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Causes and Consequences of Increasing Herbicides Use in the Cotton Production Zone of Mali

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Abstract

This paper examines the origins and impact of rapid recent growth of herbicide use among cotton system farmers. In order to trace trajectories, turning points and key causal forces governing herbicide usage and pricing, the authors have conducted interviews with herbicide importers and distributors in major markets across Southern Mali. Because hand weeding has historically dominated weed management practices in Mali, the study analyzes data from a 2017/18 survey of 400 farm households in the high-productivity soudano-sahelian zone to explore the seasonal and location opportunity cost of weeding labor and other key factors influencing herbicide adoption. These same micro-level data permit estimation of the productivity impact of herbicides, using a damage control function, as well as assessment of the profitability of herbicide use compared to alternate weed control strategies. Results from this study suggest that while herbicide profitability varies by locations, generally rapid uptake by women farmers frees up their labor time for other pursuits.

Introduction

Problem and settings

Farmers' main constraint in southern Mali is executing timely farm activities. In the zone, farmers manage several plots of different crops without appropriate equipment and labor-force. Farm activities have to be carried out within laps of time in one hazardous rainy season during the year. An activity such as weeding has to be achieved timely for expecting a good harvest. During weeding period all farms use their resources at pick level and it is hard to hire an equipment or labor-force. Poor farmers have to wait until richer farmers finish weeding to access equipment or to hire labor-force. This is more frequent with women who don't own any equipment and have to work on their husband plots first. This situation conducts to low production and low quality of products.

To overcome weed pressure farmers apply herbicides without having full information on quality, dosage and application. Herbicides even though not subsidized, its' application in the zone has grown during the last decade and half while fertilizer is subsidized at 50% by the government (Hagblade et al. 2017). Although farmers pay full commercial price for herbicide, the selling prices are relatively getting lower on markets and their availability is increasing due to the presence of many vendors and different brands on markets. This increased availability and the lower prices are explained only by a complete involvement of the private sector to supply herbicides as opposed to fertilizers where the government provides large-scale public tenders (Thériault et al. 2015). The use of herbicides affects positively production and productivity but have side effects (environmental damage, health) that can off-set all these advantages. Therefore for proper support from extension or policy decision makers, it is important to understand the causes and consequences of the growing herbicides application by farmers in the zone.

Understanding the causes and consequences of the growing herbicide use in the cotton zone of Mali will require examining supply and demand sides of herbicides. Examining the supply side includes herbicide brands, distribution system, ongoing regulation and structure of private sector system (Hagblade et al. 2017). For the demand side of herbicide, the study will focus on factors affecting on-farm adoption and levels of use.

Different crops are grown in the cotton zone including cotton, maize, sorghum, millet, rice, cowpea, peanut, vegetables and tree crops. Farmers' major cash come from cotton, vegetables and tree crops, but cereals are grown for home consumption at first and the extra is sold according to market prices. For growing these crops, farmers rely on their muscles or mostly on lower level of mechanization. To overcome individual insufficiencies, weeding is carried out by group (women or youth); the group receives a gift from the owner (cash or goat) which will serve for feast at the end of the cropping season. Growing herbicides use will surely affect these social events by reducing potential employment opportunities, particularly in the rural areas.

Herbicides use per unit of land may vary according to location and welfare (remote rural areas and urban areas). In remote areas labor unit cost is generally lower than herbicide unit cost and the opposite prevails in urban areas; a tradeoff may emerge between the farm productivity gains and aggregate employment losses (resulting from the growing use of herbicides) in the zone (Hagblade et al, 2017). By exploring these potential tradeoffs, this study examines costs of labor, herbicides, and adoption of herbicides by farmers. For the purpose of this study of herbicides adoption will be examined on maize and sorghum.

Objectives

The main objective of the study is to analyze the causes and consequences of growing herbicide use in the cotton production zone of Mali. Specifically, the study will examine:

- The distribution systems of herbicides in Mali;
- The spatial variation of costs and adoption of herbicides;
- The determinants of herbicide adoption.

