Review Article

Strategizing to Mitigate Potential Herbicide Adoption Risks in Sub-Saharan Africa: Crop and Environment-Focused Assessment

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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 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. This review, therefore, explores the potential benefits of widespread herbicide adoption in the region. Also, the study investigates the potential crop and environmental risks that may arise from the improper use of herbicides and highlights the importance of implementing mitigation strategies to ensure sustainable and responsible herbicide usage in the region.

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Introduction

Crop production is the main economic activity of the millions of smallholder farmers across Sub-Sahara Africa (SSA) (Otieno *et al*., 2020). However, the yields have remained relatively low compared to what is attainable under good management at any agroecological zones (Otieno and Mageto, 2023; Okumu *et al*., 2023). These lower yields are due to several factors, mainly soil infertility, soil acidity, pest and disease infestations, weed infestation, drought, and the use of low-yielding varieties (Otieno, 2021, 2023a; Otieno and Mageto, 2021).

Weed control is a crucial agronomic practice that farmers must prioritize, as it significantly impacts the effectiveness and efficiency of various other crop management practices, as well as the overall profitability of the farm systems (Siddiqui *et al*., 2010; Akbar and Javaid, 2015; Otieno, 2023b). Late timing and a poorly done weeding are the critical aspects of weed management leading to yield losses. 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,

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temperature, humidity, and light), and soil specific factors (e.g., fertility levels and water retention and supply capacity). For instance, weed impact is higher in SSA and regions around the tropics because of high light intensity, humidity, and temperature, which favor their growth and competitive characteristics (Otieno, 2023b). The impacts of weed infestations on yields could reach as high as 100% if no intervention is taken (Table 1). In order to control weeds, farmers have been using cultural methods characterized by the physical hand-hoeing of weeds. This method is labor-intensive and time-consuming, though it has always been assumed to be more than adequate in the region for a very long time. Nevertheless, this has changed due to the movement of youths to town in search of job opportunities, leaving elders at home who cannot carry out proper weed management. This emerging situation is pushing smallholder farmers to consider using herbicides.

Table 1: *Summary of the impact of weeds on yields of major crops grown in Sub-Saharan Africa. The yield losses reported are between weeded and unweeded crops. Adapted from Otieno (2023c).*

Crop	Country	Yield loss due to weeds
Maize	Nigeria	55-90%
Sorghum	Nigeria	40-80%
Wheat	Ethiopia, Nigeria	50-80%
Rice	West Africa countries	28-100%
Dry bean/ Faba bean	Uganda, Sudan	35-70%
Groundnut	Nigeria, Sudan, and Tanzania	46-100%
Cowpea	Burkina Faso and Nigeria	30-60%
Cassava	Cameroon	48-90%
Potato	Angola, Nigeria	50-86%
Cotton	Malawi, Nigeria, Zimbabwe	Up to 80%

Adoption of herbicide technology in Africa is still low at 5% compared to developed countries (Gianessi and Williams, 2011). However, the use of herbicide technology has at least doubled in many SSA countries in recent years, with adoption ranging from 0.1-55% (Bouwman *et al*., 2021; Otieno, 2023b). This is because farmers are trying to reduce labor demand and burdens, including on women and children since they form most of the workforce during weeding. Therefore, this research aimed to review the potential benefits smallholder farmers may get from herbicide adoption. Also, it provides potential crops and environmental risks likely to arise due to the widespread adoption of herbicide technology in the region. Finally, the research presents potential strategies based on recent research that could be used to manage these risks for safe and stable production.

Data sourcing

The data used in the research were obtained from secondary sources, mostly from various scientific publications. Some of the key search phrases used to locate the resources were; impact of weeds on crop yields in Sub-Saharan Africa (SSA), importance of herbicide, herbicide adoption in SSA, factors hindering herbicide adoption in SSA- search per individual countries, risks of using herbicides, negative impacts of herbicides on crops, negative impacts of herbicides on the environment-soil, water, air, impact of herbicide on water, impact of herbicide on air, impact of herbicide on soil, negative impacts of herbicides soil microbes, herbicide risk management on crops/soil/air/water. The sourced materials were then downloaded, read, and cited as best practice.

