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COUNTERFEIT HERBICIDES AND FARM PRODUCTIVITY IN MALI: A MULTIVALUED TREATMENT APPROACH

By

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Abstract

Rapid growth in private sector herbicide imports has led to a dramatic rise in use of commercial herbicides by Malian smallholder farmers. Given weak regulatory capacity to monitor markets, the recent proliferation in herbicide products and brands has been accompanied by widespread sales of unregistered products. We test the effects of herbicides applied to Mali's major dryland cereals, sorghum and maize, on yield and labor productivity, differentiated by gender and age. We employ a multivalued treatment model with data collected from 623 households and 1273 plots. Findings show negative effects of unregistered herbicides on yields. In contrast, the use of registered herbicides enhances labor productivity of adult male and children. However, we find no significant effects on registered herbicides on yields or labor productivity of women.

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1. Introduction

Raising the productivity of dryland cereal crops among smallholder farmers in Mali depends critically on their use of modern inputs combined with practices that protect soil and water resources. Yet, despite long-term investments in crop improvement and more recently, government subsidy programs for fertilizer, adoption rates for these inputs remain low on dryland cereals. In contrast, spurred entirely by commercial supply and farmer demand, herbicide use by smallholder farmers has proliferated. The amount of herbicides imported has more than doubled since 2000 even though farmers pay the full commercial price (Haggblade et al. 2016; INSTAT 2016).

However, our survey data from the Sudanian Savanna, an area of high productivity potential for sorghum and maize, show that not all of these herbicides are registered and farmers do not know the difference between registered and non-registered herbicides. While regulators effectively screen new herbicide products for efficacy and safety prior to registration, monitoring of the quality of herbicides actually sold in local markets following registration remains weak. As a result, a large volume of unregistered herbicides find their way onto Mali's agricultural input markets (Haggblade et al. 21016). More generally, counterfeit and low quality agricultural inputs are thought to be widespread in Sub-Saharan Africa (Ashour et al. 2016; Bold et al. 2015; MirPlus 2012).

Clearly, a situation like this has not only economic implications but important ethical considerations. Misuse of herbicides has consequences for on-farm yields and potential negative externalities for human and environmental health. Counterfeit inputs have caused considerable problems in fertilizer and seed use, but there is still scarce analysis of this problem with respect to herbicides.

Analysis of herbicide use on farms in Sub-Saharan Africa also remains limited. This paper thus contributes in general to the emerging knowledge about the use of herbicides by smallholder farmers in Sub-Saharan Africa and in particular to information about counterfeit herbicides. A recent analysis by Haggblade et al. (2016) examined the origins and consequences of the rapid growth in herbicide use in Mali, finding adoption rates that range from 25% of farmers in remote areas to 75% of farmers in areas better served by market and road infrastructure. They found that on average, herbicides costs 50% less per ha than hiring labor to weed. In Ethiopia, Minten et al. (forthcoming) found a similar rapid rise in herbicide use in Ethiopia that was driven by the private sector, strongly correlated with market access, and is contributing to significantly higher labor productivity on farms.

We build on these analyses by testing the effect of herbicide product quality on yield and labor productivity. In the absence of accredited testing laboratories in Mali, we use registered as compared to non-registered herbicides as a proxy for herbicide quality. Via registration of the product, we are also testing the effects of regulations. We measure productivity in terms of plot yields, while controlling for other covariates. Weeding labor use per ha is disaggregated by gender and age (male, female, and child labor). To test our hypotheses, we apply a multivalued treatment effects model to non-experimental data collected in 58 villages of Sudanian Savanna zone of Mali from 2014 to 2015.

