16 Managing Weeds of Rice in Africa

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Introduction

Weeds are the most frequent and widespread biotic constraint to productivity throughout the rice environments of Africa (Balasubramanian *et al.*, 2007; Diagne *et al.*, Chapter 4, this volume). Rice is a weak competitor against weeds and the majority of African farmers have few options and resources available for effective weed control (Rodenburg and Johnson, 2009). Weed competition may increase with inadequate land preparation (soil tillage and levelling), cropping intensification, the introduction of weed seeds (through manure, machinery or as a contaminant of rice seed), use of poor-quality rice seeds, use of old rice seedlings for transplanting, inadequate water management, improper fertilizer management, labour shortages for hand weeding and delayed or inappropriate herbicide applications (e.g. Becker and Johnson, 1999, 2001b). Further, as no single intervention is likely to resolve the challenges of sustainably managing weeds, several measures usually need to be combined to achieve adequate control. This chapter provides an overview of crop and weed management practices currently available, and also considers some issues likely to become relevant to African rice production systems.

Weeds in Rice in Africa

Economic importance

In sub-Saharan Africa (SSA), weeds are estimated to account for rice yield losses of at least 2.2 million tonnes (Mt) per year (Rodenburg and Johnson, 2009). Combined with costs of weed control, the financial losses easily surpass half the cost of current regional rice imports. If not controlled, weeds cause yield losses in the range of 28–74% in transplanted lowland rice, 28–89% in direct-seeded lowland rice and 48–100% in upland rice (Rodenburg and Johnson, 2009). In West Africa, it has been shown that farmers can increase their rice yields by 15–23% by applying relatively basic measures to improve weed control, such as bunding of fields to retain flood water, and timely interventions such as herbicide applications and hand weeding (e.g. Haefele *et al.*, 2000; Becker and Johnson, 2001b; Becker *et al.*, 2003).

African farmers do not, however, perceive weeds as solely undesirable. Many species often considered as weeds also feature in traditional pharmacopoeias (e.g. Stepp and Moerman, 2001) or are collected for domestic use, crop and postharvest pest control functions or as an additional source of food (Rodenburg *et al.*, 2012).

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Problem weed species

Certain weed species are particularly difficult to control or have an acute effect on the crop through strong competition for resources (nutrients, water and light) or parasitic nature. Weeds can also have secondary negative effects on a crop, crop-management or postharvest operations, and incur costs to control, complicate access to the field (with or without equipment or machinery), act as vectors of rice diseases, attract other important rice pests (like insects, rodents and birds), impede water flow in irrigation or drainage canals, or lower product quality if their seeds mix with rice grains.

Problem weeds in rice-based production systems in Africa can be characterized in a number of ways depending on their biology or on the problems they pose. Perennial rhizotomous or tuber-bearing species include *Imperata cylindrica*, *Oryza longistaminata*, *Leersia hexandra*, *Bolboschoenus maritimus*, *Sacciolepis africana*, *Cyperus halpan*, *C. esculentus* and *C. rotundus*. Examples of competitive, fast-growing or prolific-seed-producing annual weeds of rice include *Euphorbia heterophylla*, *Cyperus difformis*, *Ageratum conyzoides*, *Eleusine indica*, *Sphenoclea zeylanica* and *Ammannia prieureana*. Some grass species, like *O. barthii*, *O. longistaminata*, *Echinochloa colona* and *E. crus-pavonis*, are difficult to target in the field because of their resemblance to rice, while other species – such as *Ischaemum rugosum* and *Rottboellia cochinchinensis* – cause postharvest problems as they produce seeds that are similar in size and shape to rice grains. Weed species can be alternative hosts for diseases and pests such as *Rice yellow mottle virus* and African rice gall midge (e.g. *O. barthii*, *O. longistaminata*, *E. crus-pavonis*) or attract birds (e.g. *E. colona*), while deep-water or aquatic plants may infest and block drainage and irrigation canals (e.g. *Typha domingensis*, *Acroceras zizanioides*, *Ipomoea aquatica*, *Eichhornia crassipes*, *Salvinia nymphellula*, *Pistia stratiotes*). Another group is the parasitic weeds (e.g. *Striga asiatica*, *S. hermonthica*, *Rhamphicarpa fistulosa*), which parasitize the roots of cereal crops like rice to survive (*Striga* spp.) or to enhance their reproductive success (e.g. *R. fistulosa*), and are increasing in importance according to several reports (e.g. Rodenburg *et al.*, 2010, 2011b). Some important weeds in different rice environments are listed in Table 16.1.