Potential benefits of using herbicides by smallholder farmers

Small-scale farmers could experience a range of potential benefits by adopting herbicides, including enhanced crop growth and yields, labor savings, reduced production costs, and soil carbon sequestration (Otieno, 2023b).

The growth and yield advantages associated with herbicide use primarily come from its effective and convenient control of farm weeds at the right time. Various herbicide products, ranging from broad-spectrum to narrow-spectrum, are readily accessible for pre-emergence and post-emergence applications across different crop types (Otieno, 2023b). 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 and Reigner, 2007). The increase in yields by other crops has also been reported on cowpeas (Madukwe *et al*., 2012), groundnut (Mubarak, 2004), and maize (Janak and Grichar, 2016).

Herbicide application could also significantly reduce 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 fewer farmworkers compared to the current hand-hoeing of weeds (Bellamy, 2011; Otieno *et al.*, 2019). 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 (FAO, 2019). According to Otieno *et al.* (2019), the cost savings achieved through herbicide use can reach as high as 50-80% compared to the labor-intensive manual weeding methods. In their study on maize production in Kenya, Otieno *et al.* (2019) consistently observed lower production costs when herbicides were used, as opposed to hand-hoed weeding practices. 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 under 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 (Corbeels *et al.*, 2019).

Potential barriers to herbicide adoption among smallholder farmers

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 and governance factors. This section discusses various factors that could be 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. For instance, on average, the heads of smallholder families have attained 2-4.6 years of education across SSA (Rapsomanikis, 2015). 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 required to understand the key information, such as preparation and application (Myeni *et al.*, 2019). For instance, only 20% of farmers in Burundi and 17.3% in Rwanda could read and understand the pesticide label (Okonya *et al.*, 2019). In some countries, the number of farmers capable of reading and understanding is slightly high, 63-65%, in Kenya (Macharia *et al.*, 2013; Marete *et al.*, 2021).

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 are not suitable for their health since they rely on these weeds as their daily food source. As a result, they are not willing to try the technology despite the benefits associated with herbicide use. Such perceptions have significantly influenced farmers' technology adoption decisions (Khan *et al.*, 2008). 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 (Rapsomanikis, 2015). For instance, some effective and 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 (Anderson and Learch, 2016). 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 (Lowder *et al.*, 2016). The economic advantage of using herbicides on such small-sized farms has not been well understood based on available data; hence, it needs further research, especially in 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 proper training and pushing for adoption (Otieno, 2019). Such a wide ratio impedes herbicide technology transfer.

Potential risks of using herbicides and available mitigation strategies

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 grown crops, the environment, and human health. This section, therefore, looks at these potential negative impacts in relation to the prevailing smallholder conditions as presented in Sub-Saharan Africa and provides potential mitigation strategies.

Negative impacts of herbicides on grown crops

The potential negative impacts of herbicide applications on grown plants are mainly due to the phytotoxicity of these chemicals. Phytotoxicity is defined as the amount of visible injuries a plant presents due to herbicide application (Carvalho *et al*., 2009). These injuries could be temporary (the plants recover faster and the effects do not cause yield loss) and permanent (the plants either do not recover or the recovery process is slow and usually results in yield reduction) (Figure 1). Phytotoxicity symptoms can be divided into structural damages (e.g., chlorosis, necrosis, albinism, wilt, epinasty, and leaf rolling) and physiological damage (e.g., cycle reduction, poor germination, and growth rate reduction). As a result of herbicide phytotoxicity, reduced growth and yield have been reported in several crops, including soybean (Young *et al*., 2003), maize (Lum *et al*., 2005; Carvalho *et al*., 2009), beans (Sikkema *et al*., 2004), and cotton (Freitas *et al*., 2005).

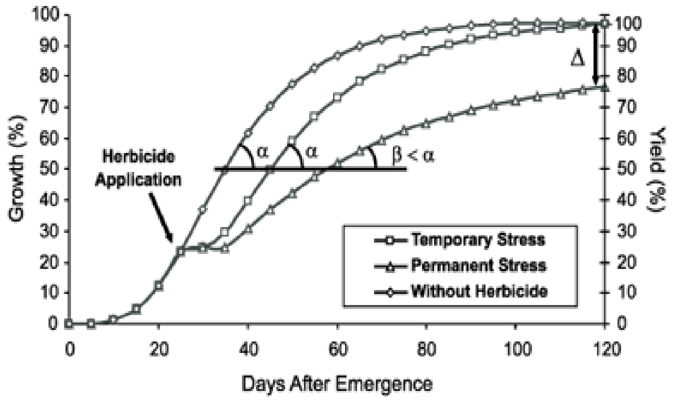

Figure 1: *Mathematical models of herbicide phytotoxicity effects on crop growth and yield of crops. The figure compares the growth of grown crops under temporary toxicity, permanent toxicity, and without herbicide toxicity. Adapted from Carvalho et al. (2009).*

