 2008 Agricultural Census and from the first three waves of the New Panel Survey (2009-2013); Kenya data is from the Tegemeo Panel Survey Data.

4.2. Trends over Time and Space

By looking at the spatial distribution of herbicide use over time for both Ghana and Zambia we can get an initial sense of what might be driving adoption. In 1991 the highest level of herbicide use was in Western Region of Ghana where most of the cocoa is grown but by 2013 the highest use rates are found in Ghana's maize belt of Northern and Brong Ahafo Regions, though use rates are quite high across the country (Figure 2).

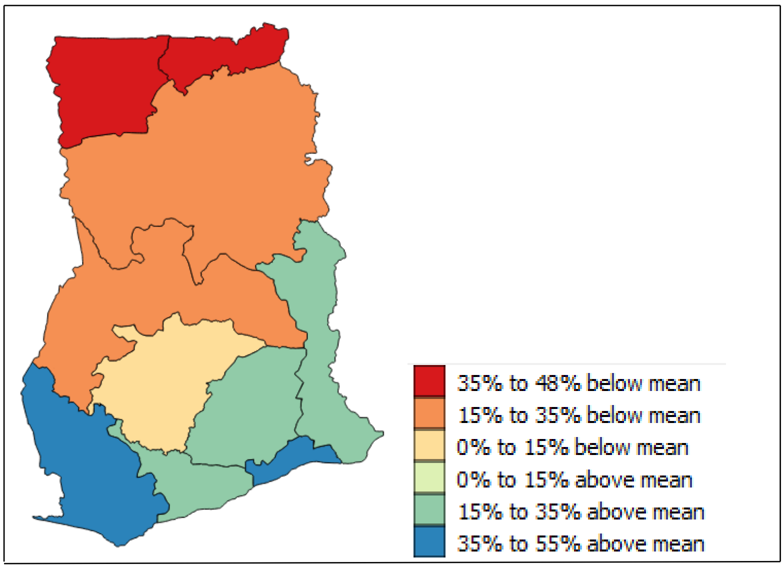
Comparing the spatial distribution of herbicide use with the spatial distribution of agricultural wages suggests that increased wage rates are not the primary driver of herbicide use (Figure 3). The highest agricultural wages in Ghana are in Greater Accra Region (where urban employment opportunities increase the demand for labor) and this area has the lowest herbicide use rates. Western Region also has higher agricultural wages presumably because there is demand for labor due to commercial production of tree crops such as cocoa and palm oil. The regions with the highest herbicide use rates have agricultural wages that are 15% to 35% below the national mean.

Figure 2. Herbicide Use over Time in Ghana by Region



Source: GLSS Rounds 3, 4, 5, and 6.

Figure 3. Percent Variation from the Mean Agricultural Wage[1] in Ghana by Region 1991-2013



Source: GLSS Rounds 3, 4, 5, and 6.

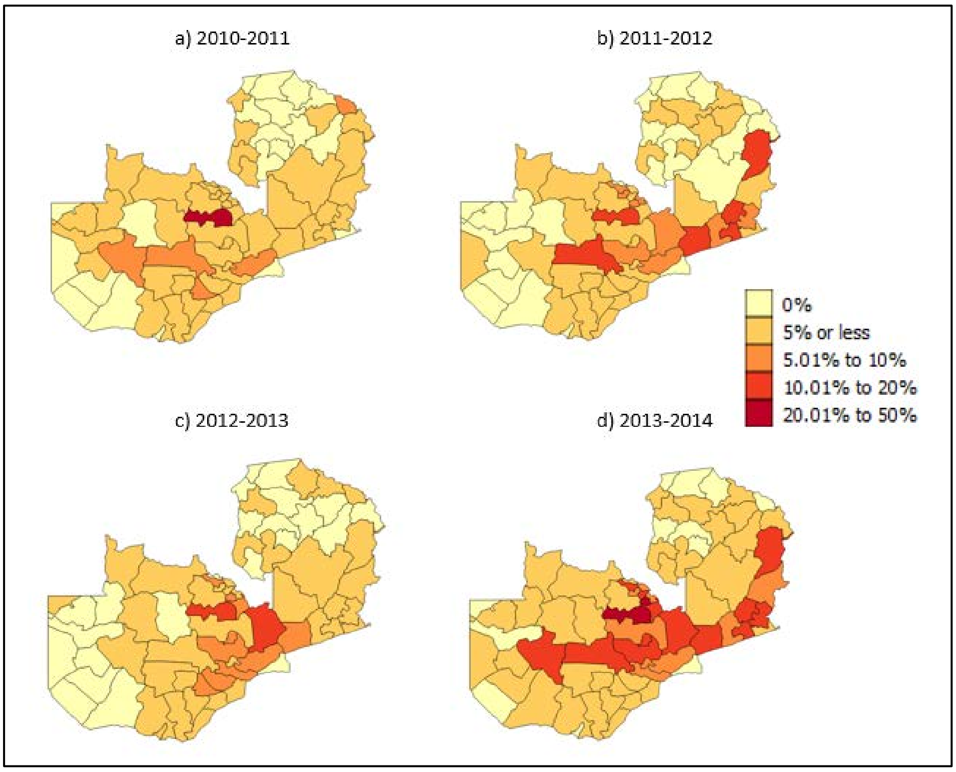
[1] Cost to pay a man for clearing for one day.

For Zambia, herbicide use rates are widely different across provinces with most herbicide use being in the cotton growing regions of Eastern, Central, Copperbelt and Lusaka Provinces and persistently low use rates in the northern and western portions of the country (Figure 4). High cotton prices in 2011 occurred simultaneously with an increase in the supply and promotion of herbicides by the cotton companies. Sales from the two largest cotton companies increased by almost ten times in 2011 (Figure 6). The cotton price fell dramatically in 2012 causing many cotton farmers to default on their loans and even more to be cautious with how much credit they took out during the 2012-2013 season (Grabowski et al. forthcoming). This can be seen in the much lower herbicide use rates in Eastern Province in that season (Figure 4c) as well as by the 30% drop in herbicide use in the country (Figure 1). However, glyphosate sales by cotton companies only fell by 9% (Figure 6), which could be possible if those using herbicides increased the areas where they applied the chemical.

