Feed the Future Innovation Lab for Food Security Policy

Research Paper 24 October 2016

Mali Food Security Policy Research Program

CAUSES AND CONSEQUENCES
OF INCREASING HERBICIDE USE IN MALI

By

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Food Security Policy *Research Papers*

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ACKNOWLEDGMENTS

The authors wish to thank Naman Keita and the team of field enumerators he led at the Institut d'Economie Rurale (IER) Programme Economie des Filières for the care and professionalism they exhibited in conducting four rounds of detailed farm household surveys as well as village-level focus groups. We are likewise grateful to Amadou Diarra, Abdramane Traoré and Boubacar Diallo for helpful insights into pesticide regulatory structures and markets. Participants at the American Agricultural Economics Association meetings in Boston in August 2016 provided constructive feedback on early analytical results. USAID/Mali has funded this work through the Projet de Recherche sur la politique de sécurité alimentaire au Mali (PRePoSAM) awarded under the Food Security Innovation Lab's Cooperative Agreement Number AID-688-A-16-00001. In addition to this USAID funding, collection of survey data utilized in this analysis was funded, in part, by the Bill & Melinda Gates Foundation under the project "Guiding Investments in Sustainable Agricultural Intensification in Africa." The authors alone assume responsibility for any remaining errors of fact or interpretation.

Published by the Department of Agricultural, Food, and Resource Economics, Michigan State University, Justin S. Morrill Hall of Agriculture, 446 West Circle Dr., Room 202, East Lansing, Michigan 48824, USA

Abstract

This paper examines the origins and impact of rapid recent growth of herbicide use in Mali. Primary data come from interviews with herbicide importers and distributors in major markets across Mali and from a 2014/15 survey of 700 farm households in Mali's Sudanian Savanna zone. Results suggest that a series of major supply-side innovations are driving growth in Mali's herbicide markets, most conspicuously a proliferation in the number of herbicide brands marketed, a shift to low-cost suppliers in China and India, and consequently falling herbicide prices. At the farm level, herbicides cost on average 50% less than hiring weeding labor. Despite low econometric estimates of damage abatement, herbicide adoption rates reach 25% in remote rural zones and 75% in more accessible rural areas. Key factors affecting adoption include spatial variation in herbicide prices and rural wage rates. At current rates, herbicide usage reduces peak season rural labor demand by 20%.

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Abbreviations

CILSS	Comité Permanent Inter-Etats de Lutte contre la Sécheresse dans le Sahel
CMDT	Compagnie Malienne pour le Developpement du Textiles
CSP	Comité Sahélien des Pesticides
DTE-Chine	Datong Enterprises
ECOWAS	Economic Community of West African States
FTE	full-time adult male equivalent
IARC	International Agency for Research on Cancer
IER	Institut d’Economie Rurale
LDC	Louis Dreyfus Commodities
MPC	Mali Protection Cultures
OMA	Observatoire du Marché Agricole
ON	Office du Niger
PRePoSAM	Projet de Recherche sur la politique de sécurité alimentaire au Mali
SOGEA	Société Générale Agricole

1. Introduction

Herbicide use has grown rapidly in Mali over the past decade and a half. Quantities imported have more than doubled since the year 2000, while unit prices have fallen by 50% in local currency and nearly 30% in dollar terms (Table 1). Unlike fertilizer, which receives a 50% government-financed price subsidy, herbicide users pay full commercial price (Thériault et al. 2015). While large-scale government tenders and public subsidies have fueled recent increases in fertilizer availability, rapid growth in herbicide use has emerged as a result of purely private sector supply systems meeting growing on-farm demand.

This paper examines the causes and consequences of rapid recent growth of herbicide use among Malian farmers. On the supply side of this growing market, the paper examines the evolving structure of private sector production and distribution systems, key intellectual property and regulatory events and the commercial branding strategies that have all favored rapid expansion of herbicide supplies in recent years. On the demand side of the herbicide market, the paper examines factors affecting on-farm adoption and use levels. Recognizing that herbicides limit damage rather than raising productivity (Lichtenberg and Zilberman 1986), the analysis investigates the effect of herbicide use on smallholder production of sorghum and maize by estimating a production function with and without damage control.

In terms of potential impact, growing herbicide use holds implications for farm productivity, labor demand and the environment. Given that agriculture employs over half of Mali's workforce and that peak-season weeding provides the single largest labor demand in many cropping systems (Gianessi and Williams 2011), rising herbicide use implies potentially significant reduction in employment opportunities, particularly for the rural poor. Potential environmental spillovers raise parallel concerns about farm worker safety, possible herbicide resistance and unintended disruptions in plant and animal populations. As a result, crucial tradeoffs may emerge between farm productivity gains, environmental spillovers and aggregate employment losses. This paper examines these three major implications of expanding herbicide use in Mali.

Table 1. Trends in herbicide imports* into Mali, 2000 to 2014

Herbicide imports	2000	2005	2010	2014	Change
Quantity (tons)	1,132	1,037	1,420	2,660	135%
Price					
000 CFAF/liter	3.9	2.9	2.1	1.9	-50%
US dollars/liter	5.44	5.55	4.27	3.91	-28%

* Three-year moving averages.

Source: Camara et al. (2003), Institut National de la Statistique du Mali (INSTAT).

The paper begins, in Section 2, with a review of data and methods. The dynamics of herbicide supply systems form the focus of Section 3, while Section 4 focuses on herbicide demand among sorghum and maize farmers in southern zones of Mali. Section 5 provides an assessment of the impact of herbicide use on farm-level productivity, employment and the environment, while the concluding section outlines key analytical and policy implications.

2. Data and methods

2.1. Supply system structure and dynamics

Data for exploring these issues come from a variety of sources. Time-series price information in local markets comes from ongoing monitoring of 10 agricultural markets by Mali's Observatoire du Marché Agricole (OMA), while a 2015 survey of 16 major input markets across Mali provides a recent snapshot of retail distribution density across farming zones (Diarisso and Diarra 2015). Trends in import quantities and prices come from trade figures tabulated by Mali's national statistical agency. Complementing these statistical data, our detailed compilation of regulatory filings at the Comité Sahélien des Pesticides (CSP) has provided a valuable trove of information about the timing of new herbicide releases, introduction of new brands, product renewal decisions as well as withdrawals from the market.

In order to understand supply system trajectories, turning points and key causal forces governing herbicide availability, utilization and pricing, the authors conducted interviews with regulators and with herbicide importers, distributors and retailers in Mali's major agricultural markets during May, June and July of 2016 (Diarra 2016). These qualitative interviews enable us to trace changes in market structure and behavior over time, focusing particularly on key actions shaping commercial strategies, product innovation, branding, packaging, pricing and marketing that are driving rapid recent changes in Mali's herbicide markets.

2.2. Farm level adoption and productivity impact

2.2.1. Adoption

To identify farm-level determinants of herbicide adoption, the paper analyzes data from a 2014/15 survey of 700 farm households in the high-productivity Sudan Savannah zone (Smale et al. 2015). Within these households, we deliberately sampled collective and individual plots managed by women and men from the inventory of all plots worked by the household in order to compare variations in management practices and outcomes. Overall, our sample includes plot-level farm data from 1,305 maize and sorghum plots, enabling us to explore spatial and gender differences in herbicide use as well as the profitability of herbicide use compared to alternate weed control strategies.