The level of damages is influenced by, among other factors:

Soil organic matter (SOM) content

There is a relationship between soil organic matter content and herbicide efficacy, which may indirectly influence the product's phytotoxicity. This relation is more for soil-applied as opposed to foliar herbicides. It has been shown that an increase in SOM significantly reduces the efficacy of the herbicides used (Tielen, 2010). This could be linked to soil microbes' degradation of herbicide compounds and the organic acids produced by decomposing SOM. As a result, the residual phytotoxicity effect of soil-applied herbicides may not be high on the subsequent grown crops.

Crop species

Some crops are naturally more resistant to herbicides than the rest due to their genetic composition. For instance, maize is naturally tolerant to the enzyme 4-hydroxyphenyl pyruvate dioxygenase (HPPD) based herbicides compared to soybean and cotton (Green and Owen, 2011). This means maize is less susceptible to HPPD herbicides than other crops, and this is important because such crops will suffer less phytotoxicity. This tolerance within crop species has been exploited in developing herbicide-tolerant crops.

Stage of the crop when the application is made

The stage of the crop when the herbicide is applied significantly influences the phytotoxicity impact. For instance, cherry plants have been found to be significantly affected by the herbicide when applied at flowering, and Fletcher *et al*. (1996) reported a yield loss of about 35% when chlorsulfuron is applied at the flowering stage. Yield depression has also been reported on crop species commonly grown by small-scale farmers, such as dry beans, soybeans, and maize (Carvalho *et al*., 2009). On the other hand, young crops are easily affected because of their softer tissues, which are easily penetrated by herbicide compounds compared to older crops. However, because these crops are young, they recover quickly from the shocks, leading to minimal or no losses.

Prevailing weather conditions

Prevailing weather has a direct influence on the health of grown crops. Drought-stressed crops are easily and heavily affected by herbicide application compared to less-stressed crops. Water availability affects crop physiological processes, mainly absorption, distribution, and breakdown of chemical compounds. Under drought, the plant cells are usually flaccid, making them penetrable by herbicides, leading to necrosis, chlorosis, and leaf rolling. Also, windy weather may result in the splashing and scattering of chemical mists onto the non-targeted plants in the nearby fields leading to retard growth and yields (Otineo, 2019).

Herbicide application rate

The application of herbicides above the recommended rates could cause a reduction in both the growth and yields of the crops compared to those within or at lower rates. The burning could be due to the herbicides absorbed via the leaf or root tissues. At high rates, hormone-based herbicides are absorbed through the roots of plants, leading to injuries. The impact of these hormonal herbicides is higher in shallow-rooted crop species and deciduous hardwood trees than in deep-rooted crops and hardwood trees (https://www.bartlett.com). For instance, Wallace *et al*. (2007) reported that cycloate and s-metolachlor were safe for spinach and only caused minor crop injury except for the high rate of ethofumesate, which resulted in high levels of injury.

Herbicide selectivity

Selectivity is the capacity of herbicide to eliminate the targeted weeds in crops without affecting yields or quality. The crop species, weed genetic characteristics, prevailing environmental conditions, and application rate influence the selectivity of an herbicide. More selective herbicides are less phytotoxic than broad-spectrum types (e.g., glyphosate, glufosinate, and pelargonic acid) (Zimdahl, 2018).

Mitigating the negative impacts of herbicides on crops

To manage the negative impacts of these herbicides on grown crops, one needs to understand and relate all the factors mentioned above for appropriate actions. These actions could be taken before or immediately after application. The following are some measures identified that could be taken to mitigate the phytotoxicity of herbicides on grown crops.

