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A Review of the Current State and Potential Benefits of Using Herbicides by Smallholder Farmers in Sub-Saharan Africa

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ABSTRACT

Poor weed control automatically results in yield losses, and the review has provided a range of 30-100% depending on the crop, weed species, and stage of the crop. The timing and efficacy of the methods matter. Across the region, farmers use different methods broadly grouped into preventive, cultural, and curative methods. Herbicide application, a form of curative method, is seen as an effective means of weed control, which is cheap, time, and labor-saving technology for adoption. Also, the technology helps in soil carbon sequestration. Hence, it could be used to improve crop productivity and profitability of already of the farming systems in the region. The current adoption of herbicides is very low across SSA, ranging from 0.1-55%. The low adoptions in SSA could be associated with low education levels, poor knowledge, and experience with technology, cultural beliefs, high poverty levels, small farm size, and weak government and intercountry policies and extension services.

INTRODUCTION

Crop production is the main economic activity of the millions of smallholder farmers living in the 170 million hectares cultivated across Sub-Sahara Africa (SSA) (Gianessi & Williams, 2011). These farmers grow a wide range of crops, i.e., cereals (e.g., maize, wheat, rice, and sorghum), legumes (e.g., dry bean, soybean, grams, lentils, cowpea, and groundnut), roots and tubers (e.g., cassava, potato, sweet potato, and yam), and fibre crops (e.g., cotton, and sisal). However, the yields have remained relatively low compared to what is attainable under good management at any agroecological zones. For instance, the current maize and potato yields are typically 12.5-40% and 30-40%, respectively, of those realized on research plots (Haverkort & Struik, 2015; Otieno & Mageto, 2021; Nicholus *et al.*, 2022). Rice and cassava yields are low, at 25% of that reported by researchers (DeVries & Toenniessen, 2001). Legume yields are also low; dry bean yields are less than 1 t/ha compared to over 2.5 t/ha under well-managed farmers (Otieno *et al.*, 2020). These lower yields are due to several factors, mainly soil infertility, soil acidity (Otieno *et al.*, 2018; Otieno, 2021), pest and disease infestations (Okeyo *et al.*, 2019; Otieno, 2019a), weed infestation (Bedry, 2007; Monteiro *et al.*, 2011; Amare, 2014; Olayinka & Etejere, 2015), drought (Mathobo *et al.*, 2017), and use low yielding varieties (Nkonya & Mwangi, 2004; Japhether *et al.*, 2006). All these constraints must be addressed if the region has to be food self-reliant through best-crop agronomy.

Weed control is one of those critical agronomic practices that farmers must always get right 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 (Table 1). Research findings have compared and reported yield losses across various crops and countries (Table 1).

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, 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 because of high light intensity, humidity, and temperature, which favor their growth and competitive characteristics than in Europe and North America (Gianessi & Williams, 2011). Farmers have been using cultural methods characterized by physical hand-hoeing before and after the emergence of weeds to control weeds. This method is labor-intensive and time-consuming, aspects that have always been assumed to have more than adequate in the region. However, this is changing due to the movement of youths to town in search of job opportunities leaving elders at home who cannot carry out proper weed management.

According to a review by Gianessi and Williams (2011), delaying the first weeding by one week during the critical period could reduce maize yields by one-third, and two weeks delay in the second weeding may reduce maize yields by one-quarter. The poor weed management resulting in low yields is forcing smallholder farmers to consider using herbicides, despite several prevailing

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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 compared to unweeded crops.

Crop	Country	Yield loss due to weeds	Reference
Maize	Nigeria	55-90%	Chikoye *et al.*, 2004
Sorghum	Nigeria	40-80%	Ishaya *et al.*, 2007
Wheat	Ethiopia, Nigeria	50-80%	Gianessi & Williams, 2011; Amare, 2014
Rice	West Africa countries	28-100%	Rodenburg & Johnson, 2009
Dry bean/ Faba bean	Uganda, Sudan	35-70%	Malik *et al.*, 1993; Ugen *et al.*, 2002; Bedry, 2007
Groundnut	Nigeria, Sudan, and Tanzania	46-100%	Sibuga *et al.*, 1989; Mubarak, 2004; Olayinka & Etejere, 2015
Cowpea	Burkina Faso and Nigeria	30-60%	Aggarwal & Ouedraogo, 1989; Madukwe *et al.*, 2012
Cassava	Cameroon	48-90%	Oerke *et al.*, 1994; Ambe *et al.*, 1992
Potato	Angola, Nigeria	50-86%	Monteiro *et al.*, 2011
Cotton	Malawi, Nigeria, Zimbabwe	Up to 80%	Prentice, 1972; Mavudzi *et al.*, 2001

factors that are likely to limit the efficient, effective, and safe use of the practice under smallholders' setup. Therefore, this research review aims to review the current state of herbicide application and the potential benefits farmers will likely enjoy upon adopting the technology.

Data Sourcing

The data and information used in this manuscript were from secondary sources from various scientific publications and recognized research institutions. Some of the key search terms and phrases used to locate the resources were; "herbicides in Sub-Saharan Africa," "herbicide adoption in SSA", "benefits of herbicides", "crop yield loss due to weeds in SSA," "factors hindering herbicide adoption", "cultural/preventive/curative weed management practices". The sourced materials were then downloaded, read, and cited. Also, based on my extensive travel and focus group discussions with farmers across Africa, some primary data (unpublished) were incorporated.

RESULTS AND DISCUSSION

Status and Classification of Weed Control Strategies used by Farmers

Several weed management strategies could be deployed at any given time depending on farm size, farmers' economic status, and education level. Weed management strategies could be categorized into three; preventive, cultural, and agronomic strategies (Labrada, 2003). The preventive category is used before a crop is sown, while cultural and agronomic refer to those methods applied during a crop growing cycle (Table 2). In SSA, plowing during land preparation and weeding during plant growth is the conventional method of weed control practiced by smallholder farmers (Otieno *et al.*, 2019). In beans, the critical period of weed control is between the second-trifoliolate and first-flower stages of growth (Otieno *et al.*, 2020). From an economic standpoint, two weeding regimes at 30 and 50 days after emergence are optimum for realizing better potato yields (Otieno, 2019b). However, farmers rarely carry out two weedings leading to considerable yield losses. For instance, in Nigeria, maize farmers who carry out one weeding experience about 42% loss of their yields compared to those farmers who carry three weedings (Chikoye *et al.*, 2004). Though farmers also carry out crop rotation and intercropping, the purpose has never been weed control. Besides, the spacing farmers use during intercropping and intercrop choice has never been up to the standard required for weed control.

Table 2: Classification of weed control practices and applicable in an integrated weed management system. Adapted from Labrada (2003)

Category	Practice	Prevailing effect	Example
Preventive method	Crop rotation	Reduction of weed emergence	Alternation between winter and spring-summer crops
	Cover crops (used as green manures or dead mulches)	Reduction of weed emergence	Cover crop grown in between two cash crops
	Primary tillage	Reduction of weed emergence	Deep ploughing, alternation between ploughing and reduced tillage
	Seedbed preparation	Reduction of weed emergence	False (stale)-seed bed technique

	Soil solarization	Reduction of weed emergence	Use of black or transparent films (in glasshouse or field)
	Irrigation and drainage system	Reduction of weed emergence	Irrigation placement (micro/trickle-irrigation), clearance of vegetation growing along ditches
	Crop residue management	Reduction of weed emergence	Stubble cultivation
Cultural method	Sowing/planting time and crop spatial arrangement	Improvement of crop competitive ability	Use of transplants, higher seeding rate, lower inter-row distance, anticipation or delay of sowing/transplant date
	Crop genotype choice	Improvement of crop competitive ability	Use of varieties characterized by quick emergence, high growth, and soil cover rates in early stages
	Cover crops (used as living mulches)	Improvement of crop (canopy) competitive ability	Legume cover crop is sown in the inter-row of a row crop
	Intercropping	Reduction of weed emergence, improvement of crop competitive ability	Intercropped cash crops
	Fertilization	Reduction of weed emergence, improvement of crop competitive ability	Use of slow nutrient-releasing organic fertilizers and amendments, fertilizer placement, anticipation or delay of pre-sowing or top-dressing N fertilization
Curative method	Cultivation	Killing of existing vegetation, reduction of weed emergence	Post-emergence harrowing or hoeing, ridging
	Herbicide application	Killing of existing vegetation, reduction of weed emergence	Pre- or post-emergence spraying
	Thermal weed control	Killing of existing vegetation, reduction of weed emergence	Pre-emergence or localized post-emergence flame-weeding
	Biological weed control	Killing of existing vegetation, reduction of weed emergence	Use of (weed) species-specific pathogens or pests

Benefits of using Herbicides among Smallholder Farmers

The potential benefits that small-scale farmers could realize from using herbicides in crop production could be grouped into three main classes; 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 herbicide are solely due to the effective and ease of timing weeds control. 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 increased yields in several crops due to 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 *et al.*, 2007). The increase in yields by other crops have also been reported by Madukwe *et al.* (2012) on cowpea, Mubarak (2004) on groundnuts, and Janak and Grichar (2016) on maize.

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 uses a few farmworkers compared to the current hand-hoeing of weeds (Gianessi, 2005; Bellamy, 2011). 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). This cost-saved has been estimated to be as high as 80% of the labor normally used in manual weeding (Parker & Vernon, 1982). Otieno *et al.* (2019) 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 (Corbeels *et al.*, 2019). Since some weeds persist, it can be challenging to practice residue retention without herbicide.

The Current State of Herbicide use and Factors Limiting Adoption in Sub-Sahara Africa

Herbicide application offers suitable alternative technology to hand-hoeing weeds as it saves time and labor. Depending on the timing of application, herbicides are sprayed to eradicate weeds before emergence from soil (pre-emergence) and 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 (Gianessi & Williams, 2011), though individual countries have recorded significant growth in herbicide adoption; 0.1% in Uganda (Gianessi & Williams, 2011), 1% in Niger and Malawi (Bouwman *et al.*, 2021), slightly above 5% in Zambia (Grabowski & Jayne, 2016), 22% in Nigeria, 27% in Ethiopia, 55% in Ghana (Bouwman *et al.*, 2021). Other countries, like Kenya and Tanzania, have reported increased and decreased growth rates (Figure 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 and burdens, including for women and children since they form the majority of the workforce during weeding.

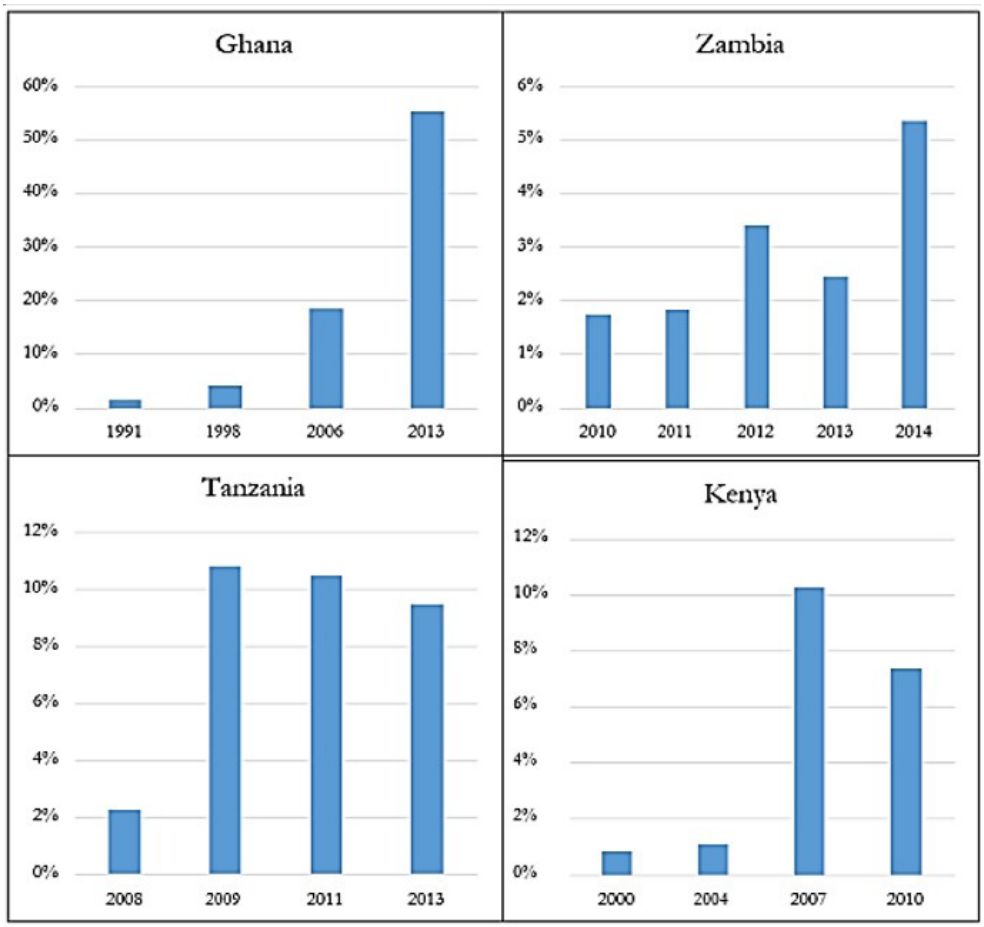

Figure 1: Trends in Household Herbicide Use over Time in Ghana, Zambia, Tanzania, and Kenya (Grabowski & Jayne, 2016).

Factors that could be Hindering 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 SSA farmers is very high, as the majority do not complete the basic primary education level (AGRA, 2017). 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.

Cultural Beliefs

Cultural beliefs are the ideas and thoughts common to several individuals that govern the interaction between these people, and between them, their gods, and other groups-and differ from knowledge in that they are not empirically discovered or analytically proved (Greif, 1994). 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 daily food source. 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 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 & 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 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 (Otieno, 2019c). Such a wide ratio impedes technology transfer.

CONCLUSION

Poor weed control automatically results in yield losses, and the review has provided a range of 30-100% depending on the crop, weed species, and stage of the attack. The timing and efficacy of the methods matter. The use of herbicides is one of the means and is considered a cheap, time-and labor-saving technology for adoption. Also, the technology helps in soil carbon sequestration. Hence, it could be used to improve crop productivity and profitability of already resource-constrained farmers in Africa. The current adoption of herbicides is very low across SSA, ranging from 0.1-55%. The low adoptions in SSA could be associated with low education levels, poor knowledge and experience with technology, cultural beliefs, high poverty levels, small farm size, and weak government and intercountry policies and extension services.

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