One interesting exception to this association between cotton production and herbicide use is that of Southern Province where cotton production is common but herbicide use rates remained at 5% or less for all years. This is not likely a result of differences in wage rates because most of the cotton growing areas has lower than average wage rates, with the exception of Lusaka Province (Figure 5). Instead one possible explanation is that in Southern Province, where cattle are culturally valued more than other cotton growing provinces, farmers may be better able to control weeds through cultivation with oxen and thus have less demand for herbicides.

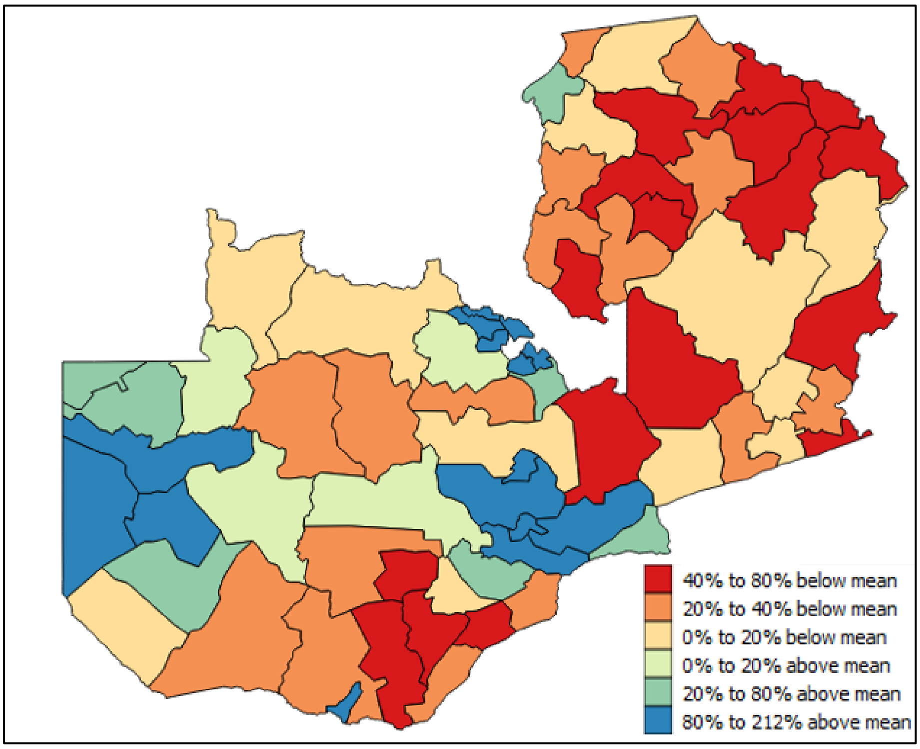
In contrast to what one would expect from induced innovation, Western Province has high wage rates and low herbicide use. This is likely because of poor roads, low population density and less commercialized agriculture than other parts of Zambia.

Figure 4. Herbicide Use Rates in Zambia by District



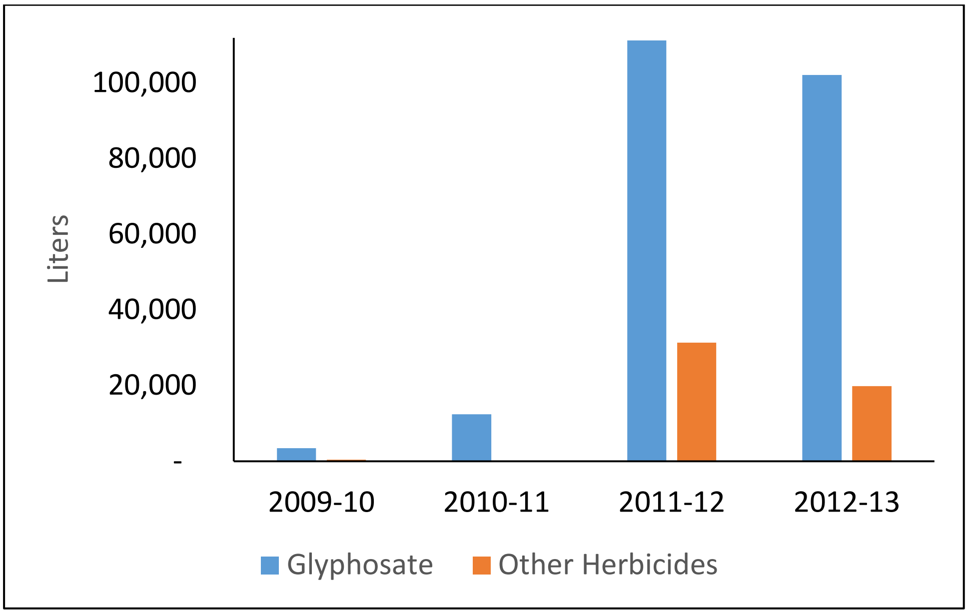
Source: CSO Crop Forecast Surveys.
Note: For simplicity the 2009-2010 map is left out as it is nearly identical to 2010-2011.