2. Methods

2.1. Data

The sampling frame is a baseline census of all sorghum-growing households (2430) in 58 villages located in the Cercles of Kati, Dioila, and Koutiala. Kati and Dioila are located in the region of Koulikoro, and Koutiala is found in the region of Sikasso. Sikasso and Koulikoro regions have the largest proportions of agricultural land located in the Sudan Savanna zone, and are the principal sorghum-producing regions in order of area cultivated and total production. As of the 2012-2013 season, the two regions represented more than 51% of total sorghum area planted in the country (Cellule de Planification Statistique du Secteur du Développement Rural (CPS-SDR)). Thus, they are priority target areas for sorghum breeding. All villages are located within the isohyets corresponding to the broad Sudan zone, near the center of that zone, just below or above the 800 mm isohyet. The zone is also favorable for maize production, which is increasingly popular as a food and cash crop.

The enumeration unit in the baseline census, and generally in Mali, is the Exploitation Agricole Familiale (EAF, or family farm enterprise). According to the national agricultural policy act (*Loi d'Orientation Agricole*), the EAF is a production unit composed of several members who are related and who use production factors collectively to generate resources under the supervision of one the members designated as head of household. The head who can be a female or male member. The primary economic activity of the head is to encourage the optimal use of production factors as these are defined by the extended family. For the EAFs we study, the first priority is universally food security. The head represents the EAF in all civil acts, including representation and participation in government programs. He or she may designate a team leader (*chef de travaux*) to supervise field work and manage the EAF on behalf or to assist the head when he/she has physical or other limitations.

The family farm enterprise is a complex organization that consists of numerous plots on which multiple crops are grown. Plots are managed collectively and individually by various members of the family. Members generally include the head, his wives and children, married sons and their wives and children, unmarried daughters and brothers of the head, and other relatives. Collective plots belonging to the whole EAF are managed by the household head or the team leader on behalf of the EAF. Individual plots belong to the EAF but are planted and managed by individual members, including both men and women. The production from these plots is not managed collectively. At each cropping season, the head distributes individual plots based on the needs of the family.

For more detailed analysis of input use in sorghum and maize production, a sample of EAFs was drawn with simple random sampling. The final sample size is 623 EAFs, with an overall sampling fraction of 25%. Enumerators inventoried all plots operated by each sampled EAF, grouping them by crop and plot management type. Considering sorghum and maize plots only (because of budget constraints), one plot was randomly sampled per management type per EAF. The total sample of sorghum and maize plots analyzed here, including those collectively and individually-managed, is 1273. We control for plot manager in our analysis, and include all sorghum and maize plots, about which we have detailed production data compared to other crops. Sorghum and maize are the major dryland cereals in this region of Mali.

The multi-visit sample survey was conducted in four rounds from August 2014 through June 2015, with a combination of paper questionnaires and computer-assisted personal interviews, by a team of experienced enumerators employed by the Institut d'Economie Rurale. Modules included: 1) inventories of plots, livestock, agricultural equipment and household assets; utilization of the harvest from the previous season; 2) input use and labor use on sorghum and maize plots; 3) measurement of area and production on sorghum and maize plots; 4) consumption expenditures and migration remittances.

2.2. Econometric strategy

We test the impacts of counterfeit and registered herbicides on two measures of farm productivity: output per ha and weeding labor per ha. We differentiate labor productivity by gender and age (men, women, and children).

Herbicide use has recently emerged in rural Mali, in the absence of any deliberate program or policy intervention. We expect that the decision to use herbicides is non-random in farming communities given that the input is novel and it has been introduced entirely by local traders or other farmers. At this early stage, users and non-users may be systematically different. Users may "self-select"—leading to potential bias in estimates of productivity impacts.

The Randomized Controlled Trial (RCT) is often seen as the "gold standard" of evaluation approaches because it eliminates selection bias (Imbens and Wooldridge 2009). Bias due to nonrandom selection can occur because of program placement or participation criteria, or through processes of self-selection. Various approaches have been recommended to address the challenge of establishing a counterfactual with non-experimental data, including the class of treatment effect models, which we employ here. These models make treatment and outcome independent by conditioning on covariates or controls.