Study area

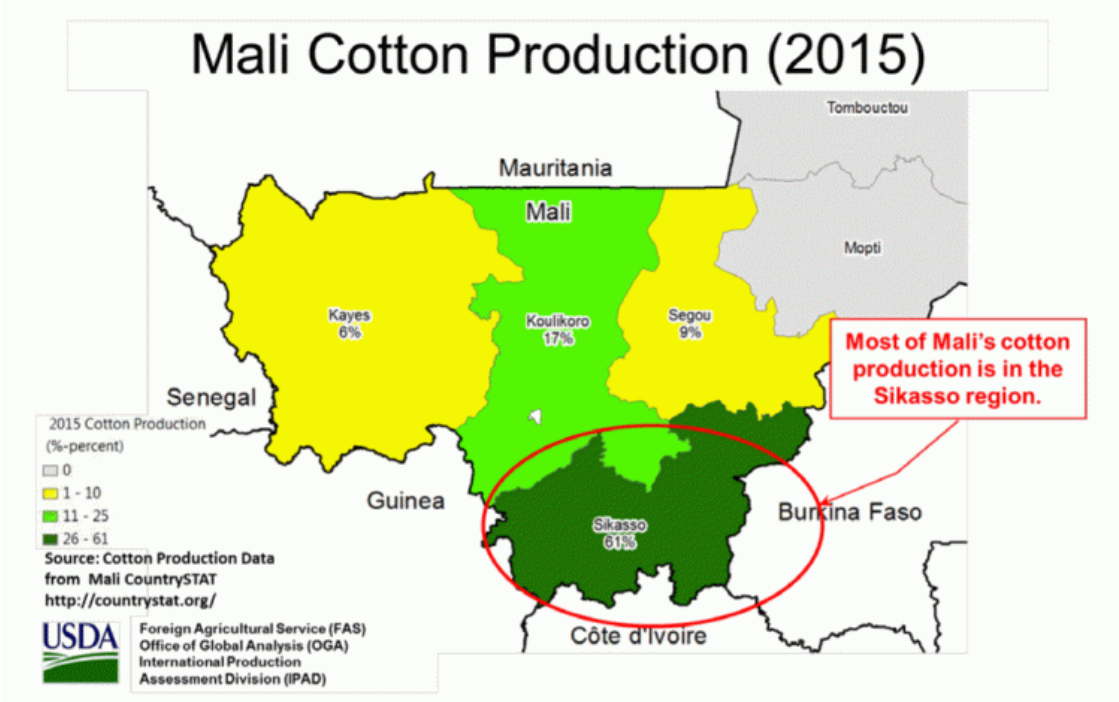
The Malian cotton zone is a region with rapid population growth and increasing market integration through the expansion of cash-crop (cotton) production. In the zone, population pressure is increasing through population growth and increased agricultural commercialization. Mean long-term annual rainfall ranges between 800 mm to 1200 mm, but with large inter-annual fluctuations typical of the Sudano-Sahelian zone of West Africa. During recent decades, the cash-crop cotton sector has rapidly expanded. From 1952, cotton production has been based on a guaranteed price announced in advance by the para-statal cotton company (the CFDT until 1974, there after the CMDT). This has facilitated an increase in commercialized cotton from 520,000 tons in 1998 to around 700 000 tons in 2017. Mali is today the largest producer of cotton in Sub-Saharan Africa. Attaining this level of production includes both extensification through the rapid extension of the cultivated area and intensification through the application of additional inputs of labor and capital per hectare (Benjaminsen 2001a, 2001b). This technological change has also been of benefit to the food crops grown in the area, resulting in increased food security during recent decades (Dione´ 1989, Raymond & Fok 1995). The cotton zone in southern Mali is today a net exporter of grains to other parts of the country as well as to neighboring countries. The land tenure systems across the zone are fairly the same.

During the decade preceding 2011, farmers' incomes in the cotton zone of Mali have been significantly affected by the downturn of the cotton economy explained by many factors including the low farm gate cotton price, the declining cotton yields and soil fertility concerns (Coulibaly 2011). In 2011, the Malian government substantially increased the farm gate cotton price as a result of the world cotton price hikes and to stimulate a revival of the domestic cotton industry. Also for the main crops, farmers had access to a 24 percent fertilizer subsidy relatively

to the market price as the government wants to intensify agricultural production by improving soil fertility levels and raising crop yields.

Mali's first green revolution was in cotton, when rapid area expansion and yield increases fueled spectacular increases in production and broad-based income growth in the cotton zone of southern Mali (Staaz et al. 2011). Cotton ranked first in export commodities and became the country's largest earner of foreign exchange. At farm level, the revenue is used to finance equipments, agro-inputs and social welfare. Cotton is grown in rotation with rainfed cereals and through it farmers can access key inputs; therefore the performance of cotton sector influences strongly the performance of cereal value chains. Any disrupt in cotton production could compromise the cereal production system in the area (concluding to low yields).

Since the price of cotton depends heavily on international market, farmers in the cotton zone are seeking to diversify into other crops, including expanded cereal production, but are limited by constraints to access to inputs on credit which is provided through the cotton system.



Source: USDA world cotton production

Data and Methods

Data source

Information on crop production and herbicides application come from a survey undertaken on a total of 200 farm households where plot managers (Common, individual male and individual female) are interviewed. During the survey, 5 enumerators carried out the household interviews,

using questionnaires. For regulations and governance of herbicides use, reports and files were consulted from extension services such as DNA, CMDT and CSP. Data from a recent study on sorghum and maize production in the Soudan-Savannah (Smale et al. 2015) have also been used. Time-series price information in local markets comes from ongoing monitoring of main agricultural markets carried out by Observatoire du Marché Agricole (OMA). Trends in import quantities and prices come from trade figures tabulated by Mali's national statistical agency (INSAT).

To capture supply trajectories, turning points and key forces governing herbicides sector, interviews have been conducted in major agricultural markets with importers, distributors and retailers. Discussions with regulators have been carried out for more precision on rules governing herbicides sale and usage in the country.

Analytical methods

A descriptive statistical analysis is carried out to characterize trends and tendencies of main pesticides prices and quantities use in the country. Share of plots receiving herbicides treatments and percentages of volumes used are computed. Labor and herbicides costs are estimated by plot manager per plot and per hectare. Qualitative information is compiled for tracing changes in market structure and behavior over time. Emphasize is put on key actions shaping commercial strategies, product innovation, branding, packaging, pricing and marketing that are driving rapid recent changes in Mali's herbicide markets (Hagblade et al. 2017).

To identify determinants of herbicide adoption, this study analyzes data collected on 200 farms households in the cotton production zone. Within these households, individual plots managed by male and female are sampled from 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 782 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. A Tobit model is used to test determinants of herbicide adoption by farmers.