Figure 5. Percent Variation from the Mean Agricultural Wage[1] in Zambia by Province 2009-2014



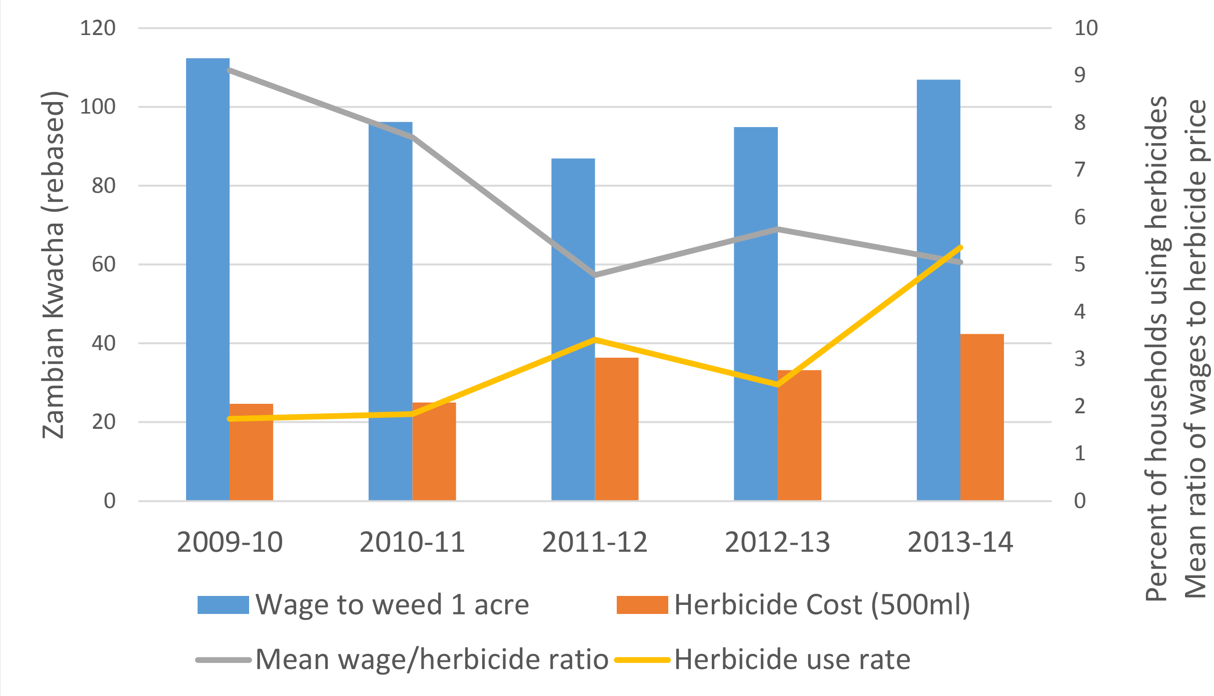
Source: CSO Crop Forecast Surveys.
[1] Wage to pay a man to weed one acre.

Figure 6. Total Herbicide Sales by NWK Agri-Services and Cargill, the Two Largest Cotton Companies in Zambia



Sources: NWK agri-services (G. Chilimina, personal communication); Cargill-Zambia (E. Mbewe, personal communication).
Note: Glyphosate is also sold as a powder and the kilograms sold were converted to liters of glyphosate concentrate (285 g = 350 ml).

Figure 7. Changes in Mean Wages, Herbicide Price, and Herbicide Use in Zambia over Time



Sources: Herbicide prices A. Shamane, personal communication; all other data, CSO Crop Forecast Surveys.

Overall in Zambia there is no significant wage trend though variation from year to year can be quite large (Figure 7). The cost of glyphosate has increased in absolute terms (not controlling for inflation), and the wage to herbicide cost ratio has actually decreased over the period where herbicide use rate has increased. This suggests that herbicide use is not a reaction to higher agricultural wages.

4.3. Econometric Analysis of What Is Driving These Trends

4.3.1. Ghana Results

The probit results show that in Ghana households that are male headed, have more adult workers, are younger, and own more land are more likely to use herbicides. The combination of positive coefficients on both the amount of land and number of available workers in models 2 and 3 suggest that labor shortages alone do not drive herbicide use (Table 5). Instead it appears that households who have greater potential for commercialized agriculture are the ones more likely to invest in herbicides.

Likewise, herbicide use in model 3 is more likely in communities where agriculture is more commercial—where there are tractors, and where farming is the primary economic activity (as opposed to fishing, handicrafts, etc.). Wages were highly variable but not significantly associated with herbicide use. Herbicide use is more likely in areas that are farther from extension centers, which is surprising and difficult to explain. Education, population density, household welfare, and distance to a paved road were not significant factors for the probability of herbicide use.

The coefficients on most regional dummy variables are significant in all models, which suggests the importance of otherwise unobserved factors related to the particular farming systems in each region. The coefficients on the year dummy variables are also significant, which could be interpreted as evidence of increasing availability of herbicides generally. Ideally future household surveys will ask about herbicide prices for each location, which would allow price and time to be modeled together.

These results are largely consistent with other studies on agro-chemical use in Ghana. Ngeleza et al. (2011) found that herbicide use was associated with larger farm sizes. Similarly, Moro (2014) found that yam producers in Ghana were more likely to use herbicides if they had larger farm sizes and sold a larger proportion of their crop. Egyir (2007) observed the opposite effect for the combined use of herbicides and pesticides for plantain production but attributed this to a more commercial focus by those with smaller farms, while larger farms tended to grow plantains for subsistence. The same study found lower use of agro-chemicals closer to Accra, which, though not expected, was attributed to the greater involvement in non-agricultural income-generating activities in that region.

Table 5. Marginal Effects from Probit Analysis of Household Herbicide Use on Any Crop in Ghana