Let y_{1i} denote the potential outcome of individual i if he/she uses herbicides and let y_{0i} if not. Let d_i denote herbicide use status by a dummy variable. For each individual, we observe $y_i = d_i y_{1i} + (1- d_i) y_{0i}$; that is, we observe y_{1i} for adopters and y_{0i} for non-adopters. The average treatment effect (ATE) and the average treatment effect on the treated (ATET) are given by: ATE=$E[y_{1i} - y_{0i}]$; ATET= $E[y_{1i} - y_{0i} \mid d_i =1]$. With observational data, we really observe only the outcome under one of the possible states. The outcome in all other cases is, in fact, potential (Rubin, 1974).

In the case of binary treatment, matching has become a popular approach (Imbens and Wooldridge, 2009), especially given the challenges of identifying appropriate instruments for two-stage least squares analysis. However, matching is based on Conditional Independence Assumption, which stipulates that the covariate vector is expected to contain all the pre-treatment variables that affect the treatment assignment. A major issue with matching methods consists in the possible presence of hidden biases caused by unobservable covariates, which is not testable.

Cattaneo (2010) proposes an alternative approach that can be used with multivalued treatment and differs in the way that treatment enters the analysis and how the ATE is estimated. This approach is of particular interest because it addresses the potential existence of selection bias and results are robust. Following this approach, we model the potential-outcome as

$$y_i = \sum_{t=0}^{2} d_i(t) y_i(t)) \qquad , \qquad (1)$$

where i is an index for observations (i=1, 2, …, N); y_i is the observed outcome of interest; $d_i(t)$ is an indicator that equals 1 if treatment type is t and 0 otherwise; and $y_i(t)$ is the outcome when treatment type is t; t is an index for treatment type (t = 0 if no herbicide is used, 1 if the herbicide used is unregistered, and 2 if the herbicide used is registered).

We estimate three multivalued treatment models to estimate the ATE and ATE as a percent of the control value. The base model is the regression adjustment (RA) model. As a robustness check, we also present average treatment effects using augmented, inverse-probability weighted (AIPW) and inverse-probability weighted, regression adjusted (IPWRA), or "doubly robust" models. Augmented, inverse-probability weighted (AIPW) and inverse-probability weighted, regression adjustment (IPWRA) estimators model both the outcome and the treatment probability. These enable consistent estimation of treatment parameters when at least one of the outcome model or treatment model is correctly specified. For this reason, these models are known as having the "doubly robust property." Unlike AIPW and IPWRA approaches, RA estimators model the outcome without any assumptions about the treatment model. Therefore, AIPW and IPWRA estimators can be more efficient than RA (Cattaneo 2010).

In addition to the multivalued model, we estimate a binary model with propensity score matching to test the effects of use vs. non-use of herbicides.

2.3. Model specification

The objective of the impact model is to quantify the potential outcomes that express changes in the yield per ha and labor use per ha of the EAF. For both productivity outcomes, we specify the fixed effects model:

$$\text{yield}=\alpha+\beta t'\text{outcomecovar}+\Theta t'\text{treatmentcovar}+\mu, \qquad (2)$$

where yield is sorghum yield in kg/ha, and *outcomecovar* is a vector of agricultural inputs applied on sorghum plots. Corresponding to a notional yield response function, we include input quantities per ha (seed, adult male labor, adult female labor, children's labor, fertilizers), as well as plot characteristics (time in minutes to travel from homestead to the plot; whether any structure has been built on the plot to offset soil and water erosion). These are the same covariates we expect to influence labor productivity.

Treatmentcovar is a vector of plot manager, household, and market covariates affective incentives for use, including the cost per ha of hiring weeding labor, the total household labor supply and whether or not the EAF received a fertilizer subsidy. In Mali, access to formalized extension structures ("encadrement") substitutes to some extent for commercial markets, influencing farmer access to inputs and services of various kinds, including subsidized fertilizer. The estimate of weeding costs per ha is derived from responses to a question asking how much would weeding labor cost if herbicides had not been applied. Since market infrastructure extends to weekly fairs conducted in villages, we include a dummy variable for the presence of a weekly fair in the village of the EAF. Finally, as described above, we recognize the social organization of production in this region of Mali, and add the characteristics of the plot manager (education of the manager, whether the plot is managed by the head or another individual male or female member of the household) among our explanatory variables.