For consequences, an analysis will be conducted to measure the aggregate labor displacement resulting from widespread herbicide adoption (comparison of changes in labor demand with expected labor supply levels). Given the complexity and time scale required for measuring environmental consequences of herbicides usage, the study has not attempted to collect primary data on these issues; it relies instead on a series of studies and reviews conducted by regional regulatory bodies and local researchers.

Results and Discussion

Herbicides use in Mali

Farmers use several herbicides registered and unregistered; the main ones found by the survey in the cotton zone are listed as follow.

Table 1: Most frequent herbicides used in the study zone (cotton zone)

Zone	Type of herbicides
CMDT-OHVN	Roundup
	Glyphader
	Kalach
	Alligator
	Accepronet
	Accepronet 400
	Aceto 900
	Diamajigui

Gender differences in herbicides use

The following tables present the comparison of herbicides use by plot manager and by type of crop (sorghum and maize) in the study zone. Each surveyed household farm has several plots of sorghum or maize and the head of the household can delegate management to elder son for common fields; also he can allocate some plots for individual use to men or women within the household.

Table 2: Number of plots using herbicides in surveyed sample

	Sorghum plots			Maize			All plots		
Plot manager	N	use	%	N	use	%	N	use	%
EAF	565	263	46,55	567	389	68,61	1132	652	57,60
Women	197	155	78,68				197	155	78,68
Men	20	18	90,00	10	6	60,00	30	24	80,00
Total	**782**	**436**	**55,75**	**577**	**395**	**68,46**	**1359**	**831**	**61,15**

Herbicides are used on more than half of the plots of sorghum (55.75%) and on 68.46% of maize plots. Individual plots have the largest share of herbicides use because in a typical household in the cotton zone of Mali, priority is given to common plots first. Since these are large plots, it takes longer time to work them. For individuals to avoid weed pressure they use herbicides on their managed plots. Also, women are not applying herbicides on maize because in the surveyed sample none of them possesses a maize plot.

Table 3: Number of plots using Glyphosate in the sample

	Sorghum			**Maize**			**All plots**		
Plot manager	**N**	**use**	**%**	**N**	**use**	**%**	**N**	**use**	**%**
EAF	565	216	38,23	567	191	33,69	1132	407	35,95
Women	197	138	70,05				197	138	70,05
Men	20	18	90,00	10	6	60,00	30	24	80
Total	**782**	**372**	**47,57**	**577**	**197**	**34,14**	**1359**	**569**	**41,87**

Glophosate is used on about 42% of crop plots among which 47.57 are sorghum plots and 34.14 maize plots. Because maize is cropped on common plots or individual men plots in the sampled household farms, herbicides are not used by women.

Gender differences in application rates (liters/ha)

On common plots (EAF) the rate of herbicides application is lower than on individual plots. Since priority is given to common plots and that there are many of them, the head of the household farm or his representative, will authorize use of equipments and labor-force on them at first. Weed pressure is reduced by early plowing on these plots and therefore less herbicide is applied on them. Individual plots that don't benefit from early plowing have to use more herbicide. The following table presents the rate of herbicides used on different crop plots by type of management.

Table4: Application rates of herbicides by gender (liters/ha)

Plot manager	Sorghum	Maize	All plots
EAF	1,12	1,72	1,42
Women	2,62		2,62
Men	3,34	2,48	3,07
Total	**1,55**	**1,74**	**1,63**

Gender differences in labor use (person-days per ha)

Table5: Number of person-day per task and by gender

Task	Women	Men	All plots
Field preparation	1298	22986	24284
Planting	2319	10491	12810
Weeding	6211,5	32201,5	38413
Harvest	10986	20406,4	31392,4
Other	15341	36647	51988
Total	**36155,5**	**122731,9**	**158887,4**

From the table, men are likely to spend more human resources in their farm activities than women. Although women intervene in all farm activities, they participate more in weeding and harvest tasks.

Cost of herbicides vs hiring weeding labor

Table6: Comparison of herbicide cost and hand weeding cost

	Cost per plot		**Cost per ha**	
Plot manager	Herbicide cost (CFA/plot)	Hired labor cost if plot manager hired labor instead of using herbicide (CFA/plot)	Herbicide cost (CFA/ha)	Hired labor cost if plot manager hired labor instead of using herbicide (CFA/ha)
EAF	13955,41	28335,51	11430,94	26007,57
Women	7168,548	16306,45	11033,41	24923,89
Men	9697,917	25000	13910,84	36046,43
All plots	12563,2	25995,49	11428,4	26095,47

Typically women in the cotton zone participate at all farm tasks on common household plots and have little time for their individual plots. They usually hire labor to execute tasks on their plots. From the table it can be noticed that hiring labor is more expensive than using herbicides and this by plot and by gender.

In summary it could be said that women manage about 25% of sorghum plots in the cotton zone of Mali, though none of the maize plots in the 20 villages we surveyed. 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. 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. 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.