	Model 1			Model 2			Model 3		
VARIABLES	Probit	aster	se	Probit	aster	se	Probit	aster	se
Male headed hh (Yes=1)				0.109	***	(0.012)	0.108	***	(0.013)
Adult workers in hh (age 13-65)				0.019	***	(0.003)	0.020	***	(0.003)
Age of head of hh				-0.002	***	(0.000)	-0.002	***	(0.000)
Education (years) of hh head				0.001		(0.001)	0.001		(0.001)
Land owned (10s of ha)				0.060	***	(0.012)	0.057	***	(0.012)
Population Density (1000/km2)				-0.068		(0.052)	-0.035		(0.050)
Welfare				0.012		(0.008)	0.012		(0.008)
Agricultural wage				-0.001		(0.006)	-0.001		(0.006)
Tractors in community							0.014	**	(0.007)
Farming as primary economic = 1							0.149	***	(0.030)
Distance to paved road (10s of km)							-0.012		(0.013)
Distance to Extension Center (10s of km)							0.011	***	(0.004)
Year 2006 = 1	0.228	***	(0.015)	0.220	***	(0.014)	0.220	***	(0.014)
Year 2013 = 1	0.537	***	(0.012)	0.571	***	(0.012)	0.573	***	(0.012)
Central Region = 1	-0.078	***	(0.019)	-0.076	***	(0.022)	-0.077	***	(0.022)
Greater Accra Region = 1	-0.249	***	(0.031)	-0.147	***	(0.055)	-0.139	**	(0.056)
Volta Region = 1	0.046	***	(0.017)	0.053	***	(0.019)	0.061	***	(0.020)
Eastern Region = 1	0.056	***	(0.017)	0.048	**	(0.019)	0.049	**	(0.019)
Ashanti Region = 1	0.094	***	(0.018)	0.116	***	(0.019)	0.121	***	(0.020)
Brong Ahafo Region = 1	0.131	***	(0.017)	0.106	***	(0.020)	0.107	***	(0.020)
Northern Region = 1	0.088	***	(0.017)	0.017		(0.020)	0.011		(0.020)
Upper East Region = 1	-0.203	***	(0.017)	-0.244	***	(0.018)	-0.246	***	(0.018)
Upper West Region = 1	-0.105	***	(0.017)	-0.163	***	(0.018)	-0.164	***	(0.019)
pseudo R-squared		0.1531			0.1999			0.2049	
likelihood value		-8,052.7			-5,393.4			-5,308.2	
% correctly predicted		70.8%			84.9%			86.1%	
Observations		15,618			11,660			11,518	

4.3.2. Zambia

Similar to the results from Ghana, model 2 and 3 shows that households in Zambia that are male headed, have more adult workers and more land are more likely to use herbicides (Table 6). Age is not significant in Zambia but the level of education is strongly significant with more educated farmers being more likely to use herbicides.

A further similarity is the lack of a positive effect of population density and agricultural wages on the probability of herbicide use. In fact, the Zambia data shows a significant negative effect of agricultural wages on herbicide use, which we interpret as a non-causal correlation associated with unobserved (and thus uncontrolled) heterogeneity in the availability of herbicides. Our logic is as follows: herbicides are probably more easily available in areas with more commercialized agriculture, which also tend to have higher agricultural wages.

In model three we attempted to control for availability of herbicides by using a dummy variable for cotton growing locations, which not only have well-developed networks of input suppliers but also have greater availability of agricultural credit for herbicides and greater extension support through the private sector. Farmers in cotton growing areas are more likely to use herbicides, but this had little effect on the negative coefficient for agricultural wages. Cotton farmers tend to focus their efforts on agriculture and have fewer non-agricultural income sources (Haggblade, Kabwe, and Plerhoples 2011). In model three the negative coefficient on the cost of transporting fertilizer becomes marginally significant, showing that farm gate prices for inputs can vary significantly and impinge on the profitability of input use.

In Zambia the analysis was able to control for a wider range of economic factors than in Ghana. The results show that farmers are more likely to use herbicides when fertilizer is cheaper or more available. As maize is one of the most important crops in the country and nitrogen is a key limiting factor in maize production, farmers tend to prioritize fertilizer purchases. Farmers who have received subsidized fertilizer are more likely to use herbicides, which suggests that the subsidy is freeing up cash to purchase other inputs. Likewise, herbicide use is more likely in areas with lower prices for commercial fertilizer (not subsidized). Furthermore, farmers tend to use herbicides more where maize prices were higher in the previous marketing year. As mentioned above in relation to cotton in Zambia, the previous price of a crop can be a good predictor of investment in commercial inputs to produce that crop.

Model three also includes a variable to capture the complementary management practice of minimum tillage (MT). Farmers who use MT are more likely to use herbicides because they are not using cultivation of the land for early weed control. Minimum tillage has been widely promoted in Zambia as *conservation farming* (Baudron, CIRAD, and FAO 2007) and is being adopted to enable earlier planting and to reduce farmers' vulnerability to drought (Grabowski et al. forthcoming).

Compared to Ghana, the adoption of herbicides in Zambia is largely understudied. We found one student thesis that found positive correlations between herbicide use and extension and education (Mbazima 1997). In addition, the report of an independent consulting firm found that herbicide use was higher in areas where CFU had more concentrated training and extension (Kasanga and Daka 2013).

Table 6. Marginal Effects from Probit Analysis of Household Herbicide Use on Any Crop in Zambia

	Model 1			Model 2			Model 3		
VARIABLES	Probit	aster	se	Probit	aster	se	Probit	aster	se
Male headed hh (Yes=1)				0.014	***	(0.003)	0.014	***	(0.003)
Adult workers in hh (age 13-65)				0.003	***	(0.001)	0.002	***	(0.001)
Age of head of hh				-0.00004		(0.000)	-0.0001		(0.000)
Education (years) of hh head				0.003	***	(0.000)	0.003	***	(0.000)
Land owned (10s of ha)				0.005	***	(0.001)	0.005	***	(0.001)
Population Density 2010 (1000/km2)				-0.005		(0.004)	-0.003		(0.003)
Received subsidized fertilizer (Yes=1)				0.015	***	(0.003)	0.016	***	(0.003)
Subsidized fertilizer received (metric tons)				0.040	***	(0.005)	0.040	***	(0.005)
Transport cost for fertilizer				-0.003		(0.002)	-0.004	*	(0.002)
Agricultural Wage				-0.008	***	(0.002)	-0.009	***	(0.002)
Fertilizer Price				-0.007	***	(0.002)	-0.006	***	(0.002)
Maize Price				0.003	**	(0.001)	0.004	***	(0.001)
Uses any minimum tillage (Yes=1)							0.039	***	(0.005)
Cotton grown in ward (Yes=1)							0.029	***	(0.003)
Year 2011 = 1	0.001		(0.004)	-0.001		(0.005)	-0.003		(0.005)
Year 2012 = 1	0.029	***	(0.005)	0.030	***	(0.006)	0.027	***	(0.006)
Year 2013 = 1	0.014	***	(0.004)	0.007		(0.005)	0.007		(0.005)
Year 2014 = 1	0.046	***	(0.005)	0.048	***	(0.006)	0.047	***	(0.006)
Copperbelt Prov. = 1	0.020	***	(0.004)	0.030	***	(0.006)	0.057	***	(0.008)
Eastern Prov. = 1	-0.011	***	(0.003)	-0.015	***	(0.003)	-0.024	***	(0.003)
Luapula Prov. = 1	-0.037	***	(0.002)	-0.037	***	(0.002)	-0.029	***	(0.004)
Lusaka Prov. = 1	-0.002		(0.005)	0.006		(0.007)	0.010		(0.007)
Muchinga Prov. = 1	-0.016	***	(0.004)	-0.032	***	(0.003)	-0.030	***	(0.003)
Northern Prov. = 1	-0.020	***	(0.003)	-0.025	***	(0.003)	-0.014	***	(0.004)
Northwestern Prov. = 1	-0.033	***	(0.002)	-0.036	***	(0.003)	-0.027	***	(0.004)
Southern Prov. = 1	-0.029	***	(0.002)	-0.034	***	(0.002)	-0.035	***	(0.002)
Western Prov. = 1	-0.024	***	(0.003)	0.002		(0.008)	0.019	*	(0.011)
Pseudo R-squared		0.0527			0.1054			0.1182	
Likelihood value		-862,523.6			-703,783.0			-688,885.3	
% correctly predicted		94.2%			94.3%			94.3%	
Observations		49,744			40,143			39,394	