To formally test determinants of herbicide use, we estimate two types of corner-solution models. Because over one-third (39%) of all plots surveyed did not receive herbicides, our sample included a large concentration of zero adoption values. Under these conditions, a nonlinear "corner solution" model is more appropriate than a linear model for testing the determinants of use. The well-known Tobit model treats the binary decision to use herbicide

(0,1) and the amount of herbicide used (> 0, conditional on use) as determined by the same underlying process. The Cragg model (1971) relaxes this assumption by allowing the vector of regression parameters β to differ between the two adoption decisions. The Tobit is nested in the Cragg model, which allows estimation of the use and intensity decisions two stages, through the use of Probit regression in the first stage followed by a truncated regression in the second stage. We use a log-likelihood ratio test of the restricted (Tobit) vs. the unrestricted (Cragg) regression to determine which model better fits the underlying data-generation process. For robustness, we also estimate the model using ordinary least squares.

2.2.2. Productivity impact and damage control

To measure the productivity impact of herbicides, we use the same farm household data set to estimate a production function with and without damage control. Unlike conventional inputs (such as land, labor and fertilizer), damage control agents (such as insecticides, fungicides and herbicides) do not increase potential output but rather reduce potential output losses. As a result, use of a standard production function to estimate the effect of damage control agents on productivity may lead to biased estimates. In their seminal work, Lichtenberg and Zilberman (1986) addressed potential upward bias by incorporating a damage control abatement function into the standard production function. However, the direction of the bias been debated (Pandey 1989). Hall and Moffitt (2002), for example, demonstrate the potential downward bias resulting from estimating a damage control model based solely on economic variables in the absence of actual data on pest populations.

Most research using a damage control abatement model has focused on insecticides, including research on Bt crops (e.g, Saha et al., 1997; Chambers et al. 2010; Shankar and Thirtle 2005; Kouser and Qaim 2014). Herbicides, as a single damage control agent, have received less attention. Previous herbicide studies have instead focused mostly on the economics of herbicide resistance (e.g., Beltran et al., 2012; Weersink et al., 2005) and weed resistance to herbicides (e.g., Owen and A Zelaya 2005).

In this paper, we estimate a production function with damage control to examine the effect of herbicide use on sorghum and maize production, following the original specification of Lichtenberg and Zilberman (1986) and the example of Carrasco-Tauber and Moffitt (1992). Following their example, we define the damage control function as $Y=F[(\mathbf{Z}), G(\mathbf{X})]$, where Y represents output value and the vector $\mathbf{Z}$ includes inputs of the standard production model. The vector $\mathbf{X}$ consists of control inputs. $G(\mathbf{X})$ is increasing in $\mathbf{X}$ and approaches an upper limit of 1, where $Y=F(\mathbf{Z})$. As $\mathbf{X}$ decreases, $G(\mathbf{X})$, and $Y=F(\mathbf{Z}, 0)$ approach the lower limit of 0, or a level that represents maximum destructive capacity. In most applied work, researchers specify the function multiplicatively as $Y=F(\mathbf{Z})G(\mathbf{X})$. The damage abatement effect represents the proportion of the destructive capacity (modeled as a cumulative density function valued between 0 and 1) offset by utilizing a given amount of a control input. In empirical work, researchers typically estimate the cumulative distribution function $G(\mathbf{X})$, which lies in a [0,1] interval, as Weibull, exponential, or logistic functions. $F(\mathbf{Z})$, thus, represents the maximum yield attainable with zero pest damage or maximum pest control.

We chose the Cobb-Douglas functional form for the production model ($F(\mathbf{Z}) = \beta_0 \prod_i \boldsymbol{Z}_i^{\beta_i}$).

The form has been extensively used in damage control analyses and is parsimonious relative to more flexible forms. We estimate the production function with damage abatement using nonlinear least squares, which imposes some restrictions on the choice of functional forms. In testing quadratic functions, which have also been applied in the literature, we obtained coefficients largely similar to those of the Cobb-Douglas formulation but statistically insignificant due to high degrees of collinearity. In estimating the G(Z) functions, we tested Weibull, logistic and exponential functional forms. Of these, only the regressions with the logistic functional form converged, suggesting a better fit to the data. Full variable descriptions and results follow in the analysis below.

2.3. Employment and environmental impact

In order to measure the aggregate labor displacement resulting from widespread herbicide adoption, the analysis below compares changes in labor demand with expected labor supply levels. Data on farm labor demand – with and without herbicides – come from a series of farm budget studies conducted by Mali's Institut d'Economie Rurale (IER), the Compagnie Malienne pour le Developpement du Textiles (CMDT), the Office du Niger and from our own farm household survey in southern Mali (Tefft 2010, Office du Niger 2012, Diarra et al. 2014, Smale et al. 2015, Kergna 2016). Labor supply estimates rely on the demographic and labor supply modules from Mali's 2009 population census, which include age- and gender-disaggregated demographic pyramids and economic participation rates (CPS/SDR 2010).

Environmental impacts from herbicide use can potentially affect farm worker safety (through direct exposure during application), consumer health (from plant residues consumed), water quality, animal populations (including fish as well as soil bacteria), weed populations and other plant species (see Wesseler et al. 2011, Waterfield and Zilberman 2012). Given the complexity and time scale required for measuring environmental impacts, this study has not attempted to collect primary data on these issues. Instead, we rely on a series of studies and reviews conducted by regional regulatory bodies and local researchers (Keita 1992, Camara et al. 2003, MIR Plus 2012).

3. Marketing and supply system transitions

3.1. Herbicide products

Glyphosate, the world's top selling herbicide, accounts for the majority of herbicide sales in Mali as well. Developed by Monsanto and first released commercially in 1976 under the trademark name Roundup, glyphosate is a broad-spectrum herbicide that kills both grasses and broad-leaf weeds (Charles 2001). Malian importers and agricultural input retailers consistently identify glyphosate as their top-selling herbicide. Offering a rough order of magnitude, farm survey data from southern Mali suggest that glyphosate accounts for about two-thirds of herbicide volumes used, while selective herbicides (used primarily on cotton, maize and rice) account for the remaining one-third (Table 2).

Over time, the number of herbicide products registered for sale in Mali has expanded rapidly (Table 3). Following registration of only a handful of cotton-selective herbicides for sale in

1995, the number and range of herbicide products has increased rapidly to 49 as of December 2015. The period since 2010 has witnessed an unusually large jump in the herbicide brands proposed and registered for sale in Mali. This proliferation of products has accompanied substantial changes in the structure of the herbicide supply system.

Table 2. Farmer use of registered and unregistered herbicides on maize and sorghum plots in southern Mali, 2014/15

Herbicide type	Herbicide registration		
	registered	uncertain	total
Percent of plots using herbicide			
Glyphosate*	34	40	74
Selective**	20	7	27
Total	53	47	100
Percent of herbicide volume used			
Glyphosate*	31	36	67
Selective**	24	9	33
Total	55	45	100

* Non-selective, total herbicide.

** Nicosulfuron, pendimethalin, atrazine, isoxaflutole, 2,4-D.

Source: CSP INSAH (2013), Smale et al. (2015) survey data analysis.