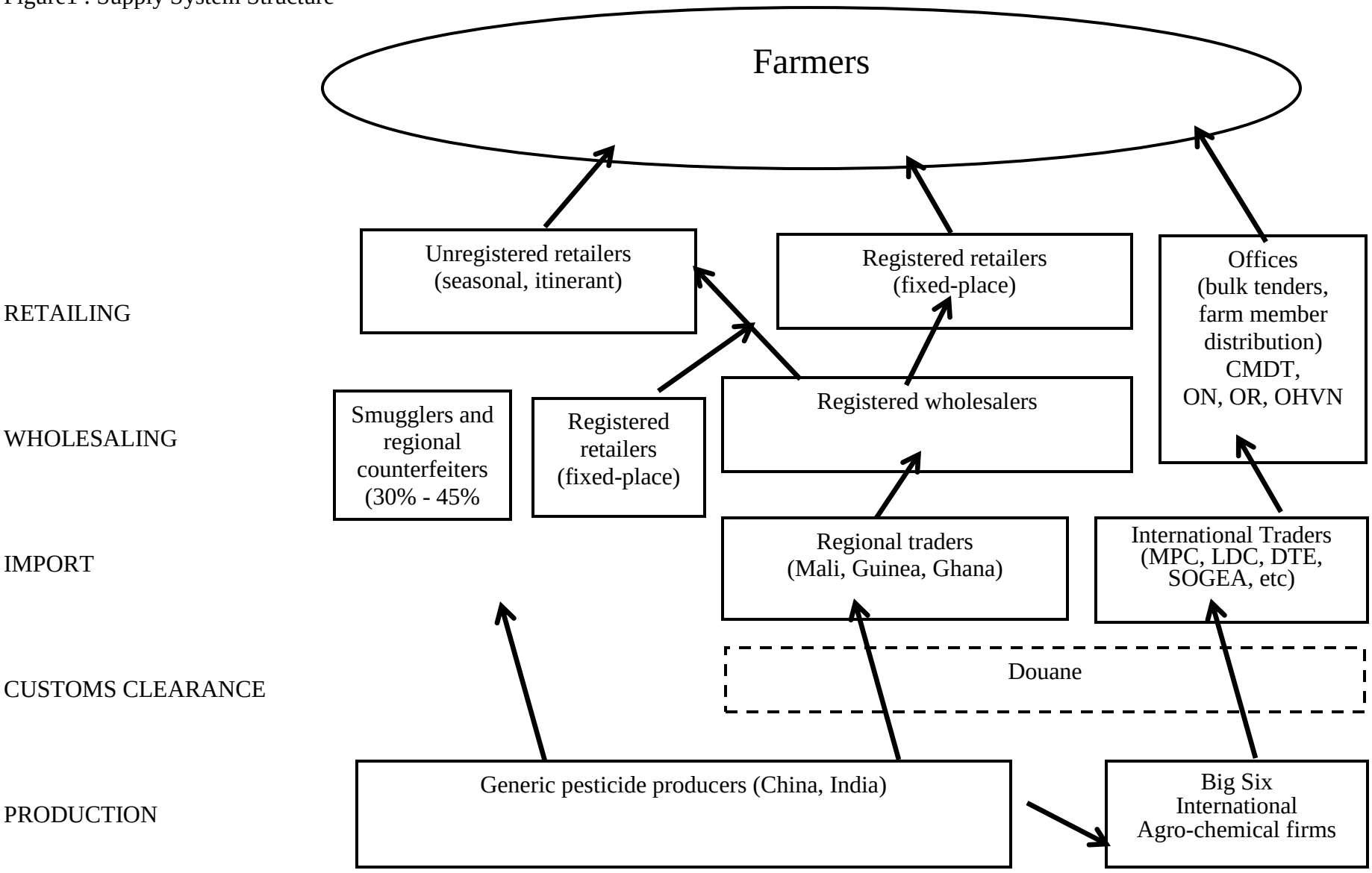
Over time, the number of herbicide products registered for sale in Mali has expanded rapidly. Following registration of only a handful of cotton-selective herbicides for sale in 1995, the number and range of herbicide products has increased rapidly to 49 as of December 2015. The period since 2010 has 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.

The herbicides distribution system in Mali

The structure of the supply system

The following figure presents the structure of pesticides supply system in Mali, which is the same as in the cotton zone where the study has been conducted.

Figure1 : Supply System Structure



There is no crop protection pesticide production taking place in Mali. Therefore, the entire national demand for pesticides is supplied by imports. The largest importer is Mali's parastatal cotton company, the Compagnie malienne pour le développement du textile (CMDT); it purchases large volumes of pesticides (primarily insecticides but also herbicides) through tender then sells them on credit through local cotton producer cooperatives. 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 representing one or more of the major international pesticide companies. They are Louis Dreyfus Commodities (LDC), Mali Protection Cultures (MPC), Datong Enterprises (DTE-Chine), Société Générale Agricole (SOGEA) and Toguna Agro Industries. From 2000, when Monsanto's Roundup went off patent, the importers have begun to market their own in-house brands of glyphosate produced for them on demand by laboratories in India or China (Hagblade et al. 2017). Louis Dreyfus Commodities (former Cygogne), for example, import Monsanto's Roundup brand of glyphosate as well as its own in-house brand, Glyphader, which it custom orders from factories in China. These major importers belong to the local chapter of CropLife, an international association of pesticide companies formed to promote the availability of quality pesticides (Hagblade et al. 2016). There are also 20 smaller registered importers who 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 Nigeria, Guinea, Ghana, Burkina Faso and Côte d'Ivoire.

Besides the registered importers, many small clandestine firms smuggle to bring in unregistered pesticides from neighboring countries or directly from China using imitation packaging designed to imitate registered brands. On village markets many permanent and occasional retailers operate agricultural input (fertilizer, seeds and pesticides) sales. Most of them are itinerant traders, operating in weekly markets. Herbicides are the most widely supplied among inputs distributors in the cotton zone as it could be seen in the following.