5. DISCUSSION AND CONCLUSION

Our results show that herbicide use in certain countries is on the rise but this does not appear to be in response to any increase in agricultural wages. One way to interpret the lack of effect of wages on herbicide use is that agricultural wages are always high enough to make herbicides desirable. The drivers of increased herbicide use appear to be increased availability of herbicides and increased ability to purchase herbicides by better-off farmers who have a commercial orientation in their production. Even in countries where herbicide use is generally on the rise, context is important. This context specificity is indicative of the complex tradeoffs farmers face in allocating their limited labor and cash resources (Tittonell et al. 2007).

In places where markets and supporting institutions continue to encourage commercially oriented agriculture we can expect herbicide use to continue to rise. This is because in such contexts farmers are more likely to be able to overcome cash constraints to commercial input use. In addition, where conservation agriculture is adopted farmers are likely to find herbicides important for controlling weeds. In many parts of Africa, farmers are likely able to find herbicides if they look for them but their safe and effective use will require in-depth training (e.g., CFU 2014).

The environmental concern posed by this increase in agro-chemicals merits the attention of policy-makers. Herbicide use can pose hazards to human health due to lack of training on proper nozzles and application regimes, lack of protective material, and lack of awareness about the danger of spraying near open water (Bishop-Sambrook 2003). The high cost of protective material led 86% of farmers in Nigeria to apply herbicides without any special protection (Banjo, Aina, and Rije 2010). In Ghana the Environmental Protection Agency is supposed to train input suppliers to provide farmers with safe handling information but this is largely unmonitored (Egyir 2007). Even literate farmers may find it difficult to obtain adequate information about safe handling as many herbicides are sold unlabeled, such as in Ghana where retailers repackaged them into smaller containers with no information but the name (Williamson 2003).

Without sufficient information and training about safe handling herbicides present a potential risk to humans and the rest of the environment. In Zambia herbicides such as Atrazine were found in the fish caught along the Kafue river (Syakalima et al. 2006). Detectable levels of the herbicide Atrazine have been found in streams and hand-dug wells in the maize belt of Ghana but not at levels beyond the WHO limits for drinking (Hope 2013). Continuing this type of monitoring will be important as herbicide usage continues to grow.

APPENDIX

STATISTICAL DESCRIPTION OF THE VARIABLES USED IN THE PROBIT MODELS

Table A1. Description of Variables Used in the Ghana Model

Variable	Mean	Std Dev	Min	Max
Household herbicide use	0.4252	0.4944	0	1
Male headed hh (Yes=1)	0.7619	0.4259	0	1
Adult workers in hh (age 13-65)	2.5984	1.6689	0	17
Age of head of hh	47.2543	15.5687	15	99
Education (years) of hh head	5.0364	4.6809	0	16
Land owned (10s of ha)	0.2373	0.4438	0	6.03
Population Density (1000/km2)	0.1349	0.1346	0.0093	9.0383
Welfare	0.7489	0.6869	0.012	29.45
Agricultural wage	0.0619	0.9147	-1.775	15.598
Tractors in community	0.1103	0.4848	0	9.9
Farming as primary economic = 1	0.9644	0.1852	0	1
Distance to paved road (10s of km)	0.0658	0.2845	0	4.5
Distance to Extension Center (10s of km)	0.9347	1.2317	0	8
Glyphosate price	6.4183	1.7327	4.52	8
Year = 1998	0.0003	0.0167	0	1
Year 2006 = 1	0.4697	0.4991	0	1
Year 2013 = 1	0.523	0.4991	0	1
Western Region = 1	0.1232	0.3287	0	1
Central Region = 1	0.0931	0.2906	0	1
Greater Accra Region = 1	0.009	0.0946	0	1
Volta Region = 1	0.1103	0.3133	0	1
Eastern Region = 1	0.1567	0.3635	0	1
Ashanti Region = 1	0.1967	0.3975	0	1
Brong Ahafo Region = 1	0.1099	0.3128	0	1
Northern Region = 1	0.1139	0.3177	0	1
Upper East Region = 1	0.0589	0.2355	0	1
Upper West Region = 1	0.0282	0.1655	0	1