Table 3. Trends in the number of herbicide products registered for sale in Mali

Herbicide categories	1995	2000	2005	2010	2015
Broad-spectrum (total) herbicides					
glyphosate	0	2	3	7	12
paraquat	0	1	0	0	0
subtotal	0	3	3	7	12
Selective herbicides					
cotton	3	2	3	7	12
maize	0	3	0	5	9
rice	1	1	0	6	16
subtotal	4	6	3	18	37
Total	4	9	6	25	49

Source: Comité sahelien des pesticides (CSP)

3.2. Supply system

Imports supply the entirety of the Malian herbicide market, with six major importers dominating the herbicide trade. The largest of these, Mali's parastatal cotton company, the Compagnie malienne pour le développement du textile (CMDT), purchases large volumes of pesticides (primarily insecticides but also herbicides) through tender then sells them on credit through local cooperatives to Mali's roughly 180,000 cotton farmers (Tefft 2010). Our field visits indicate that small volumes of CMDT-supplied inputs reach local markets as a result of cotton farmers reselling small volumes of CMDT-supplied inputs on the open market for cash. Far larger quantities of herbicides sold local markets come through the five other large commercial importers – Louis Dreyfus Commodities (LDC), Mali Protection Cultures (MPC), Datong Enterprises (DTE-Chine), Société Générale Agricole (SOGEA) and Toguna Agro Industries. Another 20 smaller registered importers compete in this space along with an unknown but likely much larger number of unregistered small traders and smugglers who import off-brand herbicides regionally from Guinea, Ghana, Burkina Faso and Côte d'Ivoire.

At the retail level, thousands of small vendors sell herbicides directly to farmers in markets all across Mali. Qualitative interviews with agro-dealers indicate that herbicides constitute a growing share of their sales, as farmer demand continues to grow. Data from a recent survey of 16 agricultural markets across Mali help to quantify the growing importance of herbicide sales. Market surveys in 2015 indicate that over two-thirds of agro-dealers in Mali supply herbicides to farmers, slightly more than sell fertilizer and significantly more than sell seeds. Geographically, herbicide sales are most prevalent in the cotton zones of southern Mali and in farming areas that lie close to major urban centers (Table 4). Spatial data, reported in Section 4.2 below, from farm household surveys reinforce these findings on the link between urban proximity and herbicide use.

Table 4. Prevalence of agricultural inputs sold in 16 markets across Mali*

	Percent of Retailers Selling Specific Inputs		
Zones	herbicides	fertilizer	seeds
Served by parastatal marketing agencies			
1 Cotton zone (CMDT,OHVN)	76%	61%	48%
2 Irrigated rice zone (ON)	61%	73%	50%
Without parastatal marketing companies			
3 Accessible zones	72%	60%	72%
4 Remote areas	58%	73%	32%
All markets surveyed	68%	66%	51%

*Markets included in each zone include the following:

1) Compagnie Malienne de Dévéloppement des Textiles (CMDT, Sikasso, Koutiala, Fana) and Organization of the Upper Niger Valley (OHVN, Ouélésebougou)
2) Office du Niger: Niono, Ségou, Macina, Kolongotomo
3) Accessible zones without parastatals: Mopti, Kati, Banamba, Diéma
4) Remote areas without parastatals: Nara, Tominian, Kéniéba, Koro

Source: Diarisso and Diarra (2015).

Seasonally, large numbers of temporary and itinerant traders enter into the herbicide trade. During the early part of the agricultural season, in June and July when farmers are preparing land and planting, herbicide sales explode as do the number of seasonal traders. Our market visits revealed bicycle repair shops, shoe repair shops, general retailers and large numbers of young men, arriving on motorcycles and in bush taxis, selling herbicides. Agro-dealers we interviewed in roughly a dozen local markets suggest that these peak season temporary and itinerant herbicide retailers often outnumber permanent sellers by a factor of 10.

3.3. Regulatory framework

Since the 1990s, following a series of coordinated efforts to control major insect infestations across the Sahel, the Sahelian countries of West Africa have regulated pesticides regionally. In 1994, the Comité Permanent Inter-Etats de Lutte contre la Sécheresse dans le Sahel (CILSS) established a regional regulatory body, the Comité sahelien des pesticides (CSP), to review and certify all pesticide products sold in throughout the nine member countries[1] (Diarra 2015). Under these rules, any pesticide passing CSP efficacy and safety reviews and registered (homologated) for sale in one member country become automatically authorized for sale throughout all nine member countries. By centralizing this regulatory review process, the CSP provides a one-stop-shop for manufacturers and importers, facilitating the review process and enabling suppliers to reduce bureaucratic costs by standardizing and centralizing review procedures. Rather than preparing nine separate dossiers for review in nine separate countries, prospective suppliers deal with a single regulator whose approval authorizes sales across a multi-country regional market.

Impressed with the simplification and economies of scale afforded by the CILSS system of regional regulation, the Economic Community of West African States (ECOWAS) in 2011 adopted the same model for all 15 members of the ECOWAS region. Moreover, ECOWAS has asked CILSS to help set up a comparable regional review body for the humid coastal member countries to serve the same function the CSP plays in the arid interior member states (Diarra 2015).

3.4. Marketing and branding

Since the introduction of the CILSS regional regulatory system, the number of herbicide brands registered for sale by the CSP has grown rapidly, particularly in the period since September of 2000 when Monsanto's patent protection for Roundup expired (Zimdahl 2016). Expiration of the Roundup patent has unleashed a parade of new glyphosate brands – worldwide as well as in Mali. Major international agro-chemical companies (including Syngenta, Dow, Bayer and Arysta) have introduced their own glyphosate brands, sold in Mali under trade names such as Kalach, Finish, Mamba Dominator and Touchdown.

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[1] The original nine CILSS member countries included Cape Verde, Senegal, Gambia, Guinea-Bissau, Mauritania, Mali, Burkina Faso, Niger and Chad.

More recently, West Africa-based traders have entered the herbicide product branding game (Table 5). In 2008, a Guinean firm registered a new brand of glyphosate, called Glycel, for sale across the CILSS member countries. The Guinean firm, Topex Agro Elevage, commissions Glycel production through an Indian manufacturer based in Mumbai. In a stark departure from the early Roundup imitators, Glycel shifted packaging from the standard Roundup white and green colors to a yellow bottle with a red cap (Figure 1). Marketed as the "Red Beret" – with tough-guy, Special Forces power – Glycel has become one of the dominant glyphosate brands sold in Mali.

A rash of imitators has copied Glycel's Red Beret packaging by enlisting an array of low-cost manufacturers in China and India to manufacture and package similar-looking glyphosate products (Figure 1). In June 2016, our survey teams identified a total of 25 brands of glyphosate for sale on the Malian market. Of these, roughly half have received regulatory approval (11 by the CSP, 1 by Ghana and 1 from Guinea) while the remaining half have not. The explosion of newly registered regional brands – with its welter of unregistered imitators – has led to widespread smuggling, customs and regulatory evasion. As a result, regulators and registered importers have raised increasing concerns about product quality and safety (MIR Plus 2012).