About 2000 inputs suppliers were organized and trained from 2008 to 2011 by AGRA through CNFA under a program called Agro-dealer Strengthening Program for Mali (ASP-M). After project termination, a local NGO, Malimark, has continued the CNFA work by providing trainings in organization and management skills for agro-dealers.

Table1: Distribution of specific inputs in Mali

Zones	Percent of retailers selling imputs		
	Herbicides	**Fertilizer**	**Seeds**
Served by parastatal marketing agencies			
- Cotton zone (CMDT, OHVN)	76%	61%	48%
- Rice zone (ON)	61%	73%	50%
Without parastatal marketing companies			
- Accessible zones	72%	60%	72%
- Remote areas	58%	73%	32%
All markets surveyed	68%	66%	51%

Source: Diarra and diarisso, 2015

Regulatory framework

The usage of herbicides in the Sahelian countries of West Africa is regulated by a body called Comité Sahéélien des Pesticides (CPS). The body reviews and certifies all herbicides sold throughout member countries. Any herbicide passing CPS safety reviews and regulated for sale in one member country becomes automatically authorized for sale in all member countries. By this process, CSP reduces bureaucratic costs to suppliers. 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 (Hagblade et al. 2016).

Based on Sahelian countries experience, the Economic Community of West African States (ECOWAS) in 2011 adopted the same model for all 15 member countries. 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 Sahelian countries. The following table presents farmers use of registered and unregistered inputs in the study zone (cotton zone).

Table 2: Percent of farmers using registered and unregistered herbicides on maize and sorghum plots in the cotton zone of Mali

Types of herbicide			
	Registered	**Unregistered**	**Total**
Percent of plots using herbicide			
- Non-selective (total) herbicide	33	40	73
- Selective herbicide	20	7	27
Total	53	47	100
Percent of herbicide volumes used			
- Non-selective	31	36	67
- Selective	24	9	33
Total	**55**	**45**	**100**

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 (Zimdahl 2016). Expiration of the Roundup patent has facilitated making new glyphosate brands-- worldwide. Major international agro-chemical companies (including Syngenta, Dow, Bayerand Arysta) have introduced their own glyphosate brands, sold in Mali under trade names such as Kalach, Finish, Mamba, Dominator and Touchdown.

More recently, traders based in West Africa have entered the herbicide product branding game. In 2008, a Guinean firm registered a new brand of glyphosate, called Glycel, for sale across the CSP member countries. The Guinean firm, Topex Agro Elevage, commissions Glycel production through an Indian manufacturer based in Mumbai (Hagblade et al. 2016). 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. Marketed as the "Beret Rouge", Glycel has become one of the dominant glyphosate brands sold in Mali.

A rash of imitators has copied Glycel's Beret Rouge packaging by enlisting an array of low-cost manufacturers in China and India to manufacture and package similar-looking glyphosate products. The 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 (Diarra et al. 2016). As a result, regulators and registered importers have raised increasing concerns about product quality and safety (MIR Plus 2012).

a. Roundup and imitators

b. Glycel and imitators

Figure2: Registered and Unregistered brands of Glyphosate sold in different markets

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. From the OMA data source, newer Glyphosate brand prices have fallen by 35% in markets across the country, while Roundup prices declined only slightly.
At the retail level, thousands of small vendors sell herbicides directly to farmers in markets all across the cotton zone. Qualitative interviews with agro-dealers indicate that herbicides constitute a growing share of their sales, as farmer demand continues to grow. Data from our survey of agricultural markets across the cotton zone help to quantify the growing importance of herbicide sales. Market surveys in 2017 indicate that over two-thirds of agro-dealers in the zone supply herbicides; this number is slightly more than fertilizer sellers and significantly more than seeds sellers. GeoFigure ally, herbicide sales are most prevalent in farming areas that lie close to major urban centers. Spatial data, reported below, from farm household surveys reinforce these findings on the link between urban proximity and herbicide use.

Table3: trends in the number of pesticides authorized for sale each year by CSP

Categories of Pesticides	1995	2000	2005	2010	2015
Herbicides	0	9	6	25	49
Insecticides	4	9	3	16	16
Fongicides	0	1	1	3	4
Total	**4**	**19**	**10**	**44**	**69**

Spatial Variation of costs and adoption of herbicides

Spatial variation of herbicides costs

In Mali farmers usually control weeds by hand pulling or by plowing during land preparation. Currently during the cropping season many smallholder farmers apply herbicides in the cotton zone on all crop plots. But for maize and sorghum more than 60% of surveyed farmers apply herbicides among which glyphosate accounts for about two-thirds of the total volume applied.

Table: Average retail prices of herbicides in the cotton zone (CFA/liter)

Zone	Type of herbicides	Selling price
	Roundup	3500
CMDT-OHVN	Glyphader	2250
	Kalach	2933

Alligator	3550
Accepronet	3483
Accepronet 400	3800
Aceto 900	4100
Diamajigui	4100

These prices vary in the space; they are cheaper in urban center and more expensive in rural areas. The following Figure represents a variation of herbicides prices from Bamako to remote villages.