Table A2. Description of Variables Used in the Zambia Model

Variable	Mean	Std Dev	Min	Max
Household uses herbicides (Yes=1)	0.0367	0.1881	0	1
Male headed hh (Yes=1)	0.7862	0.41	0	1
Adult workers in hh (age 13-65)	3.1122	1.805	0	26
Age of head of hh	44.3438	14.8688	12	104
Education (years) of hh head	6.1815	3.7983	0	19
Land owned (10s of ha)	0.3399	0.8338	0	100.75
Population Density 2010 (1000/km2)	0.0529	0.2716	0.000153	8.6842
Received subsidized fertilizer (Yes=1)	0.342	0.4744	0	1
Subsidized fertilizer received (metric tons)	0.0911	0.1872	0	7
Transport cost for fertilizer	-0.0229	0.8556	-1.8692	10.4656
Agricultural Wage	-0.1862	0.8265	-1.7792	4.0783
Fertilizer Price	0.033	0.7766	-3.5326	4.0312
Maize Price	-0.0621	0.805	-7.3935	4.7754
Uses any minimum tillage (Yes=1)	0.0935	0.2912	0	1
Cotton grown in ward (Yes=1)	0.4292	0.495	0	1
Glyphosate Price (ZMK rebased)	32.4381	6.926	24.6674	42.342
Yr 2010	0.1908	0.3929	0	1
Yr 2011	0.2119	0.4086	0	1
Yr 2012	0.1924	0.3942	0	1
Yr 2013	0.1835	0.3871	0	1
Yr 2014	0.2213	0.4152	0	1
Central Prvo. = 1	0.1506	0.3577	0	1
Copperbelt Prov. = 1	0.0768	0.2663	0	1
Eastern Prov. = 1	0.2262	0.4184	0	1
Luapula Prov. = 1	0.0744	0.2624	0	1
Lusaka Prov. = 1	0.2262	0.4184	0	1
Muchinga Prov. = 1	0.057	0.2318	0	1
Northern Prov. = 1	0.1466	0.3537	0	1
Northwestern Prov. = 1	0.0506	0.2191	0	1
Southern Prov. = 1	0.1567	0.3635	0	1
Western Prov. = 1	0.0259	0.1589	0	1

REFERENCES

Akramov, K. and M. Malek. 2012. Analyzing Profitability of Maize, Rice, and Soybean: PAM and DEA Results. Presented at the IFPRI Ghana Strategy Support Program, 12 March, 2012. Accra, Ghana. Retrieved from: http://www.slideshare.net/gssp_ifpri/competitiveness-of-maize-rice-soybean.

Banjo, A.D., S.A. Aina, and O.I. Rije. 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: 188–94.

Baudron, F, Herbert M. Mwanza, Bernard Triomphe, and Martin Bwalya. 2007. Conservation Agriculture in Zambia: A Case Study of Southern Province. Nairobi: African Conservation Tillage Network,Centre de Coopération Internationale de Recherche Agronomique pour le Développement, Food and Agriculture Organization of the United Nations (FAO).

Beltran, J.C., B. White, M. Burton, et al. 2013. Determinants of Herbicide Use in Rice Production in the Philippines. *Agricultural Economics* 44.1: 45–55. Doi:10.1111/J.1574-0862.2012.00631.X

Bishop-Sambrook, C. 2003. Labour Savings Technologies and Practices for Farming and Household in Eastern and Southern Africa: Labour Constraints and the Impact of HIV/AIDS on Rural Livelihoods in Bondo and Busia Districts Western Kenya. Rome, Italy: IFAD, FAO.

Bolfrey-Arku, G., M. Owusu-Akyaw, J.V.K. Afun, et al. 2006. Survey of Weed Management in Peanut (Arachis hypogaea L.) Fields in Southern Ghana, West Africa. *Peanut Science* 33.2: 90–96. doi:10.3146/0095-3679(2006)33[90:SOWMIP]2.0.CO;2.

Bouriquet, G. 1961. Chemical Deweeding of Crops in Madagascar, Senegal, and Mali. Presented at a joint CCTA/FAO Symposium on Weed Control 5, 23-27 October, 1961. Idaban, Nigeria.

Central Statistical Office (CSO). Various Years. Crop Forecast Survey. Lusaka: Republic of Zambia Ministry of Agriculture and Livestock and Central Statistical Office.

Conservation Farming Unit (CFU). 2014. Spraying and Herbicide Information Booklet. Retrieved on DATE from: http://conservationagriculture.org/uploads/pdf/Herbicide_Information_Booklet_2014.pptx

Darkwa, E.O., B.K. Johnson, K. Nyalemegbe, et al. 2001. Weed Management on Vertisols for Small-scale Farmers in Ghana. *International Journal of Pest Management* 47.4: 299–303. doi:10.1080/09670870110052068.

Egyir, I.S. 2007. Assessing the Factors of Adoption of Agro-chemicals by Plantain Farmers in Ghana using the ASTI Analytical Framework. Accessed 25 September, 2015 at http://www.africa-platform.org/sites/default/files/resources/assessing_the_factors_of_adoption_of_agro-chemicals_by_plantain_farmers_in_ghana.pdf.

Ekboir, J., K. Boa, A.A. Dankyi, 2002. *Impact of No-till Technologies in Ghana.* Economics Program Paper No. 02-01. Mexico, D.F., Mexico: CIMMYT: International Maize and Wheat Improvement Center.

Erenstein, O. 2006. Intensification or Extensification? Factors Affecting Technology Use in Peri-Urban Lowlands along an Agro-Ecological Gradient in West Africa. *Agricultural Systems* 90: 132–58. doi:10.1016/j.agsy.2005.12.005.

Ghana Statistical Service (GLSS). 2013. Ghana Living Standards Survey Round 6. Ghana Statistical Service. Accra: Ghana Statistical Service.

Ghana Statistical Service (GLSS). 2006. Ghana Living Standards Survey Round 5. Ghana Statistical Service. Accra: Ghana Statistical Service.

Ghana Statistical Service (GLSS). 1996. Ghana Living Standards Survey Round 4. Ghana Statistical Service. Accra: Ghana Statistical Service.

Ghana Statistical Service (GLSS). 1991. Ghana Living Standards Survey Round 3. Ghana Statistical Service. Accra: Ghana Statistical Service.