Table 16.1. Important weed species in upland, hydromorphic and lowland rice production systems in Africa. (Adapted from Rodenburg and Johnson, 2009.)

Upland		Hydromorphic		Lowland	
Rottboellia cochinchinensis	A, g	*Ageratum conyzoides*	A, b	*Sphenoclea zeylanica*	A, b
Digitaria horizontalis	A, g	*Panicum laxum*	A, g	*Cyperus difformis*	A, s
Ageratum conyzoides	A, b	*Leersia hexandra*	P, g	*Fimbristylis littoralis*	A, s
Euphorbia heterophylla	A, b	*Cyperus rotundus*	P, s	*Oryza longistaminata*	P, g
Imperata cylindrica	P, g	*Digitaria horizontalis*	A, g	*Echinochloa colona*	A, g
Paspalum scrobiculatum	P, g	*Eclipta prostrata*	A, b	*Echinochloa crus-pavonis*	A, g
Mariscus cylindristachyus	P, s	*Spilanthes uliginosa*	A, b	*Leersia hexandra*	P, g
Trianthema portulacastrum	A, b	*Commelina benghalensis*	A, b	*Oryza barthii*	A, g
Striga hermonthica	A, p[a]	*Fimbristylis littoralis*	A, s	*Cyperus iria*	A, s
Striga asiatica	A, p[a]	*Echinochloa colona*	A, g	*Bolboschoenus maritimus*	P, s
Cynodon dactylon	P, g	*Cyperus esculentus*	P, s	*Ischaemum rugosum*	A, g
Commelina benghalensis	A, b	*Cynodon dactylon*	P, g	*Panicum laxum*	A, g
Brachiaria lata	A, g	*Rhamphicarpa fistulosa*	A, p[b]	*Ludwigia abyssinica*	A, b
Cyperus rotundus	P, s			*Ammania prieureana*	A, b
Chromolaena odorata	P, b			*Cyperus esculentus*	P, s
Panicum laxum	A, g			*Cyperus halpan*	P, s
				Eclipta prostrata	A, b
				Rhynchospora corymbosa	P, s

A = annual, P = perennial; g = grass, b = broadleaved, s = sedge; p = parasitic (a = obligate hemi-parasitic, b = facultative hemi-parasitic).

Weed Management in African Rice-based Cropping Systems

Across ecosystems

Vigorous early crop growth with rapid canopy closure is imperative for rice to compete well with weeds, particularly for light. Many factors contribute to rapid early rice growth and good crop establishment, including, for example, good land preparation comprising soil tillage, bunding and levelling to enable uniform flooding depth (in continuous or temporarily flooded systems), the use of good-quality rice seed or healthy rice seedlings for transplanting and, depending on the system, timely water and nutrient management. Optimizing such components through integrated crop management (ICM) practices has been shown to reduce weed problems and increase productivity by up to 25% on farmers' fields (Becker and Johnson, 1999; Haefele *et al.*, 2000).

Hand weeding is the most widely applied intervention against weeds across rice systems. While it is effective in reducing direct competition from weeds and in preventing weeds from producing and shedding seeds, it is extremely labour demanding, requiring 250 to 780 work hours per hectare (Rodenburg and Johnson, 2009). For farm households at subsistence level, the burden of hand weeding is commonly borne by women and school-age children. Hand hoes or push weeders are often used in row-planted crops. Such tools, however, are difficult to use to control weeds in the crop row and they may also cause crop damage (Navasero and Khan, 1970). The use of power tillers or tractors for mechanical weeding is not common in SSA, but in appropriate locations (with favourable soil and hydrological conditions) such machines could alleviate some of the labour burdens associated with hand weeding. Fires, either pre- or post-season, are widely used by farmers to clear weeds from fields, and can save a considerable amount of labour where mechanization is not available. The frequent use of fire can, however, result in a shift in the weed composition towards more tolerant species such as *I. cylindrica*.