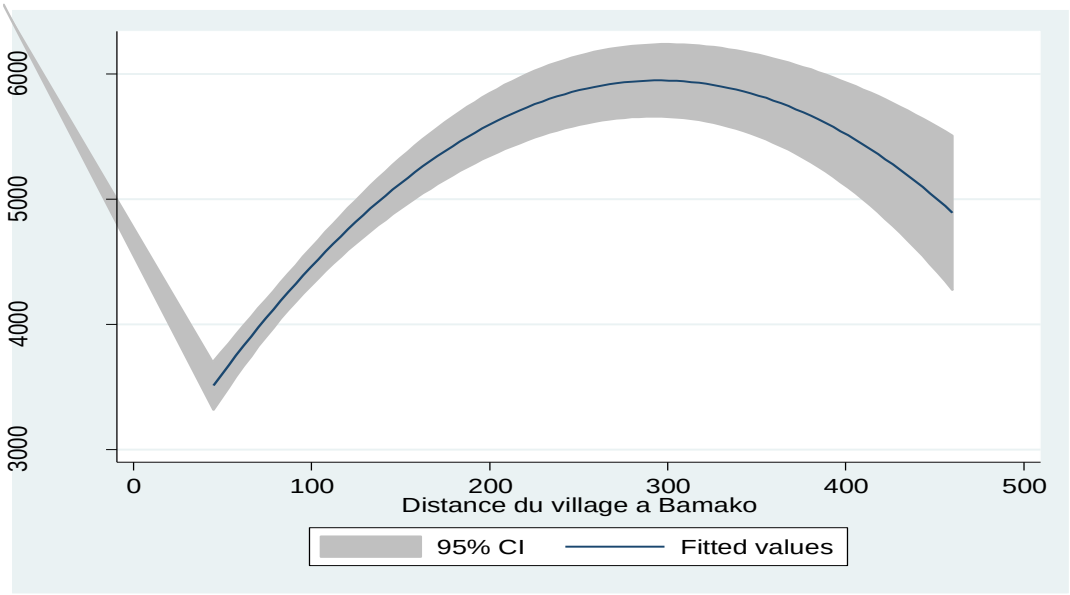


Figure 1: Price variation of herbicides (in CFA/liter)

Smale et al. 2015

The maximum price is reached at 300 km from Bamako because beyond that distance on the paved road, another urban area exists where herbicides are sold at same price as Bamako. It could be stated that the more we move from urban areas the more expensive is herbicides prices.

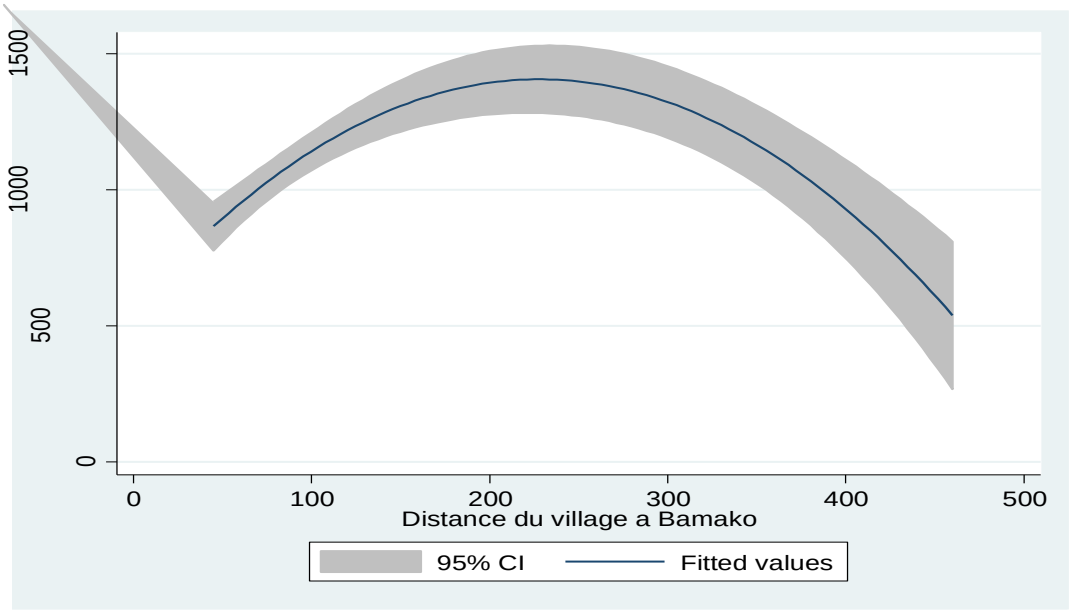


Figure 2: Wage cost of labor (in CFA/day)

Total volume of herbicide used on one hectare costs less than hiring labor-force to weed one hectare. Our survey found that farmers who apply herbicides on maize and sorghum spend about CFA 12 650 on average per hectare while if they hire labor for weeding it will cost CFA 28 600 which is more than twice as much.

Spatial variation in herbicides 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 CFA 3 850 per liter for herbicides. However in rural communities 400 km away, this price increases to nearly CFA 7 700 per liter. 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 CFA 1 650 per day for adult male weeding labor, while growers in zones 400 kilometers away pay about CFA 1 100 per day.