Figure 1. Registered and Unregistered Brands of Glyphosate Sold in Mali, June 2016

a. Roundup and imitators (above)

b. Glycel and imitators (above)

Glyphosate prices have fallen in recent years as a result of expiring patent protection for Roundup, increased competition from alternate brands, a move to low-cost Asian manufacturers and increasing efforts by unregistered brands to evade regulatory costs and formal customs duties. Since 2008, Mali's Observatoire du marché agricole (OMA) has tracked herbicide prices across ten major agricultural markets in Mali. The OMA market monitoring data indicate that glyphosate prices have fallen by about 35% in local currency (50% in dollars) among the newer glyphosate brands (such as Kalach), while Roundup prices have declined only slightly in CFA francs (Table 6). Softening prices, in turn, make herbicide uptake increasingly profitable at the farm level, as the following discussion demonstrates.

Table 5. Trends in number of glyphosate brands registered for sale within Mali

Five-year intervals beginning in	Number of brands registered International*	Regional**
1995	0	1
2000	4	5
2005	2	5
2010	1	16
2015	0	5

* International brands include those produced by the Big Six international pesticide companies: Bayer, BASF, Dow, Dupont, Monsanto and Syngenta.
**Regional brands include those registered by local firms, including products such as Glycel, Touchdown, Glyphonet and Sunoglyph.
Source: Comité Sahélien des Pesticides (CSP).

Table 6. Glyphosate retail price trends : average annual retail price in 12 markets tracked by Mali's Observatoire du Marché Agricole (OMA)

Brand	2008	2009	2010	2011	2012	2013	2014	2015	Cha
Price in CFAF/liter									
Kalach 360	4,833	4,313	4,313	2,804	2,958	3,164	3,375	3,125	-3
Roundup 360	4,833	5,250	4,938	6,000	5,000	4,458	4,479	4,375	-
Price in US dollars/liter									
Kalach 360	10.8	9.1	8.7	5.9	5.8	6.4	6.8	5.3	-5
Roundup 360	10.8	11.1	10.0	12.7	9.8	9.0	9.1	7.4	-3

Source: Observatoire du Marché Agricole (OMA)

4. Farm-level demand

4.1. Weed management options

Malian farmers have historically controlled weeds by hand weeding and by full soil inversion (plowing) during land preparation. During the 2014/15 cropping season, smallholder farmers in southern Mali applied herbicides on slightly over 60% of their maize and sorghum plots (Table 7). Among those using herbicides, glyphosate accounted for about two-thirds of the total volume of herbicides applied (Table 2).

Herbicides cost less than half as much as hiring hand weeding labor, on average, in the zones studied. Our survey of sorghum and maize farmers in southern Mali indicates that farmers who applied herbicides spent an average of $23 per hectare on herbicides. Had they hired weeding labor instead, they indicate that they would have had to spend $52 per hectare, over twice as much.

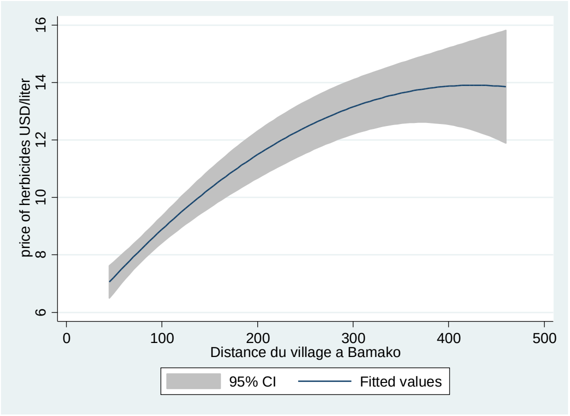
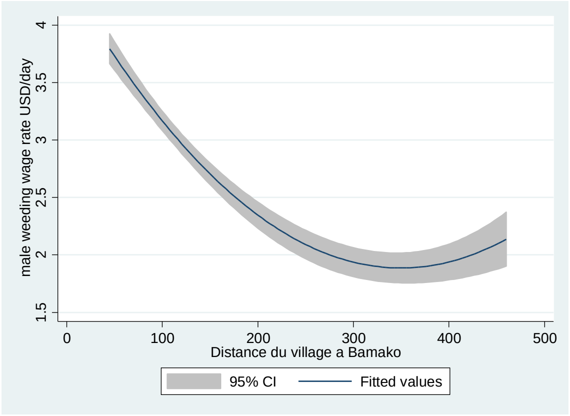
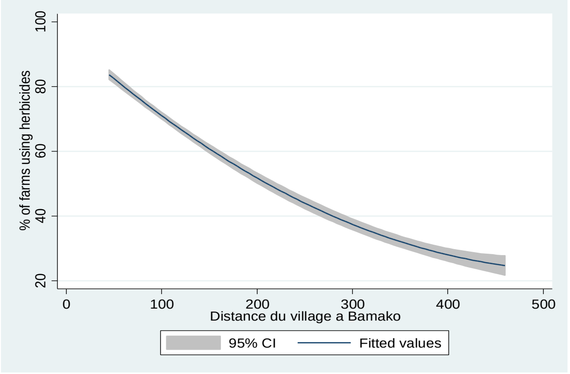
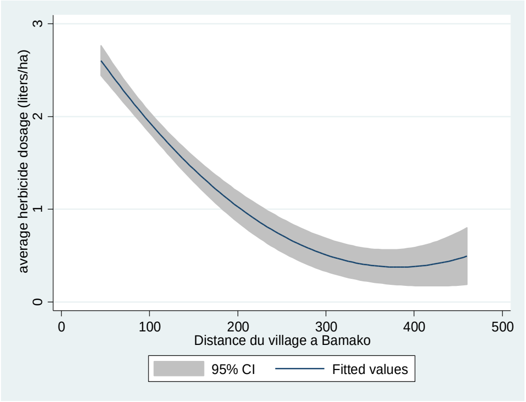
4.2. Spatial differences in adoption

The profitability of herbicide use varies substantially by location, since the relative prices of weeding labor and herbicides both vary spatially. In general, herbicide prices increase in remote areas because of high transport costs and limited competition. Since most herbicides enter Mali through depots in Bamako, prices typically increase along with distance from the capital city. In zones nearby Bamako, farmers pay about $7 per liter for herbicides. However, in rural communities 400 km away, this price increases to nearly $14 per liter (Figure 2a).

Wage rates move in the opposite direction. Given greater opportunities for nonfarm earnings in peri-urban and semi-rural areas, the opportunity cost of farm labor increases along with urban proximity. As a result, farmers within 100 kilometers of Bamako pay over $3 per day for adult male weeding labor, while growers in zones 400 kilometers away pay about $2 per day (Figure 2b).

The scissors effect – of lower herbicide prices and higher farm wages in nearby zones – leads to higher profitability of herbicide use in more accessible rural zones. In farming areas within 100 kilometers of Bamako, over 75% of farmers apply herbicides on their sorghum and maize plots, while in communities 400 kilometers away, only 25% apply herbicides (Figure 2c). Application rates likewise fall off as distance from major urban centers increases. While farmers within 100 kilometers of Bamako apply over 2 liters of herbicides per hectare, their counterparts living 400 kilometers away apply only half a liter per hectare (Figure 2d).

Figure 2. Spatial difference in herbicide prices, wage rates and herbicide adoption

a. Herbicide price (USD/liter)	b. Wage rate, adult male weeding labor (USD/day)
	
c. Herbicide adoption (% of plots)	d. Herbicide application rate (liters/ha)
	

Source: Fitted quadratic plots with 95% confidence intervals, computed from 2014/15 farm household survey described in Smale et al. (2015).