Impact model control variables are defined in Table 1. Outcome variable definitions are shown in Table 2, along with differences in the means of each outcome variable by treatment. Without controlling for other factors, lower mean yields are associated with unregistered herbicide use compared with no herbicide use, but the highest mean yields are associated with registered herbicide use. The lowest labor use per ha for adult males, adult females, or children is on plots receiving registered herbicides. In interpreting our labor outcome variables, it is important to recognize that hired labor use on farms surveyed was negligible. EAF members depend on their own labor in production, or labor sharing arrangements. These are the hypotheses we carry to the estimation.

3. Results

3.1. Descriptives

Glyphosate, which was developed by Monsanto under the trademark name of Roundup, is the world's most popular herbicide. Importers and input vendors also report that glyphosate is their top-selling herbicide in Mali (Diarra 2016). Our survey data indicate that glyphosate accounts for about two-thirds of herbicide volumes applied by farmers to their sorghum and maize plots. Selective herbicides, which are intended for use on cotton, maize and rice, represent the other third. Since many of households surveyed belong to cotton growers' associations, use of selective herbicides may reflect their experience and access to inputs via their membership. Only slightly over half of sorghum and maize plots (53%) or volume of total herbicides used by farmers surveyed (55%) were registered. The remainder were of unregistered and of uncertain quality, meaning either "knock-offs" or counterfeit.

Aside from the practice of full soil inversion (plowing) during land preparation, farmers in this region of Mali rely on hand and hoe to control weeds—and generally on the labor of family members or shared labor with friends. Asked what it would cost them to hire labor to accomplish this task rather than apply herbicides, farmers surveyed indicated that they would have spent $52. In comparison, they spend an average of only $23 per hectare on herbicides.

Among households surveyed, female household members (primary wives of the household head, but also daughters-in-law) managed about one-quarter of sorghum plots, but none of the maize plots. Sorghum and maize plots managed by male family members who were not heads of household were relatively few in number, although these often managed plots planted to cotton or other cash crops. Larger plots managed by the household head and worked collectively by members constituted over 80% of all sorghum plots and 95% of maize plots.

The data in Table 4 indicate that individual plot managers are more likely to apply herbicides on their plots than household heads are to use the input the family fields. According to social norms, the head reserves the right to demand labor on these plots, since the output benefits the family as a group; individuals must meet labor needs on their own fields after satisfying their duties—a potentially a powerful incentive for using herbicides. and often supplied after meeting needs on the family fields. Female plot managers apply herbicides on their individual fields at nearly twice the rate applied on collective fields (2.6 liters per hectare compared to 1.1 liters). Male-managed individual plots receive doses than are even higher per hectare.

3.2. Econometric findings

Before discussing the average treatment effects (ATEs), it is important to examine the quality of the matching process. Conditional probabilities of herbicide use by treatment level are shown in Figure 1. Across all three treatment levels, the density distribution of the estimated probabilities confirms that there is not much high-density mass near the values 0 or 1. Thus the common support condition is satisfied: there is substantial overlap in the distribution of the probability for non-users of herbicides, users of unregistered herbicides and users of registered herbicides.

In addition, Figure 2 presents the distribution of propensity scores and the region of common support for users and non-users. The data indicates that the common support condition is satisfied as there is overlap in the distribution of the propensity scores between the two groups. This is reflected in Figure 3, which shows the probability density functions of users and non-users.

As described in the econometrics section, we apply regression adjustment (RA), augmented inverse probability weighted (AIPW), and inverse probability weighted regression adjustment (IPWRA) to estimate the impacts of herbicide use on yield and productivity of adult male, adult female, and child labor with a multivalued treatment model (non-use, use of unregistered, and use of registered herbicides). In addition, we use overall propensity score matching PSM, we estimated the binary impact of herbicide use compared to non-use.