Herbicides provide an economically attractive alternative to hand weeding by reducing overall weeding time and enabling farmers to use time- and labour-saving crop establishment methods such as direct (broadcast) seeding rather than transplanting (e.g. Akobundu and Fagade, 1978). Herbicides are commonly used in combination with other control options. In the irrigated schemes in the north of Senegal, for instance, in direct-seeded rice most farmers rely on chemical weed control followed by hand weeding (e.g. Haefele *et al.*, 2002). However, effective and safe herbicide use requires farmers to use the appropriate product, application equipment, rates (Zimdahl, 2007) and timing (e.g. Haefele *et al.*, 2000). Subsistence farmers in SSA frequently lack sources of information or are unable to read the use and safety instructions; they also have limited market access while, in turn, markets often have a limited product range and intermittent supplies. In addition, farmers often lack sufficient financial means for the purchase of the product as well as the required application and protection equipment (Balasubramanian *et al.*, 2007). Incorrect use of herbicides may result in poor weed control (Haefele *et al.*, 2000), increased costs and phytotoxicity damage to the crop (e.g. Johnson *et al.*, 2004) or accelerate the evolution of herbicide resistance in weeds.

Choice of rice cultivar by farmers is also often, at least partly, influenced by the cultivar's ability to suppress or compete with weeds. Examples of where farmers favour competitive cultivars include the choice of Jaya in the irrigated schemes of the Senegal River valley (e.g. Poussin *et al.*, 2005) and the frequently observed use of the vigorous landraces of the African rice species *O. glaberrima* (e.g. Sarla and Swamy, 2005). Some of the newly developed lowland NERICA cultivars have useful weed-competitive traits too (Rodenburg *et al.*, 2009). Apart from these cases, however, cultivars with confirmed weed-competitive traits and good adaptation to African rice ecosystems are still relatively rare (e.g. Rodenburg and Johnson, 2009). Poor competitiveness of 'improved' rice cultivars against weeds may be a contributory factor to their limited adoption by farmers in the upland and rainfed rice areas where weeds are often a serious constraint. On the other hand, superior weed competitiveness alone is unlikely to be sufficient reason for adoption. Grain quality characteristics including colour, cooking and eating qualities, and characteristics such as cycle length and height are probably more important for cultivars to be accepted by farmers (Dalton, 2004) and there are local stresses (both biotic and abiotic) against which farmers will judge a cultivar's suitability. The challenge remains therefore to combine weed competitiveness with other desirable qualities.

Given the wide range of potential weed species in rice cropping systems, and the diverse conditions under which they germinate and grow, integrated approaches to weed management are likely to be the most effective and sustainable. Multiple strategies are required to provide control across the various periods when different weeds will be able to establish, such as when the fields dry out or are drained. Integrated weed management may also be more compatible with farmers' resources than single-component technologies that may require a high level of external inputs. The choice of different practices will depend on the production system (irrigated, rainfed upland or rainfed lowland). An overview of strategies, their application environments, and advantages and disadvantages, is provided in Table 16.2.

Table 16.2. Overview of weed control strategies in rice in Africa.

Weed control method	Target systems	Advantage	Main disadvantages	R&D priority
Hand weeding	Mainly in rainfed systems	Highly effective, prevents weed seed production; important in providing 'spot control' of problem weeds	Labour intensive, negative effects on women and children	Low
Controlled flooding	Irrigated systems	Controls most weed species	Requires large amounts of water, good infrastructure and equipment	Medium
Pre- or post-season fires	Across systems	Can reduce seed production and soil seed bank	Ineffective for species like *C. odorata* and *I. cylindrica*; can cause soil degradation	Low
Mechanical weeding	Across systems	Effective, prevents weed seed production, relatively quick	Requires availability of equipment, less effective in controlling weeds in the crop row	High
Chemical weed control, including resistance management	Mainly in larger-scale irrigated systems	Effective when applied well, labour-saving	High market dependence, requires equipment and know-how, risk of development of herbicide-resistant weeds	High
Improved rice cultivars (weed competitive or parasite resistant)	Upland systems, direct-seeded lowland systems, but not broadly applied	Effective, cheap and labour-saving	Requires combination with other genetic traits (e.g. grain quality, stress resilience)	Medium
Crop rotations, intercropping, improved fallow	Mainly in rainfed upland systems	Provides basis of resilient systems	Requires land area; risk of competition with rice crop	Medium
Integrated weed management	General	Effective and putatively sustainable	Labour and knowledge intensive	High

