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Review Article

A Mini-review of Herbicide Use in Sub-Saharan Africa: Current State, Potential Risks to Farmers, and Available Mitigation Strategies

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ABSTRACT

Using herbicides is a time-saving technology that could increase crop productivity, revenue, and food security among resource-constrained farmers in the Sub-Saharan Africa (SSA) region. However, the land sizes are small and pose a big question as to whether it is economical to embrace the technology. Again, if not used well, these products could be harmful to humans and other non-targeted organisms that significantly contribute to the well-being of the ecosystem. Across the region, 20 of 45 commonly used active ingredients have LD50 values below 2000 mg/kg. Therefore, proper selection and use of personal protective equipment are necessary to ensure the risks are managed to the lowest level possible. This research presents the current state of herbicide use in the SSA region and the potential health risks that farmers could face. It also outlines potential mitigation strategies that could be adapted for more sustainable usage.

Keywords:

Crop yield losses, herbicide, pesticide toxicity, PPE, SSA, weed IPM

INTRODUCTION

Weed control is one of those critical agronomic practices that farmers must always get right first before any of the above challenges. This is because weed infestations influence the efficacy and efficiency of several other crop management practices and the profitability of the farm systems. For instance, weed populations must first be kept as low as possible for a better return on fertilizer, pesticide, and water application. Weeds also interfere with other critical farm operations like farm preparations and harvesting. If not timely controlled, the impact of weeds could reach devastating levels putting food security in question. The impacts of weed infestations on yields could reach as high as 100% if no intervention is taken [1]. Research findings have compared and reported yield losses across various crops and countries in Africa: 55-90% on maize, 28-100% on rice, 50-80% on wheat, 35-70% on beans, 46-100% on groundnut, 48-90% on cassava, 50-86% on potatoes, and up to 80% on cotton (as reviewed by Otieno [1]. The impact is influenced by; crop-specific factors (e.g., crop type and tolerance levels, stage of the crops), weed-specific factors (e.g., the type of weeds, population, competitive ability, and the period of crop-weed interaction), climatic-specific factors (e.g., rainfall, temperature, humidity, and light), and soil specific factors (e.g., fertility levels and water retention and supply capacity) [1].

Herbicide application offers suitable alternative technology to hand-hoeing weeds as it saves time and labor. Depending on the application timing, herbicides are sprayed to eradicate weeds before emergence from soil (Pre-emergence) that have already emerged from soil (Post-emergence). With good residual effect, herbicides applied onto the soil remain active, controlling germinating weeds until the crops' critical periods are over. The use of herbicides for weed control is low and only recorded among largescale farmers with financial capacity and in state-owned farms in SSA. Among smallholder farmers, only about 5% have been reported to use herbicide in SSA, though individual countries have recorded significant growth in herbicide adoption; 0.1% in Uganda, 1% in Niger and Malawi, slightly above 5% in Zambia, 10% in Kenya and Tanzania, 22% in Nigeria, 27% in Ethiopia, 55% in Ghana [2,1]. Generally, the use of herbicides has at least doubled in recent years across SSA. This is because farmers are trying to reduce labor demand [3] and burdens, including for women and children, since they comprise most of the workforce during weeding.

Factors that could be slowing the adoption of herbicide by smallholder farmers in SSA

Although there is an increasing trend in herbicide adoption, the current levels are still low compared to other countries, which could be associated mainly with socioeconomic factors. This section discusses various factors hindering adoption in the SSA region.

Low education level: The level of illiteracy among small-scale African farmers is very high, as the majority do not complete the basic primary education level [4]. For instance, on average, the heads of smallholder families have attained 2-4.6 years of education across SSA [5]. Such low literacy levels in the region have both direct and indirect impacts on agricultural productivity as well as the adoption of technology. For the adoption and safe use of herbicides, at least a medium level of education would be

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required to understand the key information, such as preparation and application [6]. For instance, only 20% of farmers in Burundi and 17.3% in Rwanda could read and understand the pesticide label [7]. In some countries, the number of farmers capable of reading and understanding is slightly high, 63-65%, in Kenya [8,1].

Poor knowledge and experience: Small-scale farmers are the recent adopters of herbicides in the SSA region. These farmers are either less experienced or lack experience in the use and importance of herbicides, hence low adoption of the technology. Again, this is justified because herbicide use had never been among the smallholders' interests for a long time.

Culture and beliefs: Some farmers have cultural beliefs that herbicide destroys their farms and is not suitable for their health since they rely on these weeds as their source of daily food. As a result, they are not willing to try the technology despite the benefits associated with herbicide use. Such perceptions have been cited to significantly influence technology adoption decisions [9]. The situation is worsened by the low educational background that hinders the penetration of information among the locals during the technology campaign.