4.3. Gender differences in herbicide adoption

Women manage about 25% of sorghum plots in southern Mali, though none of the maize plots in the 58 villages we surveyed (Table 7). Family fields managed by the household head, which ensure basic food security for the extended family, account for 80% of all sorghum plots and over 95% of maize plots (Table 7). Typically, the head of household or his designated “chef de travaux" (usually one of his grown sons), manage these common fields, enlisting labor from the extended family as required.

In addition, the household head allocates other plots of land to adult members of the extended family, including sons and their wives, for individual management. The plot managers control proceeds from these fields, which they utilize to meet their own personal needs and those of their children. Adult men rarely grow coarse grains on their individual plots, preferring higher value cash crops. In order to supplement food for their children, adult women, in contrast, do request individual plots for growing sorghum which they often intercrop with cowpea or groundnuts.

Women apply herbicides on nearly 80% of the individual sorghum plots they manage, compared to under 50% of male-managed family sorghum plots (Table 7). Women likewise apply herbicides at over twice the rate, 2.6 liters per hectare compared to 1.1 liter on the family sorghum plots. Male-managed individual plots similarly apply herbicides more frequently and at higher doses than the male-managed family fields.

Table 7. Gender differences in herbicide adoption and rates of application

		Crop grown		
Plot manager	Plot type	sorghum	maize	total
	Number of observations			
Household head	family	565	567	1132
Woman	individual	197	0	197
Man	individual	20	10	30
Total		782	577	1359
	Percent of plots using herbicides			
Household head	family	47	69	58
Woman	individual	79		79
Man	individual	90	60	80
Total		56	69	61
	Herbicide application rate (liters/ha)			
Household head	family	1.1	1.7	1.4
Woman	individual	2.6		2.6
Man	individual	3.3	2.5	3.1
Total		1.6	1.7	1.6

Source: southern Mali farm survey analysis; see Smale et al. (2015) for survey details.

4.4. Determinants of herbicide adoption

Table 8 presents Cragg model estimates of factors affecting herbicide use among sorghum and maize farmers in southern Mali. OLS and Tobit formulations of the adoption decision produce qualitatively similar results (Annex Table A1). In practical terms, the Cragg model results confirm differences between determinants of the decision to use and extent of use. Statistically, the likelihood ratio test also favors the unrestricted (Cragg) model to the Tobit model.

The first column in Table 8 examines factors affecting the decision to use or not to use herbicides. These results suggest several clear conclusions. First of all, price variables strongly shape incentives. Low herbicide prices and high wage rates[2] both significantly increase the probability of herbicide use. Female managers of individual plots are also more likely to use herbicides than male managers of family common plots. This result may stem from women's weaker claims on family weeding labor or high perceived opportunity cost of labor by female plot managers. Although this result also holds for male managers of individual plots compared to family common plots, women account for 90% of all individually managed plots (Table 7). Sorghum plots receive less frequent herbicide application than maize. This may occur because of the frequency of maize cultivation by cotton farmers, who receive inputs (including herbicides) on credit from the CMDT. Household wealth and income transfers also significantly increase the likelihood of herbicide use. In addition to relieving cash constraints, they may signal a shortage of rural labor (temporary migration) or serve as a proxy for nonfarm earning opportunities.

In terms of quantities of herbicides used (liters per plot), prices also strongly shape herbicide use. As in the adoption decision, application rates increase with weeding labor costs and as herbicide prices fall (Table 8 column 2). Plot size clearly matters in the total amounts used (though not the likelihood of use), since larger plots require higher input volumes. However, female plot managers use less total herbicides per plot simply because their plots are much smaller. While household wealth significantly influences total herbicide quantities used, income transfers do not. Similarly, and surprisingly, household labor supply does not appear to significantly influence to either decision. Although primary education appears to increase the likelihood that a plot manager uses herbicide, it is negatively related to the extent of use. This may stem from larger quantities being used on the larger plots managed by household heads, who tend to be the most senior and least educated household members.

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[2] We have tested these models using two different measures of weeding wage rates: a) farmer estimates of hired labor cost; and b) village-level focus groups which generated a uniform village-level wage rate. The two sources produce similar mean wage rates – $3.26 and $2.89, respectively, for adult males – as well as comparable econometric results. Tables 8 and A1 report results from the farmer-based wage estimates.

Table 8. Cragg model explaining herbicide use on maize and sorghum plots in the Sudan Savanna of Mali

Explanatory variables	Decision to use (0,1)	Liters, if used (>0)
Prices		
herbicide price (USD)	-0.041***	-0.101***
	(0.010)	(0.020)
daily weeding wage (USD)	0.248***	0.060***
	(0.030)	(0.018)
Manager		
female manager	0.964***	-0.635***
	(0.142)	(0.233)
manager has primary education	0.382***	-0.480**
	(0.113)	(0.195)
Plot characteristics		
sorghum plot	-0.671***	0.073
	(0.090)	(0.174)
plot size	0.134***	0.788***
	(0.035)	(0.067)
distance plot to house	-0.004*	0.009**
	(0.002)	(0.004)
Household characteristics		
labor supply per EAF	-0.000	-0.015
	(0.009)	(0.017)
asset value of EAF (USD)	0.180***	0.456***
	(0.049)	(0.100)
transfers to EAF (USD)	0.000***	0.000
	(0.000)	(0.000)
Constant	-0.660*	-1.738**
	(0.394)	(0.831)
Observations	1,205	1,205
Value of log-likelihood function	-1945.457	

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

4.5. Future expectations

Looking forward, expected upward pressure on rural wage rates and downward pressure herbicide prices foreshadow continued growth in herbicide demand by Malian farmers. Strong labor demand in Mali's gold mines (and in neighboring Guinea) along with continued rapid urbanization seem likely to draw away rural labor and maintain upward pressure on rural wage rates. Meanwhile, herbicide prices appear likely to continue their fall. Over the past several years, a strong US dollar has significantly muted the impact of the international herbicide price fall in Mali. In coming years, as European economic malaise recedes and the US dollar becomes less attractive as a refuge for world capital flows, a gradually recovering Euro (and along with it the CFA franc to which it is tied) will translate into falling CFA-denominated herbicide prices, even if dollar prices remain flat. In the medium run, both wage pressure and falling herbicide prices appear likely to maintain incentives for expanded herbicide adoption.

Changing weed populations contribute further pressure to increase herbicide use. In the large irrigated farming perimeters of Mali's Office du Niger (ON), pressure from wild rhizomatous weeds (such as *horiza logistaminata*) have spurred increasing farmer interest in herbicides, particularly glyphosate. Agronomists in the Office du Niger report that flooding and hand weeding no longer suffice for controlling these creeping invasive weeds. Increasingly, early season glyphosate application offers the most effective means of systemic killing of these rizhomes (Soungalo 2016). Early adopting farmers report added benefits of increased organic matter as the dead weeds and rhizomes material decompose in their paddy fields. As a result, both economic and environmental forces appear poised to promote increased herbicide use in coming years.

5. Impact of herbicide use

5.1 Damage abatement in farm production

Damage control agents (such as insecticides, fungicides and herbicides) do not increase potential output but rather reduce potential output losses. Building on Lichtenberg and Zilberman (1986), we develop a damage control abatement function G(X) that we incorporate into a standard Cobb-Douglas production function F(Z) to examine the effect of herbicide use on sorghum and maize production. The damage function G(X) includes total herbicides used (liters), timing of herbicide application (early, during, late) and plowing (hours). Models that included weeding days did not converge—perhaps because of high correlations. Tables 9 below presents a full list of the variables used in this estimation, while Table 10 presents the production function estimates, with and without the damage control abatement functions.