Irrigated ecosystems

Maintaining standing water in the field is a critical weed-management strategy in irrigated rice systems. Flooding the soil to 5–10 cm water depth or more reduces the emergence and establishment rate of most weed species (e.g. Akobundu, 1987). For this to be effective, however, fields need to be well levelled, to ensure an even depth of flooding, which in turn requires skills and equipment not commonly available to resource-poor farmers in this region. Herbicides are also important means of weed control in the direct-seeded lowland systems (Johnson, 1997). Chemical control methods in irrigated lowland rice systems involve the pre-emergence applications of oxadiazon or pendimethalin, pre- or (early) post-emergence applications of butachlor, glyphosate or paraquat, or post-emergence spraying of 2,4-D, bentazon, propanil or bensulfuron (Table 16.3).

In some irrigated systems, a dry-season upland crop (e.g. maize, legumes or cotton) is grown. Such rotations provide an opportunity for alternative control measures such as a selective herbicide (Zimdahl, 2007) and the management and conditions associated with a non-rice crop may not favour troublesome weeds such as *Echinochloa* spp. A range of methods such as land preparation, hand weeding, herbicides and flooding are commonly used in an integrated manner to address problem weeds such as the perennial wild rice species *O. longistaminata* (for examples, see Rodenburg and Johnson, 2009).

Rainfed upland ecosystems

In the humid forest zone in West Africa, rice farmers traditionally managed soil fertility, weeds and other biotic stresses through shifting

Table 16.3. Common herbicides and their application range – combinations are often used to control a wider range of weed species. (Adapted from Johnson, 1997.)

	Active ingredient	Lowland	Upland	Example products	Target weeds	Known exceptions[a]
Post-emergence	2,4-D	+	+	Herbazol	B,S	*C. benghalensis*, *E. heterophylla*
	bentazon	+		Basagran	B,S	
	MCPA	+		Herbit	B,S	
	molinate	+		Ordram	G,S,(B)	*I. rugosum*
	propanil	+	+	Stam	G,(B,S)	*O. barthii*, *R. cochinchinensis*, *C. benghalensis*, *E. prostrata*, *T. portulacastrum*
Pre-/post-emergence	triclopyr		+	Garlon	B,S	
	bensulfuron	+		Londax	B,S	
	butachlor	+		Machete	B,G,S	*L. hexandra*, *O. barthii*, *R. cochinchinensis*, *C. benghalensis*, *E. prostrata*, *T. portulacastrum*
	glyphosate	+	+	Round-up	B,S,G	
	paraquat	+	+	Gramoxone	B,G,S	
	piperophos	+		Rilof	G,S	*F. littoralis*, *E. indica*
	quinclorac	+		Facet	G	
	thiobencarb	+		Saturn	G,S,B	*L. hexandra*, *O. barthii*, *R. cochinchinensis*, *A. conyzoides*, *C. benghalensis*, *E. prostrata*
Pre-emergence	fluorodifen	+	+	Preforan	B	
	oxadiazon	+	+	Ronstar	B,S,G	*O. barthii*, *C. benghalensis*, *C. odorata*, *E. prostrata*
	pendimethalin	+	+	Stomp	G,B,S	*L. hexandra*, *O. barthii*, *C. benghalensis*, *E. heterophylla*
		+		Rifit	S,G,B	

B = broadleaved; G = grass; S = sedge; [a]weed species with known resistance to the specific herbicide.

cultivation – long fallows (>10 years) alternated with short (1–3 seasons) cropping periods (e.g. de Rouw, 1995). In such systems, the fallow vegetation and a portion of the seed bank are killed by 'slash-and-burn' fires and the populations of pioneer species including crop weeds are limited by the short length of the cropping period. Such systems are still common in some areas, though they have become less widespread (Ampong-Nyarko, 1996; Johnson, 1997). Greater demand for rice and increasing population density in SSA, however, have resulted in intensification of rice production (Balasubramanian *et al.*, 2007) with reduced fallow periods leading to increased weed problems (Becker and Johnson, 2001a).