Carefully read and follow the instructions provided on the product label: Herbicide product labels have very important information that must be followed whenever using chemical products (Otieno, 2019). Farmers are expected to use the right herbicide or mixtures at the right rates and time of application (both during the day and stage of crop growth) to control specific weeds in a given crop field. Mixing herbicide products not known to be miscible could lead to a mixture that burns crops and should, therefore, be stopped.

Avoid herbicide application during drought or water stress periods: Drought not only aggravates the phytotoxicity impact but also reduces the efficacy of the herbicides. Stressed crops have altered plant architecture and physiology, leading to a high potential of suffering burns caused by herbicides. Also, herbicides may become less effective during drought, especially post-emergence herbicides, due to the lower absorption of herbicides through the cuticles. For instance, a study showed that the doses of herbicides to control *Commelina benghalensis* L. effectively increased up to 250 times at 25% of field capacity compared with herbicide application at 100% of field capacity (Chauhan and Abugho, 2013). Under water stress conditions, weeds can develop thick leaf cuticles, which decrease the permeability of herbicides entering the leaves (Chauhan and Abugho, 2013).

Maintain recommended spray intervals: Avoid close spray intervals to allow crops to recover from the temporary shocks caused by the herbicides. Application before the recommended time-lapse would mean plants are subjected to the shock so fast, which could lead to a negative impact due to permanent burns.

Ensure proper soil organic matter management: Increasing soil organic matter and carbon content through the application of charcoal, compost, manure, or organic mulch could help in reducing the concentration of pre-emergence herbicides through microbial degradation and binding of the compounds on organic compounds (UC-IPM, 2019). This is very important in mitigating the possible risks posed by the residual herbicides that are not selective to the crop in the subsequent seasons. This aspect should be taken seriously in the SSA region since most farmers do not have enough land to carry out seasonal fallow systems that give herbicide compounds time to break down in readiness for the next crop. On the other hand, herbicides with more prolonged residual effects are likely to control weeds for a more extended period, reducing production costs. These two situations are complex and require critical decision-making based on clear understanding of cropping systems, patterns, and crop species.

Use antidotes or safeners whenever recommended for the application of a given herbicide: Herbicide safeners/antidotes are chemical agents that increase the tolerance of monocotyledonous cereal plants to herbicides without affecting the weed control effectiveness (Jablonkai, 2013). In practice, these compounds are applied to the crop before planting (seed safeners) or to the soil with the herbicide formulated as a prepackaged mixture (Hatzios and Wu, 1996). Safeners such as 1,8-naphthalic anhydride (NA), MG-191, dichlormid, AD-67, BAS-145138, and flurazol have been found to offer protection to grass crops (e.g., maize) by reducing phytotoxicity caused by a wide range of herbicides including EPTC, acetochlor (Jablonkai, 2013). However, care must be taken when making the application, especially for pre-emergence herbicides, to ensure the protection is not offered to weed seeds as well by carefully reading the label and using appropriate rates and application methods (e.g., seed coat) (Abu-Qare and Duncan, 2002).

Always use selective herbicides: Avoid using herbicides that are not selective to the grown crops and with more prolonged residual effects in the soil to avoid possible impacts on the growing crops and those coming in the subsequent seasons. Non-selective herbicides can only be used on open fields or as pre-emergence.

Negative impacts of herbicides on the environment

Daily use of herbicides could negatively impact beneficial organisms, livestock, and other plants. The effects are even worse when used without proper care, leading to the development of resistant weed species and the death of living organisms. The environmental impact of using herbicides could be examined regarding the development of herbicide-resistant and ecological imbalance by killing non-targeted beneficial organisms.