Table 10 presents four production models. The standard production function in model (1) includes only inputs that enhance productivity potential. In model (2), we test the effect of total herbicides applied, treating these as we would conventional inputs in the Cobb-Douglas model. Models (3) and (4) present production models with damage abatement. Model (3) treats total herbicide usage as damage abating, while model (4) disaggregates herbicide volumes by time of application. Both models (3) and (4) include plowing as a damage abating variables, because early season soil inversion exerts a strong pre-emptive effect on weeds.

The standard production function in model (1) confirms that labor, machinery, seed and manure raise expected production levels. Larger plot sizes, likewise, produce larger harvests, other factors held constant. Labor generates the highest production elasticity and overall returns seem to be increasing since elasticities sum to more than unity. Sorghum plots, on average, produce less grain than maize plots. One of the locations, Kati, shows a lower level of grain production relative to Dioila and the omitted location, Koutiala—which is to be expected given the farming systems of the zone. When we control for crop by including the sorghum dummy, fertilizer has no significant effect on expected production; yet when both crops are combined, the effect becomes strongly significant. Small crop-specific subsample sizes prevent us from running separate regressions with the nonlinear damage abatement model.

Model (2), which introduces herbicides naively into a conventional production function, generates a negative, though insignificant estimate of herbicide productivity. Other production function coefficients remain unaffected. Because farmers apply herbicides in response to weed pressure, and because we have no good measure of weed pressure on the right-hand-side of this equation, this omitted variable likely leads to a spurious negative correlation between herbicide use and output.

The damage control function in model (3) suggests that total herbicide quantities generate a positive but small and statistically insignificant impact on output. Similarly, the temporal breakdown in model (4) reveals positive though insignificant productivity impact of planting season and late-season herbicide use. Pre-planting herbicide application produces a small but negative and statistically insignificant coefficient. Consistent with the findings of Hall and Moffitt (2002), these results suggest that econometric estimates of this sort require plot-level data on weed pressure, the omission of which complicates efforts to measure the pure productivity of herbicide use on plots experiencing low and high weed pressure. In future work, controlled agronomic trials offer a still better means of assessing the damage control and productivity impact of herbicide use.

Table 9. Variable definitions

Name	Definition
Adoption	
Use herbicide	1= use herbicide, 0 else
Extent of herbicide use	liters used
Adoption determinants	
Prices	
herbicide price (USD)	unit price paid by farmer in USD, village median for missing
daily weeding wage (USD)	daily weeding wage paid by farmer in USD, village median for missing values
Manager	
female manager	plot managed individually by female who is not the EAF head or designate=1, else 0
manager has primary education	plot manager attended primary school=1, 0 else
Plot characteristics	
sorghum plot	1= sorghum planted, 0=maize
plot size	hectares measured by GPS
distance plot to house	time in minutes to travel from home to the plot
Household characteristics	
labor supply per EAF	number of adults in EAF between 12 and 55 years of age (inclusive)
asset value of EAF (USD)	total value of household assets, excluding livestock (ln USD)
transfers to EAF (USD)	transfers in USD from absent family members in previous 12 mos
Production function [F(Z)]	
plot size	hectares measured by GPS
sorghum plot	2=sorghum planted; 1=maize
Kati	2=village located in Cercle of Kati; 1=else
Dioila	2=village located in Cercle of Dioila; 1=else
labor	log of total days of labor used
fertilizer	log of total kgs of fertilizer
manure	2=manure applied; 1=else
seed	log of total kgs of seed
machinery	log of hours of machinery use
Damage function [G(X)]	
plowing	total hours of plowing
total herbicides	total liters of herbicide
herbicides (early)	liters of herbicide applied before planting
herbicides (middle)	liters of herbicide applied within 10 days of planting
herbicides (later)	liters of herbicide applied more than 10 days after planting

Table 10. Cobb-Douglas production function with damage abatement, sorghum and maize, Sudan Savanna, Mali

	Production function		Production function with damage abatement	
	(1)	(2)	(3)	(4)
Constant	4.300***	4.300***	7.970	8.746
	(0.349)	(0.350)	(0.000)	(0.000)
plot size	0.288***	0.292***	0.468***	0.569***
	(0.051)	(0.052)	(0.079)	(0.082)
Kati	-0.717***	-0.702***	-1.287***	-1.429***
	(0.089)	(0.094)	(0.177)	(0.194)
Dioila	0.015	0.021	0.079	0.007
	(0.082)	(0.082)	(0.157)	(0.166)
sorghum	-0.780***	-0.779***	-1.311***	-1.560***
	(0.106)	(0.106)	(0.121)	(0.124)
labor	0.473***	0.472***	1.179***	0.972***
	(0.085)	(0.085)	(0.146)	(0.165)
machinery	0.167**	0.167**	0.251***	0.309***
	(0.072)	(0.072)	(0.096)	(0.111)
fertilizer	-0.009	-0.008	0.003	-0.022
	(0.022)	(0.023)	(0.037)	(0.039)
manure	0.165**	0.167**	0.263**	0.328**
	(0.071)	(0.070)	(0.134)	(0.142)
seed	0.210***	0.211***	0.335***	0.423***
	(0.043)	(0.043)	(0.070)	(0.075)
total herbicides		-0.016	0.001	
		(0.042)	(0.012)	
herbicides (early)				-0.001
				(0.017)
herbicides (middle)				0.002
				(0.015)
herbicides (late)				0.007
				(0.021)
plowing			0.004	0.004
			(0.006)	(0.006)
Observations	1,172	1,172	1,172	1,172
R-squared	0.607	0.607	0.634	0.634

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Note: Dependent variable is logarithm of production (kgs).

Machinery variable in damage abatement model is net of plowing.

5.2. Employment impacts of herbicide use

Malian farmers control weeds multiple times throughout the season, first at plowing time with full soil inversion during land preparation. After planting, they typically hand weed their fields twice. Hand weeding, at the normal rate of 12 man-days per hectare, accounts for between 30% and 40% of onfarm labor demand in dryland production of coarse cereals (see Annex Table A2). That share falls to 10% to 15% of farm labor use under irrigated rice production (because of high additional labor demands for preparation of seedling nurseries, transplanting and bird scaring) and cotton production (given repeated, heavy labor demand for insect scouting, insecticide spraying and mandatory multiple passes under hand harvesting of only fully ripe bolls).

In contrast, herbicide application requires far less labor, only 1 man-day per hectare compared to 12 man-days for hand weeding. Taking Mali's cropped area of 6 million hectares of cereals, pulses and oilseeds, hand weeding of the entire area would require 3.4 million man-months of labor compared to only 0.3 million man-months using herbicides.

As a share of total agricultural labor supply, hand weeding would require 38% of full-time adult male equivalent (FTE) workforce during the peak post-planting time period (July through August). In comparison, a shift to herbicides would require only 3% of available peak-season labor, freeing up over one-third of the rural labor force (Table 11). If herbicide adoption rates nationally attain the 60% average found in southern Mali, this would imply a reduction of 1.9 million man-months of weeding labor annually, or about 20% of peak-season agricultural labor demand.