High poverty levels and small land sizes: Most of Africa's poor citizens live in rural areas and form the bulk of farming families. The poverty level is even cuter in sub-Saharan Africa, leading to low adoption of such technologies as herbicide applications [5]. For instance, some effective selective herbicides are expensive, costing more than $ 50 to make a hectare application, hindering farmers from purchasing the recommended quantities for application throughout the season. The situation is worsened further by improper packaging as most herbicides are packed in large containers targeting large farms. This is contrary to land sizes owned by smallholder farmers in the region. In Mozambique, about 71% of farmers own less than 5 ha of land [9]. The farm sizes are even much smaller in other African countries; more comprehensive research has shown that about 80% of farmers cultivate less than 1 ha of land [10]. The economic advantage of using herbicides on such small-sized farms has not been well understood based on available data, hence needs further research, especially in terms of cost, packaging, and safety.

Weak government and inter-country policies and poor agricultural extension services: Every SSA nation has its own system that governs pesticide use within its borders, most of which contradict each other, leading to a poor flow of information and products. Again, most of these regulations are weak, which, when coupled with porous borders and numerous generic herbicides commonly found in the region, increase the complexity of their adoption and use. The demand-driven approach of getting agricultural extension services currently used in most countries, including Kenya, has also hindered the packaging and dissemination of information about herbicide use as an effective and economical technology for adoption in the region. The current extension agent to farmers ratio is very wide in the region at about 1:>1000 creating an ineffective system for any proper training and push for adoption. Such a wide ratio impedes technology transfer [11].

Potential benefits of using herbicides among smallholder farmers

The potential benefits small-scale farmers could realize from using herbicides in crop production can be looked at in three main aspects; a) improving crop growth and yields; b) labor-saving and reduction in the cost of production; and c) soil carbon sequestration.

The growth and yield benefits of using herbicides are solely due to the effectiveness and ease of timing control of farm weeds. A wide range of products ranging from broad-spectrum to narrow-spectrum is available for pre- and post-emergence applications on different types of crops. Researchers have reported effective weed control and increase in yield in several crops due to the use of herbicides: Cucumber yield increased by 24%, dry bean by 38%, sorghum by 34%, peach by 167%, potato by 29%, and rice by 160% (as reviewed by Gianessi & Reigner [12]). The increase in cowpea, groundnut, and maize yields due to herbicide use has also been reported [13,15].

Herbicide application also greatly reduces labor demand and the general cost of production. This is due to the fast application process that takes a shorter time and the use of a few farmworkers compared to the current hand-hoeing of weeds. For instance, it takes about two farmworkers to effectively apply herbicides compared to about 17-35 farmworkers required under manual hand-hoeing of weeds in a hectare of land [16]. This saving on the cost of production has been estimated to be as high as 80% of the labor typically used in manual weeding [1]. Otieno et al. [17] consistently recorded low production costs when herbicides were used compared to when weeds were hand-hoed in maize production in Kenya. The time saved may be used to apply sound agronomic management to more farms or mitigate the risk of inadequate weed control during labor scarcity periods, e.g., when household members are sick or in school.

Soil carbon sequestration is another benefit that could be realized due to herbicide use as practiced with minimum/no-tillage. It should be noted, however, that meta-analyses indicate minimum/no-tillage can only result in significant increases in soil carbon when combined with crop rotation or intercropping and residue retention [18].

Risks of using herbicides and Farmers' health

Despite the reported benefits, such as increases in crop growth and yields, time savings, and reduction in the cost of production, the use of herbicides could have temporary to permanent negative impacts on human health. This section, therefore, looks at these potential negative impacts and how prevailing smallholder conditions influence them. It also covers potential mitigation strategies.

Like beneficial organisms, herbicides could pose serious health risks to humans if not selected and used well. Several herbicide products are currently available in the market for use in the region, and these products could have mild to worse health-related complications if not well used. The risk of herbicides on applicators, bystanders, and consumers could be examined in terms of exposure period: Short term (or acute toxicity) or long-term (chronic toxicity) health risks. According to Anderson and Phillips [19], acute toxicity can be defined as the adverse effects occurring following oral administration of single or multiple doses of a substance given within 96 hours, while chronic toxicity is defined as the adverse effects occurring after repeated or continuous use of these products for a major part of the life span. The effects on fertility, reproduction, and gene mutation are important aspects to consider when assessing the chronic toxicity of herbicides.