Development of herbicide-resistant weeds

Resistant weeds have evolved genetically to increase their ability to tolerate one or more herbicide types previously used to control them (Vrbničanin *et al*., 2017). The use of herbicides over a long period and lethal doses have led to the development of resistance among various weed species, rendering some products ineffective and uneconomical. The mechanisms of resistance development, such as target site resistance, enhanced metabolism, sequestration, gene amplification, and decreased absorption, have been comprehensively covered by Heap (2014). Common weeds such as *Lolium rnultijlorum*, *Avena, fatua, Setaria viridis, Digitaria insularis, Sorghum halepense, Kochia scoaria, Amaranthus palmeric, Conyza canadensis, Amaranthus tuberculantus,* and *Echinochloa crus-galli*), have developed resistance to most of the commonly used herbicides (e.g., glyphosates, atrazine, mesotrione, acetochlor, and topramezon) when used on major crops such as wheat, maize, rice, and soybean (Heap, 2014; Chahal *et al*., 2018). In summary, over 288 weed species have shown resistance to over 152 commonly used herbicides globally, according to Heap (2014). In Africa, South Africa has reported about 14 herbicide-resistant weed species (Figure 2), followed by Egypt with 3 species, according to Heap (2014). In terms of crop, wheat has the highest resistant species (81 weed species), followed by maize (63 weed species), rice (52 weed species), and soybean (50 weed species) (Heap, 2014). The impact of such evolution within weed species would result in yield losses, increased cost of production, low return on agricultural investment, and global food insecurity. For instance, management of herbicide-resistant Horseweed, Palmer amaranth, and Barnyardgrass has been reported to increase production cost by \$28.42, \$48, and \$64 per hectare, respectively (Mueller *et al*. 2005; Norsworthy *et al*., 2012). There is no adequate data on weed resistance in Africa simply because the region has been a low consumer of herbicide products for years; hence, there is not much research priority.

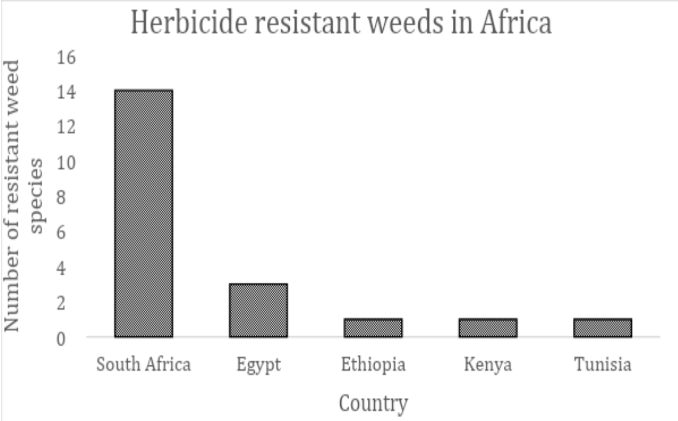

Figure 2: *Countries with confirmed cases of herbicide-resistant weed species in Africa. Adapted from Heap (2020).*

Ecological imbalance through the killing of non-targeted beneficial organisms

Macro and micro-organisms that directly or indirectly aid the production of desired crops are collectively referred to as beneficial organisms. Benefitial organisms help improve soil fertility and aeration, control crop pests and diseases, and help in the pollination process. If their populations are drastically lowered or completely wiped out by herbicides, farmers will likely face an upsurge in incidences of pests and diseases, low crop pollinations, and general ecological imbalances. Herbicide products have shown low to high toxicity levels for these organisms. For instance, common herbicide active ingredients, including metsulfuron, triclopyr, and glyphosate, are toxic to spider mites (*Tetranychus lintearius*) (Searle *et al*., 1990), phosphinic acid, triketone, triazine, glycine, phenoxy-carboxylic acid, chloroacetamide, isoxazole, sulfonylurea negatively affect the total and cumulative predatory activity of predatory Spider (*Pardosa egrestis*) (Korenko *et al*., 2016), glyphosate affects reproduction and population of *Chrysoperla externa* soybean pest control agent (Schneider *et al*., 2009), glyphosate and sulfonylurea affect micro-organisms responsible for biological nitrogen fixation in legumes (Zobiole *et al*., 2011; Rose *et al*., 2016), and glyphosate and atrazine disrupt earthworm and bees ecology and causing bodyweight loss and death (Correia and Moreira, 2010; Dai *et al*., 2018; Gill *et al*., 2018). The period of exposure to herbicides is a critical factor to consider when looking at their toxicity to beneficial organisms. With the evidence presented here, the long-term usage of these herbicides could result in the build-up of economically important crop pests and diseases due to partial or complete eradication of their natural enemies. Again, farmers could face a reduction in the soil fertility build-up because of killing of important fungi and bacteria that help in soil N fixation and mineralization of SOM. The results of these negative impacts include an increase in the cost of production as farmers have to rely on inorganic fertilizers to maintain nutrient supply, pesticide and fungicide applications for pest and disease control, and depression of crop yields.

Mitigating the negative impacts of herbicides on the environment

Adoption of an integrated weed management (IWM) system: The IWM system does not entirely rely on herbicides (Heap, 2014). Important practices that are incorporated under IWM include the adoption of cultural weed control methods like mulching and cover cropping; weed control through physical/ mechanical methods (e.g., hand weeding, slashing, and mowing under tree crops and uprooting); use of living organisms like beetles and grazing of animals under tree crops combined with localized weeding around tree bases; proper field selection that ensures crops are produced in fields that are not heavily infested with obnoxious weeds; reduction in the introduction of these resistant weeds into the crop fields by always planting weed-free seeds and managing the field-to-field movement of weed seeds; and carry out early weeding before weeds reach the flowering stage to avoid the development of a new generation of weed species that are tolerant to herbicides. Crop rotation is another practice capable of helping reduce herbicide resistance, especially of weed species specific to a given crop. For instance, the practice has been reported to decrease blackgrass density when spring crops were introduced into the rotation scheme (Valverde, 2003). Introducing other crops in the rice-wheat sequence was observed to greatly interrupt the incidence of isoproturon-resistant *P. minor* weed (Malik and Singh, 1995).

Herbicide rotation and/ or use of herbicide mixes: Herbicide rotation is the sequential application of herbicides with different modes of action on the same field in a season. Rotating pesticides based on their mode of action has been recommended as the best way of dealing with resistance (Powles *et al*., 1996; Otieno and Alwenge, 2020). Herbicide mix, on the other hand, refers to mixing more than one type of herbicide product/formulation at the time of application. Herbicide mixtures can undergo three types of interactions, namely additive, synergistic, and antagonistic (Gandini *et al*., 2020). The use of herbicide mixtures not only helps to slow down the development of resistance but also results in the efficient and effective control of weeds if the interaction is synergistic, including those that may have started to develop resistance to a component of the mixture (Gandini *et al*., 2020).

Proper selection and judicious application of herbicide: The selection of better products should be based on the type of weeds present in the field, the stage of the weed, and efficacy. Once the weed species have been identified, herbicides with new active ingredients should be preferred over those with already reported resistance levels. Care must always be taken to ensure that rates are used within the recommended optimum range to reduce the development of resistance (Neve, 2007; Otieno and Alwenge, 2020). This information could be sourced from the product label or primary data based on region-specific trials. Also, there is a need to evaluate the toxicity level of the herbicide selections to other beneficial organisms such as bees, butterflies, predatory mites, ladybirds, and earthworms and only apply less toxic products- preference should always be given to products with low environmental impact risks.

Avoid spraying or washing used farm equipment on grazing fields or watering points, as this may lead to contamination. Also, avoid herbicide drifting into grazing paddocks when spraying farms nearby. To reduce potential drifts, leave buffer zones between the farms. If a drift is suspected to occur, keep livestock away from such fields until the compounds have dissipated-check the product label for more on product half-life, re-entry interval, and pre-harvest interval.

Conclusions and Recommendations

The review research underscores the potential benefits and risks of widespread herbicide adoption in Sub-Saharan Africa. Poor weed control automatically results in yield losses, and the use of herbicides is the latest technology the region is moving towards. Crop yields have been observed to increase by up to 167%, depending on crop and region, and the cost savings reach as high as 50-80% compared to the labor-intensive manual weeding methods. While herbicides offer time-saving advantages and the potential for increased crop productivity of already resource-constrained farmers, the risks to human health and the environment should not be ignored. By implementing the proposed mitigation strategies, farmers can enhance productivity while minimizing negative impacts on the ecosystem. It is crucial to foster research collaboration, policy support, and capacity-building efforts to tailor solutions for the specific challenges faced in Sub-Saharan Africa, ensuring sustainable and responsible herbicide usage for the region's farmers.

Novelty Statement

This research delves into the untapped benefits of embracing herbicide adoption across Sub-Saharan Africa, shedding light on the potential advantages. Additionally, it scrutinizes the probable risks to crops and the environment stemming from improper herbicide application based on recent research in the region. The study emphasizes the critical need for implementing mitigation strategies, underlining the importance of responsible and sustainable herbicide usage in the region, supported by the latest and region-specific data.

Author's Contribution

Otieno H.M.O. came up with the research theme, researched, and developed the complete manuscript.

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