As upland cropping systems have intensified, herbicides have sometimes become an important control method, such as in rice–cotton rotation systems in the savannah zone (Johnson, 1997). Herbicides used in rainfed upland rice systems include fluorodifen, oxadiazon and pendimethalin applied pre-emergence, butachlor, piperophos and thiobencarb applied pre- or early post-emergence, and 2,4-D, bentazon, MCPA, propanil and triclopyr sprayed post-emergence (Table 16.3).

Rotations of rice with non-cereal crops like cowpea, soybean and groundnut are common in subsistence systems, and changing of cropping practices may aid the management of problem rice weeds (Rodenburg and Johnson, 2009). While such practices impact on weed species composition in rice (Kent *et al.*, 2001), studies on rotations and intercropping in rice-based systems in Africa are scarce. Such methods, for example, have been advocated in the control of *Striga* spp., for which rotations or the use of 'trap crops' have been proposed and tested in cereal crops other than rice (as reviewed by Rodenburg *et al.*, 2010). Such approaches could be validated and promoted for rice-based cropping systems in the future.

Improving the 'quality of fallow vegetation' in rotation systems has been proposed to reduce weed growth and improve soil fertility (Becker and Johnson, 1998). Such improved fallows use weed-suppressing legumes that continue to grow after rice harvest, thereby reducing weed growth and build-up of the weed seed bank during the off-season. Such 'short fallow' rotation systems in the forest and savannah zones of West Africa have been shown to increase rice yields by 20–30% and lower weed growth in the crop (e.g. Becker and Johnson, 1998). The choice of fallow species, plant population density, planting date and crop management, however, needs to be carefully considered to avoid competition for resources between the legume and the rice. Despite possible advantages, intercropping, improved fallow systems or relay cropping with legumes show low farmer adoption rates in Africa. This lack of adoption has been suggested as being due to the additional labour and energy required for clearing and incorporation of the legume into the soil, unfavourable land-tenure agreements, poor crop establishment, additional costs of inputs, and a lack of direct economic benefit of the legume (e.g. Tarawali *et al.*, 1999).

Rainfed lowland ecosystems

Bunding of fields in rainfed lowland systems improves water management, and increases the periods for which the soil remains flooded, and has been shown to decrease weed biomass by 25% (Becker and Johnson, 2001b). Extending the period of flooding reduces opportunities for weeds to germinate and establish. In addition, most of the weed control strategies described above can also be applied in rainfed lowland systems, although the use of rotations with non-rice crops is usually restricted to the dry season due to the limited range of crops tolerant of the flooded or waterlogged conditions of the wet season.

Future Weed Management Issues

Crop intensification, labour and water shortages, changing environmental conditions, and the evolution of herbicide-resistant weed ecotypes will limit the options and 'set the agenda' for weed management issues in rice in Africa in the future (e.g. Rodenburg and Johnson, 2009). Decreasing labour–crop area ratios expected in rice-production areas in SSA may cause farmers to gradually shift from transplanting to direct seeding. In Asia, the transition to direct seeding, coupled with an increased reliance on herbicides, resulted in a shift in the weed population structure to one dominated by grass species such as *Echinochloa* spp., *Leptochloa chinensis*, *I. rugosum*, *L. hexandra* and 'weedy' rices (Rao *et al.*, 2007). If rice farmers in Africa follow a similar model, such weeds, which are already present in African rice systems, are expected to rapidly become dominant. While there are as yet no confirmed cases of herbicide resistance among important rice weeds in Africa (Rodenburg and Johnson, 2009), populations of herbicide-resistant weed ecotypes are likely to develop. The problem may, however, already exist. Propanil, for example, has been observed to be less effective in controlling *E. colona* in Senegal than in the past (Haefele *et al.*, 2000), and the continuous use of a single product is quite common in SSA due to the limited range of products available on the local market. Changes in environmental conditions such as increased levels of atmospheric CO_2, increased temperatures and rainfall irregularities may also render weeds more resistant (e.g. Patterson *et al.*, 1999). This may have serious consequences for systems where herbicides are the main means of weed control.