In general, most of the products used in SSA are very toxic (Table 1). Hence should be used with caution to abate potential health risks. From this research, out of 45 active ingredients assessed (the complete list is not presented), 44% have LD50 below 2000 mg/kg (Table 1). The use of glyphosate-based herbicides is currently a serious topic due to cancer claims. The compound has been found to cause numerous disturbances in cell physiology

and induces many cellular alterations in humans [20]. These alterations could be deleterious depending on the organ and its functions. Samsel and Seneff [21] reported interference with the normal functions of cytochrome P450 enzymes and the synthesis of aromatic amino acids, which in turn make the human body prone to many serious diseases like gastrointestinal disorders, obesity, heart diseases, depression, autism, diabetes, infertility, and cancer. Other herbicides have been grouped and comprehensively discussed [22]. These products could cause mild to severe side effects depending on the type (organic versus synthetic), quantity, and exposure period.

Acetochlor is considered mildly toxic and not posing genetic or carcinogenic hazard to humans [23]. However, there are reports which are not supportive of these ideas [24]. The impact of atrazine in humans is unclear due to mixed reporting among studies. According to the International Agency for Research on Cancer and the United States Environmental Protection Agency, atrazine is classified as "not likely to be carcinogenic" and confirmed by researchers [25-28]. However, research by Fan et al. [29] reported endocrine-disruption effects in fish, amphibians, reptiles, and rodents- the induction of mammary and prostate cancer in laboratory rodents- and the correlation between atrazine and similar reproductive cancers in humans leading to a conclusion that the product is an important risk factor. Similar to atrazine, dicamba has reported mixed results with no clear carcinogenicity effects [30-32]. Khalil [33] characterized the risks of human dietary exposure to dicamba residues in crops and found low risks to humans (HQ < 1) though marked as a DNA damage agent by González et al. [34] and peroxisome proliferators by Gupta [22].

This research review, therefore, shows that no single herbicide is 100% safe once in the human system. Meta-analyses have consistently concluded a lack of strong direct association between commonly used herbicides and human cancer, though they admitted lack of adequate data from relevant studies and requested more targeted research [27,35-38].

Table 1: Summary of toxicity of commonly used herbicides (technical grade active ingredient) with LD50 values equals to or less than 2000 mg/kg in Sub-Saharan Africa. This list was extracted from 45 active ingredients considered. The Globally Harmonized System of Classification and Labelling of Chemicals (GHS) and LD50 values were extracted from World Health Organization (WHO) database [39].

Active ingredient	GHS	LD50 in mg/kg	Toxicity statement
Ametryn	4	110	Class II
Paraquat	3	150	Class II
Bromoxynil	3	190	Class II
Cyanazine	3	288	Class II
Haloxyfop	4	300	Class II
Metribuzin	4	322	Class II
2,4- Dichorophenoxy acetic acid	4	375	Class II
Diclofop-Methyl	4	565	Class II
MCPA	4	700	Class II
Alachlor	4	930	Class II
Tralkoxydim	4	934	Class II
Quizalofop-Pterfuryl	4	1012	Class II
Pendimethalin	4	1050	Class II
Mecoprop Esters	4	1050	Class II
Bentazone	4	1100	Class II
Propanil	4	1400	Class II
Quizalofop	4	1670	Class II
Hexazinone	4	1690	Class II
Dicamba	4	1707	Class II
Atrazine	4	2000	Class II

The effects of these herbicides on farmers are likely to be high and lethal in SSA compared to developed nations due to the following predisposing features;

i. High illiteracy level among users: Sub-Saharan African small-scale farmers are among the poorest and most illiterate in the population and composition strata. As outlined in the previous section, most farmers hardly completed five years of lower-grade study. This means they cannot afford to purchase quality personal protective equipment and cannot read and interpret user guides on the product labels. In fact, research in Uganda found that 40% of the farmers who use pesticides do not know the toxicity color codes of the products [40]. In Kenya, 65% of farmers do not know the correct meaning of all the main and simple pictograms used in pesticide labeling [41]. This means they cannot discriminate among toxicity levels and select fewer toxic products, thus picking products as long as they can control the targeted weeds. Further assessment by Oesterlund et al. [40] found that farmers use their mouths to unblock prayer nozzles leading to greater acute oral exposure risks.

ii. Over-reliance on farmer-to-farmer sources of crucial information: Farmer to farmer learning method is always the best in technology dissemination and adoption, and it is the most commonly used method by farmers in the SSA region. However, the method could be dangerous when farmers learn about a technology none of them is well conversant with. For instance, in SSA, herbicide use is uncommon among smallholder farmers, but the adoption is increasing. Research has reported that less than 16% and 23% of farmers seek advice from extension officers and read herbicide labels before making applications, respectively [42], and this means that the majority of farmers turn to their neighbors for advice during the application process. Several researchers, including Macharia et al. [41], support this conclusion. Combined with low education and inability to read and understand instructions on the product label, there is a high chance that wrong information is being passed across the farming community, which could lead to severe intoxication.