Table 11. Weeding share of agricultural labor demand in Mali, 2015

1. Area cropped in cereals, pulses and oilseeds (millions of hectares)			6.0	
2. Weeding labor requirements	hand weeding	herbicides	savings	
a. per hectare (mandays/ha)	12	1	11	
b. mandays per year (millions)	71.6	6.0	65.7	
c. man-months per year (millions)	3.4	0.3	3.2	
		person-months		
3. Agricultural labor force (millions)	people	annual	peak season	
a. annual full-time adult male equivalents (FTEs)	3.0	35.9	9.0	
b. economically active population (EAP)	4.4	53.4	13.3	
c. total population	10.6			
Weeding labor as a share of agricultural labor force (percent)				labor force FTEs
4. Peak season labor share (June, July, August)	hand weeding	herbicides	savings	(person months
a. weeding labor as share of adult male equivalents (FTE)	38%	3%	35%	9.0
5. Annual labor share (January - December)	hand weeding	herbicides	savings	labor force FTEs
a. weeding labor as share of adult male equivalents (FTE)	10%	1%	9%	35.9

Source: Annex Tables A2-A3.

Farmers in most areas of Mali complain about tight seasonal labor supplies, which they attribute to rapid urbanization and large-scale outmigration of young males seeking work in the goldmines of Mali and neighboring Guinea. Demographic pyramids and age-cohort workforce participation rates from rural Mali confirm the large net outmigration among males aged 20 to 39 (CPS/SDR 2010, p.23). Comparison of male and female labor force age cohorts suggests that roughly 20% of males aged 25-34 have left rural areas to work elsewhere (Annex Table A3). Viewed from a labor market perspective, growing farmer demand for herbicides suggests keen interest in reducing onfarm labor requirements (Foltz 2010).

5.3. Environmental impact

Environmental concerns about the impact of repeated, concentrated insecticide applications motivated the establishment of a Sahel-wide regional pesticide regulatory body several decades ago (Diarra 1998, Abiola et al. 2004). Major locust invasions in 1974-5 and in 1986-9 triggered a series of large-scale regional spraying programs as well as the emergence of localized stockpiles of highly toxic chemical insecticides. Scattered reports of poisoning among humans, birds, fish and bees raised growing fears about both human safety and environmental impact (OTA 1990). Bracketing these episodic anti-locust campaigns, large-scale insecticide application continues annually on Malian cotton farms. Growing insect resistance, in turn, has forced Mali’s CMDT to supply an evolving cocktail of insecticides to their contract cotton farmers (Tefft 2010). During the 1990s, as a result of growing insect resistance and increased cotton production, the volume of insecticides applied on cotton fields doubled, exacerbating worries about toxicity in humans (Keita 1992, Camara et al. 2003). Ultimately, growing concerns about insecticide impacts on human health and the environment led the regional grouping of Sahelian countries to establish a pesticide regulatory body for the nine member states of the Comité permanent Inter-Etats de Lutte contre la Sécheresse dans le Sahel (CILSS). In March 1994, CILSS established the Comité Sahélien des Pesticides (CSP) as the legal body regulating all pesticides, including insecticides, fungicides and herbicides.

In Mali, as elsewhere, herbicides fall under the same regulatory rules as insecticides. Nevertheless, differences in toxicity and environmental impact frequently emerge. Glyphosate, which accounts for two-thirds of the volume of herbicides used in Mali, has historically been considered one of the world’s least toxic herbicides due to its low reported toxicity in mammals and low retention in soils (Franz et al 1997). Recently, however, the EU has placed glyphosate under active review due to a 2015 finding by the WHO’s International Agency for Research on Cancer (IARC) which reclassified glyphosate from a Class 3 (slightly hazardous) to a Class 2a (moderately hazardous) pesticide with potentially carcinogenic impact on humans. This revised rating remains controversial (WHO 2009, Wessler 2016). In general, other herbicides pose greater dangers to human health and to the environment. As a result, the CSP has formally banned two herbicides – paraquat and atrazine. Despite this legal ban, our survey teams found both products available in small quantities in local markets. As an order of magnitude, our farm survey in southern Mali suggests that these two banned herbicides account for roughly 5% of herbicide volumes applied by farmers.

CSP regulators require that firms proposing to sell a new herbicide product in Mali supply detailed information about the active ingredients as well as biological testing and toxicity results. Agricultural researchers at Mali's national research institute (IER) conduct laboratory tests as well as two years of field trials to assess biological efficacy and selectivity of each proposed herbicide, at a cost of roughly $8,000 to the proposing firm (IER 2013). Required toxicity testing takes place in Burkina Faso. After provisional approval by the CSP, firms technically have three to six years to supply more detailed information on herbicide behavior in the environment (including rates of degradation and mobility in both soil and water), its impact on non-target organisms (including humans, fish, reptiles, algae, birds, bees and soil invertebrates) and residue analysis of affected foods (CSP 2015).

In practice, however, the high cost of environmental testing coupled with an absence of certified local testing laboratories results in only cursory assessment of environmental impacts (Cissé 2012). A small number studies has examined insecticide impacts on human health and the environment (Keita 1992, Camara et al. 2003). But to our knowledge, no studies of the environmental impact of herbicides have taken place in Mali. Instead, international evidence on glyphosate and on major selective herbicides provides the environmental evidence and guidelines on which Sahelian regulators rely. Looking forward, ongoing concern about insecticide use (particularly in cotton production and in malaria and locust control) appears likely to increase pressure for improved environmental impact monitoring of all pesticides, including herbicides.

6. Conclusions and Policy Implications

Steady increases in herbicide availability in Mali, over the past decade and a half, have dramatically altered farmer options for managing weeds. Falling herbicide prices have made weed control via herbicides increasingly viable compared to hand weeding. Profitability of herbicide use varies spatially, depending critically on the unit price of herbicides (which increases with distance from the major import depots in Bamako) and the opportunity cost of labor (which increases with proximity to major urban centers). Across a broad swath of southern Mali, our survey results suggest that farmers using herbicides can control weeds at roughly 50% of the cost of hiring weeding labor. As a result, rather than hand weeding, a majority of Malian farmers have begun to use herbicides to control weeds. This paper has reviewed the causes and consequences of this ongoing herbicide revolution. Together, these findings highlight a series of research and policy implications going forward.