The result reported in Table 5 show no significant impact of registered herbicide use on yield. In fact, herbicides reduce damage from weeds rather than enhancing the yield potential of the crop. Still, ceteris paribus, we might expect a larger harvested output per acre if damages have been offset by use. On the contrary, the regression indicates that the use of unregistered herbicide has a significantly negative effect on harvested yields, controlling for other covariates. Household members who manage plots where they applied unregistered herbicides would expect an average yield loss of 218 kg/ha. Considering that the overall mean yield is only 1141 ha, this amount is important in terms of magnitude. Overall, the binary PSM model confirms that the overall impact of herbicide use on crop yields is not significantly different from zero.

Impacts on weeding labor appear to be stronger, as might be expected given that labor bottlenecks are the primary incentive for using this input. Among the households surveyed, adult male labor is by far the largest category. The labor of adult male household members is demanded heavily on the collective plots, and particularly in land preparation and weeding. The labor of adult female household members is deployed across a broad range of household and farming activities; their individual plots are small in size, and generally intercropped with legumes. The data show low overall levels of female labor use in weeding. Child labor efforts are also relatively minor compared to those of adult males.

Consequently, the impacts of all categories of herbicide use on the labor productivity of adult males is strong and positive (corresponding to a negative sign since the variable is labor days per hectare). Registered herbicides have the greatest impact, which is almost twice as large as unregistered herbicides (an average decrease of 7.9 vs. 4.6 days). We discern no significant impact on the weeding labor productivity of adult females, perhaps reflecting the small numbers of days they reported. However, the use of registered herbicides does appear to reduce the weeding labor of children (increasing their productivity) by about 1.950 days. This implies that children in households who use registered herbicides are less likely to be employed in weeding activity, which has important ethical implications.

4. Conclusions and policy implications

This study contributes in general to the emerging knowledge about the use of herbicides by smallholder farmers in Sub-Saharan Africa and in particular to information about counterfeit herbicides. We find that the use of unregistered herbicides is associated with lower yields, but that the use of all herbicides, and in particular, registered products, enhances the productivity of male labor and child labor in weeding. The effect on productivity of female labor in weeding is not statistically significant, which we attribute to intercropping on smaller women's plots, and low reported amounts of labor.

Use of registered herbicides improves child welfare by reducing the demand for their labor. Policies and regulation to support the use of registered herbicides could be beneficial, but more research is needed on health and environmental implications. Future research might further test these hypotheses using techniques for quality directly through laboratory testing, and a sample of farmers from more regions of Mali.

Clearly, the large volume of unregistered herbicides currently in use poses a problem for farmers as well as potential problems for consumers and the environment. These findings suggest a need for improved regulatory practices. Here, it's important to distinguish between the pre-registration review system, which works very well, and the post-registration market monitoring, which functions very poorly. For over 20 years, Mali has participated in a regional regulatory review process. Since 1994, the Comité Permanent Inter-Etats de Lutte contre la Sécheresse dans le Sahel (CILSS) has operated a regional regulatory body, the Comité sahelien des pesticides (CSP), to review and certify all pesticide products sold in throughout the Sahelian member countries, including Mali. Under these common rules, any pesticide passing CSP efficacy and safety reviews and registered 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. This model economizes on scarce technical manpower and laboratory facilities by pooling talent from across the member countries. Specialists at the FAO and across West Africa consider the CSP regulatory model to be, « probably the most successful example of regional harmonization in Sub-Saharan Africa » (Traoré et al. 2011, p.16).

In contrast, post-regulatory monitoring remains very weak. The growing numbers of unregistered and counterfeit herbicide products available on the market lead to mounting farmer4 concerns about product quality and safety. Yet the environmental impacts of herbicide use remain largely unmonitored in Mali (Haggblade et al. 2016).

Looking forward, policy makers in Mali 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.