iii. Inconsistency in using personal protective equipment: It is normal and common to find farmers carrying out risky processes such as measuring herbicide volumes, making dilution volumes, and carrying out application processes without personal protective equipment such as gloves, breathing masks, goggles, and overalls. In Uganda, for instance, the majority of farmers (73%) use ordinary clothes when making applications [40]. According to Okonya et al. [7], over 50% of farmers do not use PPE in Rwanda and Burundi, with over 90% of the farmers in both countries not wearing hand gloves and waterproof jackets during spraying. Instead of face and nose masks, these farmers use handkerchiefs as masks. Under such conditions, herbicide mists directly contact the skin and are heavily inhaled, thus posing health risks.

iv. Poor storage of unused or used herbicides and disposal of herbicide containers: Agro-dealers and farmers store their products under high temperatures with poor ventilation compared to the commonly recommended cool and sometimes under refrigeration conditions. Again, most farmers store these products in the same houses where they live and sleep, predisposing the households to high contamination risks. For instance, in Imenti North, 68% of farmers were found to store pesticides in the same house they live in [8]. Also, farmers do not separate expired from unexpired products, which could lead to confusion and pesticide exposure. In Nigeria, over 90% of farmers carry out this practice and keep pesticides either in their bedrooms, their sitting rooms or

stored together with food because they fear that the chemicals would be stolen if kept elsewhere [43]. At the market, mobile agro-dealers usually carry and sell their products in the open sun and sometimes under poor sheds. Such high temperatures could lead to a reaction and breakdown of active ingredients producing something more toxic and lethal [44].

v. Use of highly toxic pesticide products: Generally, farmers in SSA have access to a low supply of new herbicide technology, leading to greater risks of using very old and highly toxic products. For instance, the commonly used and available products in the region are reported to include alachlor, atrazine, and paraquat dichloride [40,42]. These products have been classified as highly hazardous according to the new methodology by Jepson et al. [45], aiming at a safer selection of pesticides to reduce human and environmental health risks.

vi. No warning signpost on sprayed farms and poor timing of harvest time: One of the safe pesticides use conditions is to always mark by putting signpost warning people of places where the application has been made until at least for the period stated on the product label. This has never been practiced by the farmers in the region, making people more exposed. The situation is even worse in the rural where farmers usually gather and cook these weeds as local delicacies- this is oral contamination. The impact of such acts could also be felt by free-ranging livestock mistakenly feeding on such farms and grazing on plots along the sprayed farms that may have received herbicide drifts.

Potential mitigation actions

The safe use of herbicides begins with proper field scouting and identifying the weeds to be controlled because some are product specific and need to be identified. Another important step is the proper selection of herbicides, which depends on the weed species identified. This should be done to avoid using herbicides that are classified as highly hazardous- those that are carcinogenic, teratogenic, have adverse effects on human fertility or are restricted under international conventions (e.g., Stockholm, Rotterdam conventions) due to their adverse effects on the environment [45]. When handling herbicide products (measuring, mixing, and praying), the applicator should always have quality PPE (chemical-resistant rubber gloves, breathing masks, footwear, and overalls) [11]. The quality of the PPE should be as directed by the type of product being handled. For instance, use double-layer PPE and either eye or respirator or both when handling high-risk pesticides and single-layer PPE when handling low-risk pesticides [45]. During application, herbicides should be sprayed downwind to avoid inhaling or making dermal contact with mists. To reduce risks after application, one should wash the body, sprayers, and PPE with detergents and water. All the used and unused herbicides should be labeled appropriately and remain in their original containers during storage. These stores should be cool and well-ventilated, separated from sleeping rooms, food stores, and water stores. This is crucial in ensuring they are not mistakenly used for any other purpose. At the field, all the sprayed plots should be marked with signposts at every corner of the farm, notifying and warning residents to keep off the sprayed fields for the given re-entry periods.

Conclusion and Recommendations

Poor weed control automatically results in yield losses. The use of herbicides is cheap and time-saving hence could be used to improve crop productivity of already resource-constrained farmers in Africa. However, any herbicide could be harmful depending on the amount that enters the body and the exposure period. Therefore, care must always be taken when selecting and handling these products- less toxic products to be selected and use of quality personal protective equipment whenever handling any products to guarantee low exposure risks. Harmonization of pesticide regulation policy across Sub-Saharan Africa could also ensure herbicide use is well-informed and regulated, thereby eliminating cross-border movement of more toxic and generic products.

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