Gianessi, L.P., T. Bruce, C. Foyer, N. Halford, et al. 2009. Solving Africa's Weed Problem: Increasing Crop Production and Improving the Lives of Women. In P*roceedings of Agriculture: Africa's "Engine for Growth" - Plant Science and Biotechnology Hold the Key'*, 12-14 October, ed. T. Bruce, C. Foyer, N. Halford, et al. UK: Rothamsted Research. *Aspects of Applied Biology* 96: 9–23.

Gianessi, L.P. 2013. The Increasing Importance of Herbicides in Worldwide Crop Production. *Pest Management Science* 69.10: 1099–105.

Giller, K.E., E. Witter, M. Corbeels, and P. Tittonell. 2009. Conservation Agriculture and Smallholder Farming in Africa: The Heretics' View. *Field Crops Research* 114.23: 23–34. doi:10.1016/j.fcr.2009.06.017.

Goeb, J. 2013. *Conservation Farming Adoption and Impact Among First Year Adopters in Central Zambia.* IAPRI Working Paper No. 80. Lusaka, Zambia: Indaba Agricultural Policy Research Institute.

Grabowski, P., J. Kerr, S. Haggblade, S. Kabwe. Forthcoming. Determinants of Adoption of Minimum Tillage by Cotton Farmers in Eastern Zambia. Manuscript submitted for publication.

Haggblade, S., S. Kabwe, and C. Plerhoples. 2011. *Productivity Impact of Conservation Farming on Smallholder Cotton Farmers in Zambia*. FSRP Working Paper No. 47. Lusaka, Zambia: Food Security Research Project.

Hayami, Y. and V.W. Ruttan. 1971. Agricultural Development: An International Perspective. Baltimore, MD/London: The Johns Hopkins Press.

Hope, F.A. 2013. Human Health Risk Assessment of Atrazine in Water and Soil in Selected Municipalities in Ashanti and Brong-Ahafo Region of Ghana. M.Ph. dissertation. University of Ghana.

Ishaya, D.B., P. Tunku, and N.C. Kuchinda. 2008. Evaluation of Some Weed Control Treatments for Long Season Weed Control in Maize (Zea Mays L.) under Zero and Minimum Tillage at Samaru, in Nigeria. *Crop Protection* 27.7: 1047–1158.

Jayne, T.S., T. Yamano, M.T. Weber, D. Tschirley, et al. 2003. Smallholder Income and Land Distribution in Africa: Implications for Poverty Reduction Strategies. *Food Policy* 28.3: 253–75.

Kasanga, J. and O. Daka. 2013. Broad - Based Survey to Establish Baseline Conditions and Collection of Data for Monitoring the Impact of the Second Phase of the Conservation Agriculture Programme (CAP II) Survey Results 2013 Final Report. London: IMCS Limited for CFU. Retrieved from http://conservationagriculture.org/cfu-research

Klerkx, L., B. Van Mierlo, and C. Leeuwis. 2012. Evolution of Systems Approaches to Agricultural Innovation: Concepts, Analysis, and Interventions. In: *Farming Systems Research into the 21st Century: The New Dynamic,* ed. Ika Darnhofer, David Gibbon, and Benoit Dedieut. The Netherlands: Springer.

Kombiok, J.M. and A.Y. Alhassan. 2007. Tillage Effects on Subsequent Weed Types, Population, and Biomass in Maize Cropped in Northern Savanna Zone of Ghana. *Journal of Sustainable Agriculture* 30.1: 47–57. doi:10.1300/J064v30n01_06.

Lotter, D. 2014. Facing Food Insecurity in Africa: Why, After 30 Years of Work in Organic Agriculture, I Am Promoting the Use of Synthetic Fertilizers and Herbicides in Small-Scale Staple Crop Production. Published online: 7 October 2014 in *Agric Hum Values* 32. 111–18, by Springer Science Business Media Dordrecht. doi:10.1007/s10460-014-9547-x.

Mavudzi, Z., A.B. Mashingaidze, O.A. Chivinge, et al. 2001. Improving Weed Management in a Cotton-Maize System in the Zambezi Valley, Zimbabwe. Presented at the BCPC Conference: Weeds, 12-15 November 2001. In Volume 1 and Volume 2 Proceedings of an International Conference. Brighton, UK.

Mbazima, K.M. 1997. Factors Affecting the Adoption of the Use of Herbicides in Small- and Medium-scale Maize Production: The Case of the Copperbelt and Central Provinces of Zambia. MBA Thesis, Copperbelt University, Zambia.

Moro, S. and Kwasi Ohene Yankyera. 2014. Trade Potential Factors Influencing Herbicides Use of Yam Farm Households in Kpandai District in Northern Region, Ghana. *Journal of Agriculture and Environment for International Development* 108.1: 29–42.

Mutambara, J., G.B. Ayoola, E.P. Ejembi, T. Avav, et al. 2013. Production and Productivity of Maize Subjected to Modern and Traditional Methods of Weed Control Options in Federal Capital Territory, Nigeria. *Journal of Agricultural Extension and Rural Development* 5.5: 107–114. Can be accessed at http://www.academicjournals.org/app/webroot/article/article1379757398_Mutambara%20et%20al.pdf.

Muoni, T., L. Rusinamhodzi, and C. Thierfelder. 2013. Weed Control in Conservation Agriculture Systems of Zimbabwe: Identifying Economical Best Strategies. *Crop Protection* 53.November: 23–28.

Muthamia, J.G.N., F.M.J. Maina, J.O. Okuro, et al. 2004. Participatory On-Farm Trials on Weed Control in Smallholder Farms in Maize-Based Cropping Systems. In *Integrated Approaches to Higher Maize Productivity in the New Millennium: Proceedings of the Seventh Eastern and Southern Africa Regional Maize Conference, 5-11 February 2002,* ed. D.K Friesen and A.F.E. Palmer. Nairobi, Kenya, CIMMYT, KARI.

National Bureu of Statistics. 2009, 2011, 2013. Tanzania National Panel Survey Dar es Salaam: NBS, United Republic of Tanzania.

National Bureau of Statistics. 2008. Agriculture Sample Census Survey 2007/08. National Bureau of Statistics, Dar es Salaam: NBS, United Republic of Tanzania.