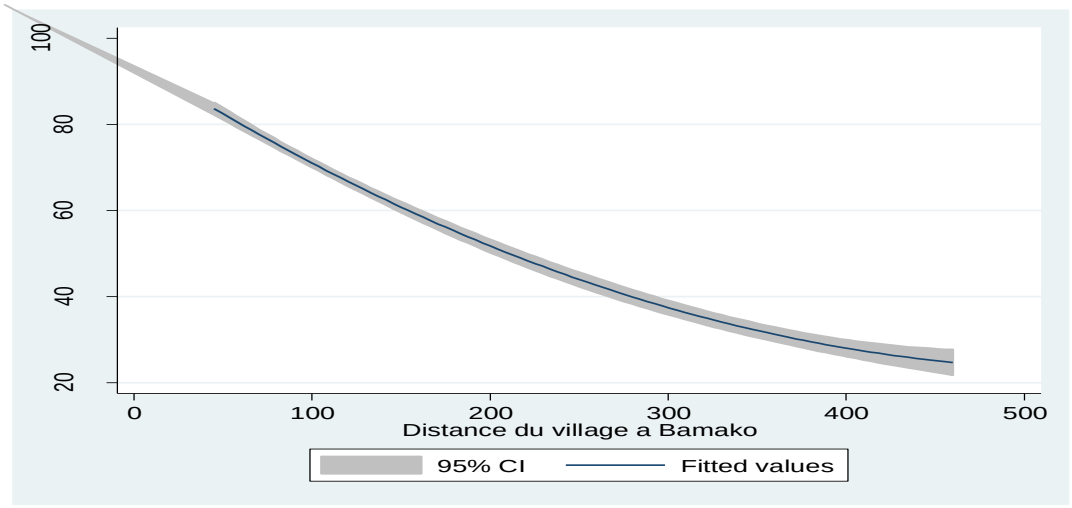


Figure 3: Percentage of farmers using herbicides in the study zone

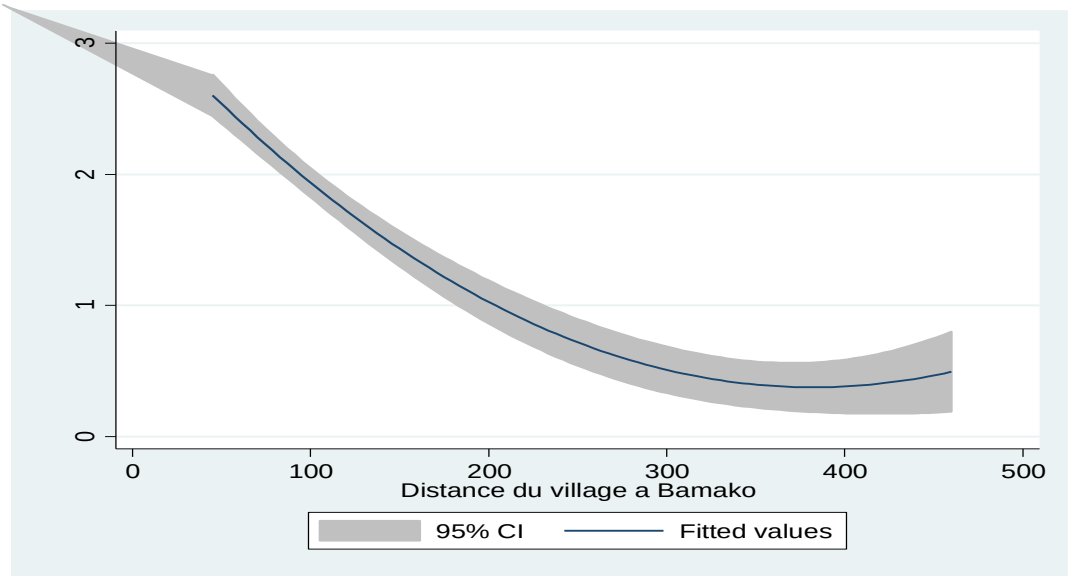


Figure 4: Average herbicide dosage

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 3). 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 4).

Determinants of herbicide adoption

OLS and Tobit formulations of adoption decision produce similar results (see table below). The first column in the table examines factors affecting the decision to use or not to use herbicides. These results suggest that price variables strongly affect the decision to use or not use herbicides. Lower herbicide prices and higher wage rates determine both significantly the

probability of herbicide use in the zone. Individual managers of individual plots are also more likely to use herbicides than male managers of family common plots. This result comes from the fact that individuals don't have full access to family labor or equipment during the weeding period or the higher opportunity cost of labor on individual plots. But in the zone, women account for 90% of all individually managed plots.

	1	2
RHS variables	**OLS**	**Tobit**
Sorghum Dummy	-0.6828***	-1.2286***
	(0.1105)	(0.1717)
Plot Size	0.3765***	0.4592***
	(0.0434)	(0.0655)
Individual Plot	0.3330**	0.8849***
	(0.1562)	(0.2337)
Herbicide Price (CFA)	-0.0881***	-0.1316***
	(0.0128)	(0.0195)
Daily Weeding Wage (CFA)	0.2610***	0.3981***
	(0.0618)	(0.0889)
Distance Plot To House	0.0009	-0.0010
	(0.0029)	(0.0044)
Manager Has Primary Education	0.0418	0.2840
	(0.1319)	(0.1971)
Number Of Active Adults Per EAF	-0.0078	-0.0124
	(0.0111)	(0.0168)
Asset Value Of EAF (CFA)	0.3829***	0.6050***
	(0.0610)	(0.0946)
Transfers To EAF (CFA)	0.0006***	0.0009***
	(0.0002)	(0.0002)
Constant	-0.1715	-1.6173**
	(0.4905)	(0.7606)
Observations	1,205	1,205
R-squared	0.1754	
Log likelihood		-2094,949

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

In practice, sorghum plots receive less frequent herbicide application than maize. Usually in the rotation system, maize comes after cotton and benefits, farmers receive inputs (including herbicides) on credit from the CMDT. Household wealth and income transfers also significantly increase the probability of herbicide use. With cash provided by transfers or from family wealth farmers may hire extra labor-force or equipment to execute timely weeding

activity. Transfers are sent by family members who migrates temporally or by relatives occupying a job in urban cities.