In lowland rice, where increases in temperature or rainfall variability will likely have a smaller direct impact, CO_2 increases may cause a crop that uses the C_3 photosynthesis pathway (like rice) to become more competitive against weeds that use the C_4 pathway. At the same time, C_3 weed species, such as the perennial rhizotomous *O. longistaminata*, *L. hexandra*, *B. maritimus*, *S. africana* and *C. halpan* may benefit and become even more difficult to control (Rodenburg *et al.*, 2011a) as increased CO_2 has a stimulating effect on belowground growth (Oechel and Strain, 1985). If, however, in response to water scarcity, water-saving production methods are implemented in irrigated systems, overall weed competition will increase (e.g. Krupnik *et al.*, 2012) and a shift can be expected to species favouring hydromorphic conditions such as *A. amplectans*, *E. colona*, *E. indica*, *Panicum repens*, *C. esculentus*, *Eleocharis* spp., *Scirpus maritimus*, *Ageratum conyzoides* and *Eclipta prostrata*.

Climate change is expected to have a greater impact on rainfed production systems as these are most vulnerable to rainfall irregularities and are populated by most of the C_4 weeds and all of the parasitic weed species. In rainfed systems, the area infested with parasitic weeds could increase, particularly in places where soil degradation and erratic rainfall become prevalent (Rodenburg *et al.*, 2010). Furthermore, because of their likely greater drought and heat tolerance, C_4 species like the perennial grasses *I. cylindrica*, *Paspalum scrobiculatum* and *Cynodon dactylon*, the annual grasses *R. cochinchinensis*, *Digitaria horizontalis*, *E. indica*, *Dactyloctenium aegyptium*, *Pennisetum purpureum* and *E. colona*, and the sedges *Fimbristylis littoralis*, *C. rotundus* and *C. esculentus* are likely to become more competitive with rice (Rodenburg *et al.*, 2011a).

A relatively recent approach to weed control is the combined use of non-selective herbicides with herbicide-resistant rice cultivars. These approaches may have the labour-saving benefits of conventional chemical control without the concomitant phytotoxicity risks, and would provide technically sound solutions for the control of important yield-reducing weeds, such as wild or weedy rices in irrigated and rainfed lowlands, and parasitic weeds in uplands (Rodenburg and Demont, 2009). These technologies, however, will require careful stewardship to reduce the incidence of gene-flow to wild or weedy rice relatives causing them to develop herbicide resistance. Also, the reliance on a limited range of herbicide molecules would inevitably result in the evolution of herbicide resistance among a wider range of weed species. In addition, effective seed and microcredit systems would be a prerequisite to successful application of these technologies (Demont *et al.*, 2009). Meeting such prerequisites, however, is likely to be a challenge for most rice-growing areas in SSA.

Likely changes in the economic environment for rice production in Africa will mean that weed management systems must evolve to improve labour productivity. Farmers are likely to make increased use of herbicides and integrated measures. They are also required to improve the timing of operations and targeting of certain growth stages for given species to give the best chance of control. Such changes will inevitably mean that weed control will become more 'knowledge intensive', and for this farmers will require better and more timely access to information resources than they have at present.

Concluding Remarks

Additional options to manage weeds are required to augment the limited range currently available to rice farmers in Africa. Approaches are needed to target local problem weeds and these must be tailored to local practice and resource availability. Strategies also need to anticipate likely future changes in soil fertility, water availability and population pressure, while addressing environmental concerns by avoiding excessive dependency on herbicides. Emerging weed problems include species such as hemi-parasitic, annual grass and perennial rhizotomous weeds. These weeds are likely to get worse, and effective strategies are required to control them. Moreover, future climate change adaptation strategies for rice-based production systems, such as alternative cropping system designs or improved stress-tolerant cultivars, should simultaneously address possible implications for weed competition.

There are many gaps in our knowledge of the crop and weed interactions in relation to the environment and management practice. A better understanding of these interactions would support predictions of likely changes in weed communities and strengthen the development of appropriate and effective knowledge-based technologies as part of an integrated weed management approach. Development efforts should include training farmers in integrated crop and weed management, optimal and safe herbicide use, and the establishment of practical and low-risk finance systems (e.g. microcredit). Meanwhile, national and regional policies to stimulate favourable and functional input markets, infrastructure and biosafety regulations would help African rice farmers to effectively manage weeds.

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