6.1. Drivers of herbicide intensification

Rapid changes in private sector supply systems are driving growth in herbicide use among small farmers in Mali. Since Monsanto's Roundup went off patent in 2000, international agrochemical firms and regional commodity traders have released a series of new glyphosate brands accompanied by new packaging, branding and marketing efforts that feature extensive advertising – on radio, tv, through dealers and privately financed onfarm demonstrations. Increased competition among herbicide brands and suppliers, coupled with a broad move to new low-cost production sites in Asia, has resulted in declining herbicide prices. From a policy perspective, this purely private sector driven herbicide growth stands in stark contrast with Mali's fertilizer policy, which relies on public procurement tenders and 50% price subsidies. Like African governments more generally, who have spent $1 billion on fertilizer subsidies over the past decade, Mali's government spends heavily on fertilizer subsidies (Jayne and Rashid 2013). In 2015, fertilizer subsidies accounted for half of Mali's annual agricultural budget (Thériault et al. 2015). Given tepid productivity results reported to date from Mali's large-scale fertilizer subsidies, the counter-example provided by Mali's private-led herbicide surge offers a possible opportunity for discussing less costly models for promoting input intensification.[3]

Peak-season labor shortages, likewise, contribute to growing farmer demand for herbicides. Despite widespread concerns about Sub-Saharan Africa's demographic bulge and impending youth unemployment, Malian farmers appear to be coping, instead, with labor shortages, particularly during the peak agricultural season (Foltz 2010; IFAD 2014; Loch 2014). In part, rapid recent success in raising primary school enrollment rates in Mali, from under 30% in 1990 to over 80% today, may have softened, or at least delayed, the anticipated labor supply surge (World Bank 2010). Outmigration to urban areas and to gold mines, amounting to roughly 20% of the rural males aged 25-34, also contributes to current labor shortages in rural areas. Underlining farmer concerns about labor scarcity, rural wage rates and the opportunity cost of labor that drives them, our econometric results point to labor costs as the second major factor (along with herbicide price) governing herbicide use by Malian farmers. From a policy perspective, more careful evidence on the opportunity cost of rural labor, particularly female labor, will offer important insights into economic alternatives available to rural laborers of different sexes and in different locations and seasons.

6.2. Impact of growing herbicide use

Malian farmers – even female farmers managing very small plots – voluntarily pay full commercial prices for herbicides. They obviously perceive benefits from herbicide use. Among the benefits, they achieve higher profits (cutting weed control costs in half compared to hand weeding), reduce peak season labor bottlenecks and consequently improve timing of other onfarm operations. Complementarities also arise between herbicide use and fertilizer productivity, since improved weed control serves to focus fertilizer-induced productivity gains on food crops rather than on weeds (Barrows et al. 2014, Wesseler and Smart 2014). Looking forward, agronomic work on minimum tillage systems, in which herbicides reduce land preparation requirements, may offer further savings (Zimdahl 2007).

Despite broad enthusiasm from farmers, our econometric measurement of damage abatement generates insignificant (though positive) results, likely because of our inability to control statistically for weed pressure on individual plots. This key omitted variable influences both farm output (negatively) and levels of prophylactic herbicide application rates (positively), leading to spurious negative correlation. Future empirical work will require careful information on plot-level weed pressure, preferably direct measurement rather than recall-based farm surveys. For this reason, controlled agronomic experiments under farmer

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[3] Ariga and Jayne (2009) present a similar alternative model for promoting increased fertilizer use.

conditions will likely offer the best prospects for accurately assessing the impact of herbicide use on farm production.

Environmental impacts of herbicide use remain largely unmonitored in Mali. Yet the growing numbers of unregistered and counterfeit herbicide products available on the market lead to mounting concerns about product quality and safety. Looking forward, policy makers will increasingly require better monitoring of pesticide product quality and environmental impact. The CILSS model of regional regulatory review, which economizes on scarce scientific personnel and laboratory facilities, has proven efficient in vetting herbicide products prior to release. Regional sampling and studies across common Sahelian agro-ecological zones could perhaps offer parallel economies in environmental monitoring.

Employment impacts of herbicide use appear substantial. At current rates of herbicide application, farmers are able to reduce peak season labor use by roughly 20%. Our estimates suggest that full-scale adoption could potentially reduce peak season labor demand by as much as one-third. Going forward, policy makers will want to learn more about what alternatives women and men farmers pursue when herbicides free up labor time they would otherwise spend weeding. Do herbicide purchases enable them to expand cultivated area, buy leisure time, more time with children, more time tending small stock or time to pursue more lucrative income-earning activities? Only after answering this question will researchers be able to evaluate the full impact of increased herbicide availability on employment and welfare in rural farming communities across West Africa.

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Annex Table A1. OLS and Tobit adoption models explaining herbicide use (liters per plot) on maize and sorghum plots, Sudan Savanna, Mali

Explanatory variables	OLS	Tobit
Prices		
herbicide price (USD)	-0.083***	-0.122***
	(0.013)	(0.019)
daily weeding wage (USD)	0.093***	0.147***
	(0.015)	(0.022)
Manager		
female manager	0.430***	1.084***
	(0.157)	(0.235)
manager has primary education	0.006	0.244
	(0.131)	(0.196)
Plot characteristics		
sorghum plot	-0.632***	-1.140***
	(0.110)	(0.170)
plot size	0.430***	0.552***
	(0.044)	(0.066)
distance plot to house	0.001	-0.002
	(0.003)	(0.004)
Household characteristics		
labor supply per EAF	-0.006	-0.009
	(0.011)	(0.017)
asset value of EAF (USD)	0.357***	0.564***
	(0.061)	(0.094)
transfers to EAF (USD)	0.001***	0.001***
	(0.000)	(0.000)
Constant	-0.337	-1.925**
	(0.487)	(0.756)
Observations	1,205	1,205
R-squared	0.188	
Value of log-likelihood function		-2084.162

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Annex Table A2. Weeding labor requirements by crop

	Labor (mandays)				Weeding share	
Crop	weeding	other onfarm	post-farm	total	on-farm labor	t
Sorghum	12	18	8	38	0.40	0
Millet	10	20	12	42	0.33	0
Maize						
hand shelled	12	20	13	45	0.38	0
mechanical shelling	12	20	3	35	0.38	0
Rice						
irrigated, transplanted	12.5	63.5	23	99	0.16	0
with bird scaring	12.5	134.5	23	170	0.09	0
Cotton						
CMDT	12	67	3	82	0.15	0
IER	12	94	3	109	0.11	0

Sources: Tefft (2010), Office du Niger (2012), Kergna (2016).

Annex Table A3. Agricultural population and rural economic activity rates

Age	Agricultural population (2009, thousands)			Participation rate (percent)		Economic active population (thousands)			Adult male equivalency rates		Adult male full-time equivalents		
cohorts	male	female	total	male	female	male	female	total	male	female	male	female	total
0-4	816	741	1,557	0	0	0	0		0	0	0	0	
5-9	788	729	1,517	56	44	441	321		0.10	0.10	44	32	
10-14	592	479	1,071	59	41	349	196		0.85	0.65	297	128	
15-19	490	450	940	57	43	279	194		1.00	0.80	279	155	
20-24	339	363	702	52	48	176	174		1.00	0.80	176	139	
25-29	264	348	612	48	52	127	181		1.00	0.80	127	145	
30-34	221	267	488	52	48	115	128		1.00	0.80	115	103	
35-39	201	225	426	53	47	107	106		1.00	0.80	107	85	
40-44	189	202	391	52	49	98	99		1.00	0.80	98	79	
45-49	137	134	271	55	45	75	60		1.00	0.80	75	48	
50-54	134	122	256	57	43	76	52		1.00	0.80	76	42	
55-59	109	81	190	64	36	70	29		0.65	0.45	45	13	
60-64	106	83	189	70	30	74	25		0.65	0.45	48	11	
65-69	67	39	106	78	22	52	9		0.65	0.45	34	4	
70+	118	79	197	83	17	98	13		0	0	0	0	
2009 total	4,571	4,342	8,913	56	44	2,138	1,588	3,726			1,522	983	2
Annual population growth rate			0.03										
Estimated totals, 2015			10,643					4,449					2

Source: ILCA (1990), CPS/SDR (2010).

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