Plot size also affects the use of herbicides in terms of quantities applied (liters per plot) but not the decision to use. Plot size clearly matters in the total amounts used (though not the likelihood of use), since larger plots require higher input volumes (Smale et al. 2016). However, individual plot managers use less total herbicides per plot simply because their plots are much smaller. Manager level of education, distance from household to farm and the number of labor-force in the household don't affect the decision to use herbicides. Although the number of household labor-force appears to not affect the decision to use herbicides by a plot manager, it is negatively related to the extent of use. This may stem from all labor-force in the household being used on common plots managed by household heads.

The rate of urbanization is increasing in Mali, drawing labor-force from rural areas cities will result in farms without any producing power (human and equipments), therefore les production. Also the youth is accruing in the gold mining areas far from the producing zones where most of them end up being sick and inapt for farming. These reasons will cause a shortage of labor-force and maintain the wage rate or make it higher. There is also the growing availability of herbicides on the markets due to liberalization of making herbicides. Newer brands and newer importers are increasingly entering the market resulting in lower herbicides prices.

The combination of these factors will enhance the growing use of herbicides by farmers in different regions of the country.

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 orhiza 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.

Conclusions and Policy Implications

Important increases in herbicides quantities (registered and unregistered) entering Mali and their diversity have influenced farmer options for controlling weeds. Lower herbicide prices have made weed control via herbicides an increasingly viable alternative to hand weeding. Distance from major depots centers of herbicides makes variable their use profitability. Results from our survey suggest that farmers can control weeds at roughly 50% of the cost of hiring weeding labor.

The herbicide supply system based mainly on private sector has encouraged the growing use of herbicides by farmers in Mali. When Monsanto's Roundup patent went off in 2000,

international firms and regional traders have released new glyphosate brands accompanied by marketing efforts. Increased competition among herbicide 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% publicly financed price subsidies (Smale et al. 2016). Mali's government spends heavily on fertilizer subsidies during this decade. In 2017, fertilizer subsidies accounted for over half of Mali's annual agricultural budget.

Labor shortages contribute to growing farmer demand for herbicides. Migration to urban areas and to gold mines of the labor-force enhanced labor shortages in rural areas.

By using herbicides farmers reduce costs by half and they achieve higher benefits. 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). Agronomic work on minimum tillage systems, in which herbicides reduce land preparation requirements, may offer further savings (Zimdahl 2007).

Environmental impacts of herbicide use remain unknown and 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.

Employment impacts of herbicide use appear substantial. At current rates of herbicide application, farmers are able to reduce peak season labor use. 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 rural farming communities in West Africa.

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Appendix

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: DNSI (2000), Camara et al. (2003), INSTAT (2016).

Table 4. Composition of pesticide imports into Mali, 1990 to 2014

Pesticide category	1990-4	1995-99	2000-04	2005-09	2010-14	annual increase (%)
A. Volume (tons)						
Herbicides	275	1,056	868	1,321	2,587	5.0
Insecticides	1,846	1,984	2,707	3,135	3,094	1.1
Fongicides		338	59	183	446	0.8
B. Value (millions of CFAF)						
Herbicides	478	3,330	3,132	3,231	5,080	5.3
Insecticides	2,083	4,292	6,863	4,312	6,313	2.4
Fongicides	398	180	183	366	787	1.5
Total	2,959	7,802	10,178	7,909	12,180	
C. Price ('000 CFAF/liter)						
Herbicides		3.2	3.7	2.4	2.0	-1.3
Insecticides	1.1	2.2	2.6	1.8	2.1	1.4

Source: INSTAT (2016).

Table 5. 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 2. Farmer use of registered and unregistered herbicides on maize and sorghum plots in southern Mali, 2014/15 (percent of plots using herbicides)

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
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* 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	0	2	3	7	12
maize	0	3	0	5	9
rice	0	1	0	6	16
subtotal	0	6	3	18	37
Total	0	9	6	25	49

Source: Comité sahelien des pesticides (CSP)

Table 5. Trends in number of glyphosate brands registered for sale with in 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, Glyphonetand Sunoglyph.
Source: Commité 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	Change
Price in CFAF/liter									
Kalach 360	4,833	4,313	4,313	2,804	2,958	3,164	3,375	3,125	-35%
Roundup 360	4,833	5,250	4,938	6,000	5,000	4,458	4,479	4,375	-9%
Price in US dollars/liter									
Kalach 360	10.8	9.1	8.7	5.9	5.8	6.4	6.8	5.3	-51%
Roundup 360	10.8	11.1	10.0	12.7	9.8	9.0	9.1	7.4	-31%

Source: Observatoire du Marché Agricole (OMA)

Table 9. Variable names and definitions

Name	Definition
Adoption	
Use herbicide	1= use herbicide, 0 else
Extent of herbicide use	liters used
Adoption determinants	
sorghum plot	1= sorghum planted, 0=maize
plot size	hectares measured by GPS
individually-managed	plot managed individually by male or female who is not the EAF head or designate=1, else 0
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 mission
distance plot to house	time in minutes to travel from home to the plot
manager has primary education	plot manager attended primary school=1, 0 else
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(x)]	
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 pre-emergence
herbicides (middle)	liters of herbicide applied during emergence
herbicides (later)	liters of herbicide applied late

Source: