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Review Article

Challenges of weed management in rice for food security in Africa: A review

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Abstract

Rice is one of the most important crops for food security in Africa. However, there is a large gap between its present demand and supply. Weed competition is basically one of the major constraints in rice systems in Africa, leading to 48–100% yield reduction and sometimes complete crop failure, thereby threatening food security. Weed control methods currently employed to avoid such losses are predominantly hoe-weeding and herbicide application. Hoe weeding is tedious, inefficient, time consuming, associated with high labour demands and often too expensive for the average farmer to afford. Herbicide use on the other hand, does not provide season-long weed control. Moreover, there are not many herbicides that can control different kinds of weeds with one application. Thus, to optimise yield, financial, social and environmental costs and benefits, integrated and ecological weed management approaches are advocated. Future weed research should therefore be focused on delivering information for the implementation of these approaches. This would require improved knowledge of weed biology and ecology, prioritization of problematic weed species, development of competitive rice cultivars and timely weed control. To address the diversity of weed problems in rice systems in Africa, however, research innovations must take full account of farmer's local conditions using farmers' participatory approaches. This review suggests that knowledge-based integrated novel approaches must be developed to assist farmers in coping with the challenges of weed management for sustainable rice production.

Keywords: weed interference; integrated weed management; hoe weeding; herbicides; food security

INTRODUCTION

Rice (*Oryza sativa* L.) is the most important food crop of the developing world and the staple food of more than half of the world's population (Seck et al., 2012). It is the most rapidly expanding food commodity both in consumption and production, and therefore a central crop for food security in Africa (Seck et al., 2012). Rice consumption was more than tripled from 9.2 Mt to 31.5 Mt during the period of 1990 to date in Africa (USDA, 2018). Rice is currently cultivated in rainfed upland and aquatic ecologies in 40 countries in Africa on nearly 10 million ha with about 25 million tones production (GRiSP, 2013). Rice production in Africa is already a highly strategic and priority element and will continue to be so in the coming decades, be it in terms of food security, poverty alleviation, youth employment and use of scarce resources. It is the most consumed staple food, providing about 27% of the calories of billions of people across several countries in Africa (GRiSP, 2013; Udemezue, 2018).

Based on the expected population growth, income growth, and rice acreage decline, global demand for rice will continue to increase from 479 million tons milled rice in 2014 to 536–551 million tons in 2030 (GRiSP, 2013). Africa will certainly experience a huge increase in demand for rice as never before. However, there is lopsidedness in the present level of production and yield of rice in Africa as compared to its demand and consumption pattern. Reports indicated that the average rice yield in Africa is still around 2.1 t/ha (USDA, 2018). This is far below the potential productivity of rice in the region, and global average production of 5.4 t/ha (GRiSP, 2013). Thus, there is a great challenge to improve the productivity of rice to ensure food security for the growing human population.

Of all the factors attributed for the low yield of rice, weed competition is one of the most deleterious resulting in about 48 to 100% yield reduction (Adeyemi et al., 2017; Adigun et al., 2017; Kolo et al., 2020). On a global scale, 37% of the rice yield is considered to be lost to weeds (Oerke and Dehne, 2004). In Africa, weeds account for yield losses estimated to be at least 2.2 million tons per year, valued at $1.45 billion, and equating to approximately half the current total imports of rice to this region (Rodenburg and Johnson, 2009). Improving weed control in farmers' field was reported to increase rice yields by 15–23% and reduce yield loss by 1 t/ha (Becker et al., 2003; Nhamo et al., 2014). However, actual weed management in Africa is always a challenge, and compared to most other field crops, weed management in rice systems is much more demanding. Rice is a weak competitor against weeds, and sown at close spacing, which makes mechanical weed control difficult, thus resulting in high yield reduction (Becker et al., 2003; Johnson et al., 2018).

Hoe weeding is the predominant weed control method in rice systems in Africa (Gianessi, 2013; Adigun et al., 2017). However, the efficacy of hoe weeding is often compromised by the continued wet conditions characteristic of the beginning of the rainy season. Hoe weeding under wet conditions often causes weed to re-root and re-establish, necessitating several rounds of weeding to keep the crop weed-free and avert yield losses (Gianessi, 2013). This is however, tedious, inefficient, time consuming and associated with high labour demands (Ogwuike et al., 2014; Datta et al., 2017). In addition, labour for manual weeding is scarce and often too expensive for the average farmer to afford (Adigun et al., 2017; Daramola et al., 2019). Consequently, farmers spend a large amount of time in weeding operation (Daramola et al., 2020). In upland rice systems, hand weeding was estimated to take 173 to 376 person-hours per hectare, depending on the number of weeding interventions (Ogwuike et al., 2014). Weeding is reported to negatively affect women and children's wellbeing because of the high labour burden and drudgery involved (Bergman et al., 2012; Ekeleme et al., 2016). Despite the effort expended in hoe weeding by farmers, however, weeds still cause considerable yield losses, because most of the weeding operations are done well after the crops have suffered irrevocable damage from weeds (Becker et al., 2003; Adeyemi et al., 2017). Alternatively, herbicides are quite effective and efficient in suppressing weeds in rice if properly used. Herbicides reduce drudgery and protect crops from early weed competition (Rodenburg et al., 2011). However, there are not many herbicides that can control different kinds of weeds with one application, and their efficacy is further limited when they are used alone (Adigun et al., 2017; Daramola et al., 2019). They rarely provide a season-long weed control. Moreover, herbicides for weed control in rice are often not available to smallholder farmers at the time of need and, when available, farmers lack the requisite knowledge and skill to use herbicides correctly. Although herbicide use alleviates the problem of labour for weeding, incorrect use may bring about other environmental problems (Ekeleme, 2009). Application characteristics such as herbicide choice, rate and timing, are reported to frequently deviate from the recommendations (Rodenburg and Johnson, 2009) with potential negative consequences for the environment, human health, crop performance (Sims et al., 2018) and hence, food security.

Considering these constant threats, improving weed management is one of the key strategies to increase rice production and hence, food security in Africa. Until weed management is improved, Africa farmers will not produce optimal rice yields, since farm families cannot plant more area than they can weed. Even if land and other inputs were available, without innovations in weed control, they are doomed to stay "very small-scale farmers" and will be unable to improve their livelihoods and food production. Currently, there is paucity of research on weed ecology and weed management practices in rice systems in Africa. The small numbers of useful available scientific information on weed management in rice systems are scattered among many journals and books, which are not always accessible by smallholder farmers (Ismaila et al., 2013). Furthermore, expertise in weed science in Africa is limited and both the general public and government tend to allocate weeds a low priority. Therefore the aim of this review is to describe the current weed management practices and identify the challenges and prospects to guide future weed management research in rice systems in Africa.

Important rice weeds in Africa

Many weed species have been reported to infest rice in Africa (Table 1) but the extent of damage inflicted on the rice crop varies with the type of weed species involved (Rodenburg and Johnson, 2009). Weeds that cause major problems in upland rice ecology include perennial weed species such as *Imperata cylindrica*, *Cyperus rotundus* and *Chromolaena odorata*, the annual weed species such as *Digitaria horizontalis* and *Euphorbia heterophylla* and the parasitic weeds including *Striga hermonthica* and *Striga asiatica* (Ishaya et al., 2007; Adigun et al., 2017). In lowland rice ecology, perennial weeds *Oryza longistaminata* and *Cyperus* spp.; annual weeds *Echinochloa* spp., *Oryza barthii*, *Cyperus difformis*, and *Cyperus iria* have been reported to cause serious losses (Rodenburg and Johnson, 2009; Adeyemi et al., 2017). Characteristics that distinguish problematic weeds in rice systems are high competitiveness, short growth cycles (e.g. *D. horizontalis, C. difformis)*, high multiplication rates (e.g. *E. heterophylla*), similarity in appearance with rice (*O. longistaminata)*, rapid re-establishment after disturbance (e.g. *C. rotundus*, *C. esculentus*, *Imperata cylindrica, C. odorata*), ability to reproduce before rice harvest and submergence tolerance (Rodenburg and Johnson, 2009; Ismaila et al., 2013).

A review of literature on weeds in rice systems in Africa yielded 40 different weed species (Table 1). However, the most cited weed species are *Rottboellia*

Table 1. Rice weed species composition in Nigeria

Weed species	Plant family	Ecology
Broad leaf weeds		
Tridax procumbens (Linn.)	Asteraceae	Upland/lowland
Euphorbia heterophylla (Linn.)	Euphorbiaceae	Upland
Commelina benghalensis (Burn.)	Commelinaceae	Upland
Gomphrena celosoides (Mart.)	Amaranthaceae	Upland
Spigelia anthelmia (Linn.)	Loganiaceae	Upland
Boerhavia diffusa (Linn.)	Nyctaginaceae	Upland
Talinum, triangulare (Jacq.) Willd.	Portulacaceae	Upland
Laportea aestuans (Linn.) Chew	Urticaceae	Upland
Ipomea triloba (Linn.)	Convolvulaceae	Upland/lowland
Chromolaena odorata (L.) R.M. King and Robinson	Asteraceae	Upland
Amaranthus spinosus (Linn.)	Amaranthaceae	Upland
Ludwigia spp.	Convolvulaceae	Lowland
Striga sp.	Scrophulariaceae	Upland
Bidens pilosa (Linn.)	Asteraaceae	Upland
Senna mimosoides (Linn.)	Casalpiniaceae	Upland
Ageratum conyzoides (Linn.)	Asteraceae	Upland/lowland
Cleome viscosa (Linn.)	Clemaceae	Upland
Phyllanthus amarus (Schum)	Euphorbiaceae	Upland
Sphenoclea zeylanica (Gaertn.)	Campanulaceae	Lowland
Nymphaea lotus (Linn.)	Nymphaeaceae	Deep water
Aspilla africana (Pers.)	Asteraceae	Upland
Oldenlandia corymbosa (Linn.)	Rubiaceae	Upland
Grasses		
Digitaria horizontalis (Willd.)	Poaceae	Upland
Paspalum scrobiculatum (Linn.)	Poaceae	Upland/lowland
Panicum maximum (Jacq.)	Poaceae	Upland
Axonopus compressus (Sw.) P. Beauv.	Poaceae	Upland
Eleusine indica (Gaertn.)	Poaceae	Upland
Rottboellia cochinchinensis (Lour.) Clayton	Poaceae	Upland/lowland
Cynodon dactylon (Linn.) *Pers*	Poaceae	Upland
Bracharia spp.	Poaceae	Upland
Eragrostis spp.	Poaceae	Upland
Oryza barthii (A. Chev.)	Poaceae	Lowland
Setaria spp.	Poaceae	Upland
Echinochloa spp.	Poaceae	Lowland/hydromorphic
Imperata cylindrica (Linn.)	Poaceae	Upland/lowland
Pennisetum spp.	Poaceae	Upland
Sedge		
Cyperus rotundus (Linn.)	Cyperaceae	Upland/lowland
Cyperus esculentus (Linn.)	Cyperaceae	Upland
Kyllinga spp.	Cyperaceae	Upland/lowland
Cyperus difformis (Linn.)	Cyperaceae	Lowland

cochinchinensis, Digitaria horizontalis, Ageratum conyzoides, Tridax procumbens, Panicum spp., *Cyperus* spp., *Oryza longistaminata, Euphorbia heterophylla and Echinochloa colona* (Usman et al., 2001; Ishaya et al., 2007; Ismaila et al., 2013; Adeyemi et al., 2017; Adigun et al., 2017).

Current weed management practices in rice systems in Africa

Cultural weed control

Cultural weed control is the commonest method employed by most African farmers to reduce weed infestation in rice (Akobundu, 1987; Ismaila et al., 2013). Cultural control is the use of common practices such as land preparation, planting method, soil fertility management, mulching, mixed cropping, crop rotation, flooding, variation of crop row spacing, competitive rice cultivars, cover crops etc. for the proper management of weeds, water and soil (Silva et al., 2007; Rodenburg and Johnson, 2009). The effect of timely fertiliser application (Adigun et al., 2017; Kolo et al., 2020), narrow row spacing (Kasim et al., 2017) and optimum seed rate (Ampong-Nyarko and De Datta, 1991; Johnson, 1996) to suppress weeds have been reported in rice systems in Africa. Apart from grain yield increase, Kasim et al. (2017) reported that 14 cm row spacing was more effective in reducing weed density and biomass than 20 cm row spacing in upland rice. The use of narrow row spacing reduced weed infestation and increased rice grain yield due to rapid canopy cover which reduced light penetration thereby limiting the growth and development of weeds underneath the canopy (Johnson, 1996; Kasim et al., 2017). Nitrogen fertiliser application at 90 kg ha^{-1} in two splits at 3 and 6 weeks after emergence was reported to favour the rice crop than weeds resulting in improved rice competitiveness and increased yield (Adigun et al., 2017). Furthermore, application of nitrogen at 120 kg ha^{-1} reduced weed infestation and ensured optimum crop yields in upland rice (Adagba et al., 2002).

The use of competitive rice cultivars with inherent capacity to smother infesting weed species has also been reported (Ekeleme et al., 2008; Ekeleme et al., 2009; Kolo and Umaru, 2012). Ekeleme et al. (2009) reported that CG-14, a tall landrace rice variety showed superior weed competitive ability compared to ITA-150, WAB-56-104, NERICA-1, NERICA-2, and NERICA-4. The results of Kolo and Umaru (2012) also showed that inter-specific NERICA-1 variety was more weed suppressive and produced greater grain yield than FARO 46. It was reasoned that increased competitiveness of NERICA-1 might be due to its morphological characteristics such as rapid early growth, drooping leaves, good tillering ability and high specific leaf area. In another study conducted in hydromorphic soils, the tall variety OS6, incurred 24% less yield reductions from weed competition than the semi dwarf cultivar ANDNY11 (Akobundu and Ahissou, 1985). Generally, rice cultivars with tall stature and droopy leaves are reported to be more competitive (Haefele et al., 2004; Ekeleme et al., 2008), but there may be a trade-off because of low genetic yield potential and susceptibility to lodging among other factors (Ekeleme et al., 2009).

Flooding has been used as an important cultural weed management option in lowland rice systems in Africa because many weeds will not germinate in anaerobic conditions. Akobundu (1987) reported that maintaining a flood layer of 5–10 cm suppressed the growth of most weed species and enhanced the productivity of transplanted lowland rice. Mulching is another cultural weed control method feasible in upland rice but not widely practiced in Africa. According to Akobundu (1987), mulching inhibits weed seed germination by shading and through the release of allelopathic substances (Akobundu, 1987).

Mechanical weed control

Mechanical weed control is any physical activity that inhibits unwanted plant growth (Akobundu 1987). Mechanical weed control techniques manage weed populations through physical methods that remove, injure, kill, or make the growing conditions unfavourable (Silva et al., 2007). Some of these methods cause direct damage to the weeds through complete removal or causing a lethal injury. Other techniques may alter the growing environment by eliminating light, increasing the temperature of the soil, or depriving the plant of carbon dioxide or oxygen (Tuet al., 2012). Mechanical weeding in rice includes tillage, hand pulling, hoeing, and mowing (Akobundu 1987). Mechanical weed control has potential in rice production. However, many farmers in Africa are limited by unavailability and poor access to resources for mechanical weed control (Ismaila et al., 2013). Hence, fields are often inadequately tilled, which favours luxuriant weed growth and increased cost of weed control (Akobundu and Fagade, 1978). Manual hoeing is the most pre-dominant mechanical weed control measure against weeds in rice systems in Africa (Adesina et al., 1994). However, this method is tedious and requires a lot of labour input. Up to 250–780 hours ha^{-1} of labour for mostly women and children are required to prevent economic rice yield losses (Akobundu and Fagade, 1978; Akobundu, 1987). Conventionally, farmers weed rice field three times, but in rice farms where perennial weeds, such as *Imperata cylindrica* are predominant, extra hoe weeding may be required (Akobundu, 1987) as these are capable of rapid regrowth from rhizomes.

Biological weed control

No published evidence is available on farmer's adoption of biological weed control in rice in Africa. This is probably because of the constraints associated with the implementation of biological control, and farmer's limited access to the technologies. Biological control agents are very host specific and their use requires a relatively high skill level which is lacking among farmers in Nigeria (Akobundu, 1987). Although studies conducted outside Africa have identified pathogens for the biological control of weeds such as *Cyperus rotundus* (Kadir and Charudattan, 2000), *Bidens pilosa* and *Euphorbia hirta* (Hong et al., 2004), weeds that also occur in rice fields in Africa. No reports are available, however, on the use of such biological agents in controlling these weeds in rice systems in Africa.

Chemical weed control

Chemical weed control is an important weed control method which involves the use of different herbicides applied as pre-plant incorporated, pre and post-emergence of crops to control weeds (Johnson, 1997; Adigun and Lagoke, 2003). Herbicides are currently the most widely used for weed control in rice systems due to decline in labour for manual weeding, particularly when large areas are planted (Ismaila et al., 2013). The adoption of chemical weed control in rice systems has been on the increase in Africa due to its higher profitability, economic benefits, requirement of less weeding time and labour input (Ogudele and Okoruwa, 2006; Saleh and Oyinbo, 2017). In upland rain-fed rice system, herbicide application was found to be more profitable than manual weeding (Ekeleme et al., 2009; Saleh and Oyinbo, 2017).

Herbicides are often used in combination with other weed control methods. In Africa, most farmers depend on herbicides followed by hoe weeding (Saleh and Oyinbo, 2017). However, most farmers lack the knowledge of proper herbicide application due to limited access to information and high level of illiteracy (Ekeleme et al., 2009). Hence, herbicide applications are often too late, and the rates incorrect or poorly applied thus causing additional risks to human health. This may result in inefficient weed control, increased costs, phytotoxicity damage to the crop and consequently reduced crop growth and yield (Ekeleme et al., 2009; Ismaila et al., 2013). Herbicides used on broad-leaved weed species in rice in Africa are 2,4-D and MCPA, whereas, butachlor, oryzoplus, propanil, molinate, oxadiazon, and thiobencarb are commonly used against grass weeds (Usman et al., 2001). The effectiveness of Oryzoplus and butachlor as pre-emergence treatment against *Cyperus rotundus*, *Euphorbia heterophylla* and *Digitaria horizontalis* has been reported (Adigun et al., 2017). In upland rice, cinosulfuron (0.2–0.6 g/l) reduced S. *hermonthica* infestation (Adagba et al., 2002) whereas good weed control was also reported by using mixtures of pretilachor with dimethametryne and piperophos with cinosulfuron (Enyinnia, 1992; Ishaya et al., 2007). In irrigated rice, thiobencarb, fluorodifen, and oxadiazon proved successful in reducing weed infestation (Akobundu, 1981; Okafor, 1986). Pretilachlor + dimethametryne at 2.5 kg a.i./ha and piperophos + cinosulfuron at 1.5 kg a.i./ha performed well as they effectively controlled weeds and resulted in better growth and rice grain yield that was comparable to the hoe-weeded control (Ishaya et al., 2007).

Integrated weed management (IWM)

Considering the diversity of weed problem in rice systems, no single method, whether manual, mechanical, biological or chemical can provide the desired level of efficiency under all situations (Chauhan et al., 2012; Mishra et al., 2017). Hence the need to integrate different methods and strategies to widen the weed control spectrum and efficiency for sustainable rice production. Integrated weed management involves coordinated use of multiple tactics for optimising the control of all classes of weed in an ecologically and economically sound manner (Knezevic, 2014). This approach recognises that single tactics has resulted in increased cost of weed control, shifts among weed species and herbicide-resistant biotypes, and hence focuses on diversity of weed control methods rather than relying on one single method (Chauhan et al., 2017).

Studies have shown that the integration of pre-emergence herbicides with manual hoe weeding was more effective in reducing weed infestation in various rice systems in Africa (Rodenburg and Johnson, 2009; Adigun et al., 2017). Adigun et al. (2017) reported that the integration of pre-emergence oryzoplus application at 2.0 kg a.i./ha followed by supplementary hoe weeding at 6 weeks after sowing (WAS) reduced weed density and biomass and subsequently increased grain yield of upland rice than sole herbicide and hoe weeding. Shave and Anzenge (2017) also reported that conventional tillage followed by 2 hoe weedings at 3 and 9 WAS gave more efficient weed control and higher grain yield of low land rice compared to sole application of hoe weeding. In another study, integration of post-emergence herbicides propanil + oxadiazon at 3.0 + 1.0 kg a.i/ha and propanil + fluorodifen at 1.4 + 1.8 kg a.i./ha controlled weeds effectively and gave similar grain yields to that from hand-weeding twice (Okafor, 1986). The results of Danmaigoro et al. (2019) also showed that application of pendimethalin followed by one hoe weeding at 6 WAS produced significantly higher growth and grain yield of rice than hoe weeded control. Other examples of integrated practices in Africa rice systems are fertiliser application combined with manual hoe weeding and herbicide application

(Adigun et al., 2017) and narrow row spacing in combination with herbicide application (Kasim et al., 2017). Adigun et al. (2017) reported that nitrogen fertiliser application at 90 kg ha^{-1} in combination with pre-emergence application of propanil + 2, 4-D at 2.0 kg a.i./ha followed by hoe weeding at 6 WAS provided season-long weed control and increased grain yield of rice than hoe weeding or the herbicides applied alone. The result of Kasim et al. (2017) showed that butachlor at 1 kg ha^{-1} and 14 cm×14 cm spacing gave efficient weed control and optimum grain yield in rice. Despite the advantages of IWM, farmers in Africa are often constrained to adopt this method due to poor access to information and limited inputs.

Future research

In spite of advances in weed management in rice, weed infestation is still a major challenge to rice production, and countries in Africa are particularly vulnerable. Having reviewed the available literature on rice weeds and current weed management practices in Africa, the following strategies need to be considered for future research that can improve weed management in rice systems in Africa.

Ecologicy-based weed management and prioritisation of problematic weed species

There is need for improved knowledge of weed ecology, biology and competitive mechanisms for effective weed management. Resources use should be optimised to reduce yield losses in rice systems, rather than focusing on weed-free conditions that increase cost of weed control. Understanding the competitive mechanisms of problematic weeds will help to improve preventive measures against them. Prioritising and targeting the problematic weed species, rather than all infesting weed species could help to reduce labour input and cost of weed control without reduction in yield. Different weed management practices are likely to result in differential responses among the major weed species. Hence, weed management strategies for particular species should consider the ecology and biology of that species and this can be used as a basis to develop more sustainable management practices.

Timing of weed control

Timing of weed control is important because crops have critical periods during which weed competition affects yield and beyond which effects are not detrimental to crop growth and yield (Knezevic and Datta, 2015). The critical period of weed interference is the period during which weed infestation is most detrimental to crop yield (Daramola et al., 2020). Few studies have been conducted on the effect of different periods of weed interference in rice systems in Africa (Adeyemi et al., 2017). However, there is still a dearth of information on the critical periods for weed control in rice systems. The critical period of weed interference determines the number of times the rice crop has to be weeded to avert yield loss and, therefore, the labour requirement for weeding rice. The number of hoe weeding and amount of herbicides used could be reduced if they were applied only during critical periods of weed control. Identification of the critical period of weed control in various rice systems will therefore not only enhance integrated weed control but will also reduce the cost of weed management.

Developing a weed competitive rice variety

Assessment of varietal differences with respect to competitiveness with weeds is important to deliver cost-effective and environmentally friendly weed management packages (Zhao et al., 2006). Studies have indicated that rice varieties with high yields under weed-free conditions are also likely to have high yields under weed competition (Lemerle et al., 2001; Zhao et al., 2007). Combining yield potential with improved competitiveness is therefore a viable option for effective weed control and increased rice yield in Africa. There have been only limited efforts, compared to the challenges faced, to develop locally adapted rice varieties suitable for African ecology. Hence, there is a need to intensify breeding activities to develop improved varieties with traits that confer weed competitiveness and high yield potential. Better understanding of morphological and physiological traits that confer competitiveness is also needed to identify suitable parents for marker-assisted breeding programs. In this respect, the gene pools of the African wild (*Oryza glaberrima)* and cultivated rice (*Oryza sativa*) species and the NERICAs (*Oryza glaberrima* × *Oryza sativa)* varieties are options yet to be exploited.

Integrated crop and weed management approaches

Weed management strategies that are financially, socially, and environmentally cost-effective can only be achieved through integrated approaches (Knezevic, 2014). Approaches that combine crop management to achieve increased competitiveness with optimum plant population densities and vigorous crop growth together with weed management options that prevent, suppress, and control weeds are viable options to improve weed control and increase yield in rice systems in Africa. There is need for further research on the compatibility of various weed control options when used in an integrated approach.

Educating farmers on improved weed control

The level of literacy among rice farmers in Africa tends to be low which limits the transfer and adoption of improved weed control by farmers. Improved weed management practices should be tested on farmer fields to increase farmer's participation. Rice farmers in Africa would be best served by effective weed control options that are easy to read, learn and apply, and relatively independent of agro-industries. Moreover, the farmers have to be thoroughly educated about adverse ecological consequences of herbicide use (such as loss of insect species) and also about potential risks to human health when no protection of skin and respiratory tract is used.

CONCLUSIONS AND RECOMMENDATIONS

Current weed control practices inrice-based cropping systems in Africa such as manual hoe weeding, herbicides, fallow, flooding, crop rotations, tillage practices and fertiliser management are inadequate for sustainable rice production for the ever increasing population. The high level of illiteracy among rice farmers in Africa, labour shortages, lack of access to information, inputs, and credits are important constraints to weed control, typical of rice farms in Africa. For rice systems to be sustainable, ecological approaches to weed management are required. Rice farmers in Africa would be best served by effective weed management strategies that are affordable, easy to learn and apply, and not labour intensive. Data on importance and distribution of specific weed species are required for improved priority setting for weed research perspective for the future. As rice systems in Africa are diverse, weed research needs to be relevant to different regions and rice growing systems while generating knowledge and technologies that are locally applicable to farmers. In different regions and environment, basic knowledge of the biology and ecology of important weed species for each ecosystem will provide insight on the management strategy to be developed.

Research efforts should also be geared towards refining integrated weed management for various cropping systems and agro-ecological regions. Rather than relying on single strategies of manual hoe weeding and herbicide application, future strategies for improved weed management in rice production systems should place greater attention on problematic weed species, proper timing of weed removal, reduction of weed emergence, developing competitive cultivars and minimising weed interference. These can be achieved by genetic and management improvements. To realise such improvements may require intensified breeding activities and marker assisted breeding programs to enlarge the range of available germplasm with desirable traits such as resistance and tolerance to parasitic weeds, improved crop competitiveness, enhanced nutrient and water uptake, high yield and grain quality and improved resistance to other biotic and abiotic stresses. Weeds can also be exploited as a source of valuable genetic materials for crop breeding programs. Recognising smart and improved rice growing methods and water management would also be needed to increase rice yield and reduce water use with the advent of climate change, changing weed populations and labour shortages. Further development may focus on herbicides with high efficacy and low toxicity to the environment, bioherbicides as an alternative to chemical herbicides for rice farmers in Africa, innovative strategies for the use of herbicides in terms of rate and tank mixture with a focus on early weed management and improved rice harvesting and processing techniques that minimises weed seed contamination thus increasing the acceptability and marketing of rice in Africa.

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