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Annex: Tables and Figures

Table 1. Definition of impact model control variables

Control variable	Definition
Treatment	
individually-managed	plot managed individually by male or female who is not the EAF head or designate=1, else 0
manager	head=1; individual male not head=2; individual female not head=3
education	plot manager attended primary school=1, 0 else
labor supply	number of adults in EAF between 12 and 55 years of age (inclusive)/total area operated by EAF
weeding cost	cost of hiring weeding labor per ha
subsidy	EAF benefited from fertilizer subsidy=1, 0 else
market	weekly market fair in village=1, 0 else
village	village fixed effect
Outcome	
seed	quantity of seed used per ha
fertilizer	kgs of fertilizer applied per ha
male labor	number of adult male person-days (14 years and above) per ha
female labor	number of adults female person-days (14 years and above) per ha
child labor	number of children person-days (under 14 years) per ha
machinery use	hours of equipment use her ha
manure	manure use on plot=1, 0 else
location	time in minutes to travel from home to the plot
erosion control	any anti-erosion structure built on plot=1, 0 else

Source: Authors

Table 2. Impact model outcome variables, definitions and means, by treatment

Outcome	Definition	No herbicide	Unregistered herbicide	Registered herbicide
yield	grain kgs harvested/ha (measured by GPS)	1183	890	1346
male labor productivity	days weeding labor per ha for adult males;	21.1	20.5	17.9
female labor productivity	days weeding labor per ha for adult females	6.13	8.01	3.77
child labor productivity	days weeding labor per ha for children (12 years and under)	3.38	4.18	2.83

Source: Authors. N=1273 plots, 623 EAFs.

Table 3. Farmer use of herbicides by category, Sudanian savanna of Mali, 2014/15

Herbicide type	Herbicide registration		
	registered	uncertain	total
% of plots	53	47	100
% of volume	55	45	100

Source: Authors

Table 4. Farmer use of herbicides by crop and plot management type, Sudanian savanna of Mali, 2014/15

		Crop grown		
Plot manager	Plot type	sorghum	maize	total
	Percent of plots using herbicides			
Household head	collective	47	69	58
Female	individual	79		79
Male	individual	90	60	80
All		56	69	61
	Herbicide application rate (liters/ha)			
Household head	collective	1.1	1.7	1.4
Female	individual	2.6		2.6
Male	individual	3.3	2.5	3.1
All		1.6	1.7	1.6

Source: Authors

Table 5. Average treatment effects, by outcome and model

	RA	AIPW	IPWRA	PSM
ATE on Yield				
ATE				
not registered	-218.3*	-218.3*	-218.3*	
registered	67.00	67.00	67.00	
Users of herbicide				1.876
ATE on adult male weeding labor				
ATE				
not registered	-4.567*	-4.567*	-4.567*	
registered	-7.885***	-7.885***	-7.885***	
Users of herbicide				-8.061***
ATE on adult female weeding labor				
ATE				
not registered	-0.996	-0.996	-0.996	
registered	-1.361	-1.361	-1.361	
Users of herbicide				-1.599
ATE child weeding labor				
ATE				
not registered	-1.640	-1.640	-1.640	
registered	-1.950*	-1.950*	-1.950*	
use herbicide				-1.342
N	1137	1137	1137	1136

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Figure 1. Conditional densities for probability of treatment, by category

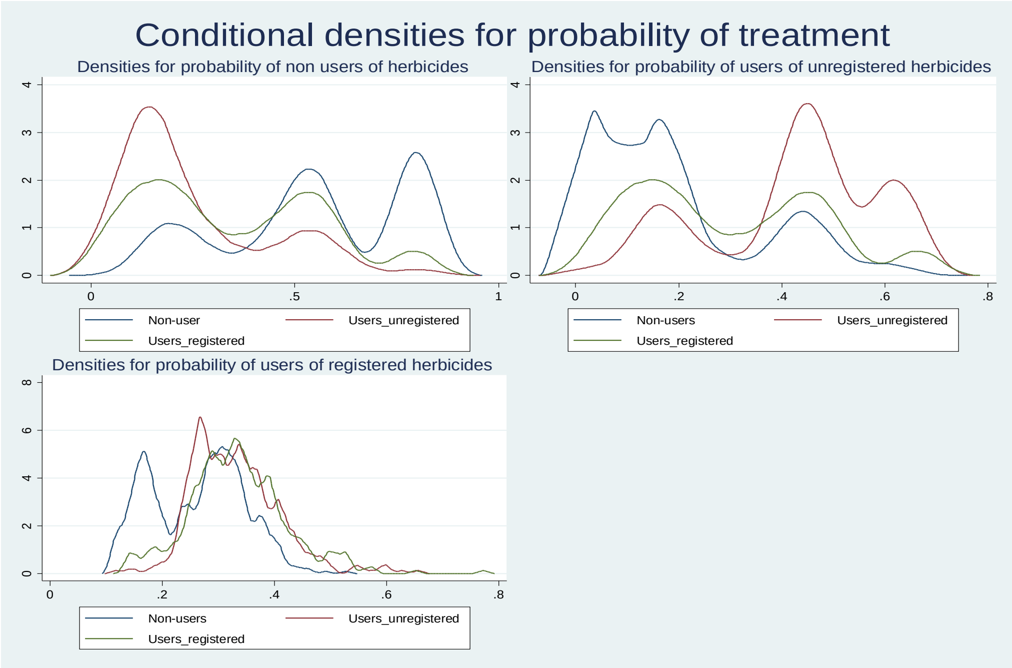

Figure 2. Propensity score distribution of herbicide use, users and non-users

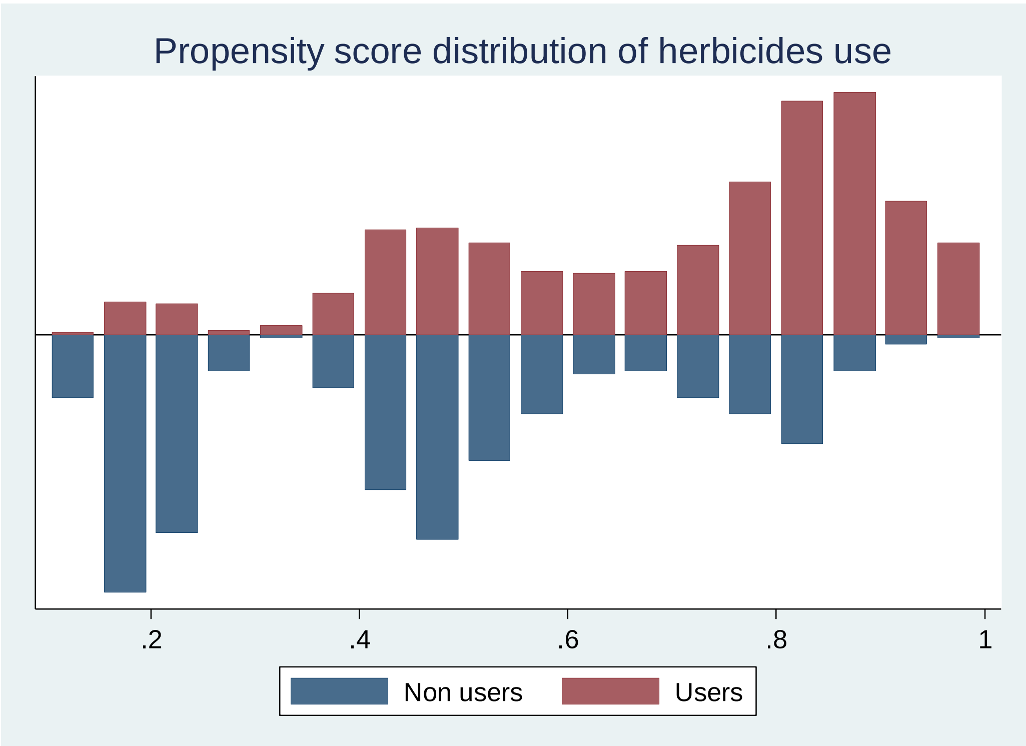

Figure 3. Probability distribution of herbicide use