National Statistical Office. 2011. Third Integrated Household Survey 2010/11. National Statistical Office. Lilongwe: Republic of Malawi.

National Statistical Office. 2013. Integrated Household Panel Survey 2013. National Statistical Office. Lilongwe: Republic of Malawi.

Ngeleza, G.K., R. Owusua, K. Jimah, and S. Kolavalli. 2011. *Cropping Practices and Labor Requirements in Field Operations for Major Crops in Ghana: What Needs to be Mechanized?* IFPRI Discussion Paper No. 01074. Washington, DC: International Food Policy Research Institute.

Ntow, W.J., H.J. Gijzen, P. Kelderman, and P. Drechsel. 2006. Farmer Perceptions and Pesticide Use Practices in Vegetable Production in Ghana. *Pest Management Science* 62.4: 356–65. doi:10.1002/ps.1178.

Nyanga, P.H., F.H. Johnsen, and T.H. Kalinda. 2012. Gendered Impacts of Conservation Agriculture and Paradox of Herbicide Use among Smallholder Farmers. *International Journal of Technology and Development Studies* 3.1: 1–24.

Obuo, J.E.P., J. Oryokot, A. Okuni, J. Okwadi, et al. 2001. Improving Weed Management in Uganda through the Development of Sustainable Draught Animal Technologies. In *The BCPC Conference: Weeds, 2001, Volume 1 and Volume 2.* Proceedings of an International Conference Held at the Brighton Hilton Metropole Hotel, 12-15 November, ed. D.V. Clay and M.J. Drinkall. Brighton, UK. British Crop Protection Council.

Oppong, F.K., K. Osei-Bonsu, and F.M. Amoah. 2008. Appraisal of Some Methods of Weed Control during Initial Establishment of Cocoa in a Semi-Deciduous Forest Zone of Ghana. *Ghana Journal of Agricultural Science* 40.2: 67–72. doi:10.4314/gjas.v40i1.2155.

Orr, A., B. Mwale, and D. Saiti. 2002. Modelling Agricultural 'Performance': Smallholder Weed Management in Southern Malawi. *International Journal of Pest Management* 48.4: 265–78. doi:10.1080/09670870210149808.

Overfield, D., 2000. *Socio-Economic Study of the Uptake of Herbicide Technology in Maize Cropping Systems.* Final Technical Report No. R7404 (ZA0301). London: DFID. Crop Protection Programme.

Pingali, P.L., Y. Bigot, and H.P. Binswanger. 1988. Agricultural Mechanization and the Evolution of Farming Systems in Sub-Saharan Africa. Washington, DC: World Bank Publications.

Quiñones, E.J. and X. Diao. 2011. *Assessing Crop Production and Input Use Patterns in Ghana: What Can We Learn from the Ghana Living Standards Survey (GLSS5)?* Ghana Strategy Support Program Working Paper No. 24. Accra, Ghana: IFPRI.

Ragasa, C., A. Dankyi, P. Acheampong, et al. 2013. *Patterns of Adoption of Improved Maize Technologies in Ghana*. Ghana Strategy Support Program (GSSP) Working Paper No. 36. Accra, Ghana: IFPRI.

Rogers, E.M. 2003. *Diffusion of Innovations*, 5th Edition. New York: The Free Press.

Sheahan, M. and C.B. Barrett. 2014. *Understanding the Agricultural Input Landscape in Sub-Saharan Africa: Recent Plot, Household, and Community-Level Evidence*. Policy Research Working Paper No. WPS 7014. Washington, DC: World Bank Group.

Shetto, R.M., E.M. Kwiligwa, S. Mkomwa, and M. Massunga. 1993. Weed Control by Draft Animals: Experiences in the Southern Highlands of Tanzania. In Animal Power for Weed Control, ed. P. Starkey and T. Simalenga. A resource book of the Animal Traction Network for Eastern and Southern Africa (ATNESA). Wageningen, The Netherlands: Technical Centre for Agricultural and Rural Cooperation (CTA).

Syakalima, M., K. Choongo, R. Mwenechanya, et al. 2006. Pesticide/Herbicide Pollutants in the Kafue River and a Preliminary Investigation into Their Biological Effect through Catalase Levels in Fish. *Japanese Journal of Veterinary Research* 54.2,3: 119–28.

Tatenda, R., J. and M. Stanford. 2013. Efficacy and Economics of Manual and Chemical Weed Control Strategies in the First Year of Conservation Agriculture Adoption in the Highveld Areas of Zimbabwe. *Global Advanced Research Journal of Agricultural Science* 2.9: 231–41.

Tegemeo Institute. 2000 and 2004. Rural Household Survey 2004. Njoro, Kenya: Egerton University, Tegemeo Institute and Michigan State University.

Tegemeo Agricultural Policy Research and Analysis (TAPRA). 2007 and 2010. Rural Household Indicator Survey. Njoro, Kenya: Egerton University, Tegemeo Institute and Michigan State University.

Tegemeo Agricultural Policy Research and Analysis (TAPRA). Various dates. Tegemeo Panel Surveys 2000, 2004, 2007, 2010. Njoro, Kenya: Egerton University, Tegemeo Institute.

Tittonell, P., M.T. Van Wijk, M.C. Rufino, et al. 2007. Analysing Trade-offs in Resource and Labour Allocation by Smallholder Farmers Using Inverse Modelling Techniques: A Case-Study from Kakamega District, Western Kenya. *Agricultural Systems* 95.1,3: 76–95.

Wall, P.C. 2007. Tailoring Conservation Agriculture to the Needs of Small Farmers in Developing Countries: An Analysis of Issues. Journal of Crop Improvement 19: 137–155.

White, B. 2012. Agriculture and the Generation Problem: Rural Youth, Employment, and the Future of Farming. *IDS Bulletin* 43.6: 9–19.

Williamson, S. 2003. *Pesticide Provision in Liberalised Africa: Out of Control?* AgREN Paper No. 126. London: ODI's Agricultural Research and Extension Network (AgREN).