Chapter 17
Strengthening Farmers' Knowledge for Better Weed Management in Developing Countries

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Introduction

Of more than 3 billion people (nearly half of the world's population) who live in rural areas, around 2.5 billion derive their livelihoods from agriculture [1], which remains crucial to developing countries and their economies for meeting the demands of affordable food, feed, energy, and the security of their populations. Approximately, three quarters of the world's agricultural value is generated in developing countries and, in many of these, the agriculture sector contributes as much as 30% to gross domestic product (GDP). It has been observed that GDP growth from agriculture benefits the incomes of poor people two to four times more than the

Developing regions, which are referred to throughout the chapter, consist of Africa; the Americas excluding Northern America, Latin America, and the Caribbean; Asia excluding Japan; and Oceania excluding Australia and New Zealand. Developed regions are Northern America, Europe, Japan, Australia, and New Zealand

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GDP growth in other sectors of the economy. The agricultural sector has the greatest potential for improving rural livelihood and eradicating the poverty of developing countries, as a significant number of the rural population in developing countries depends primarily upon small-scale, subsistence-oriented, agriculture-based family labor. However, they have limited access to technologies, in addition to essential resources, alternative livelihood, and production options.

By 2050, the world population is projected to reach 9.1 billion, up by 32 % from 2010. In absolute terms, the world's population is expected to grow by 2.2 billion. Over 85 % of population growth is expected in large urban centers and megacities in developing countries [2]. Of those additional people, almost 1 billion will live in Africa. Asia's population will increase by more than 1 billion, including 400 million more people in India. In comparison, China's slowing and ensuing negative growth will add only 63 million people [3]. Demand for food is predicted to rise 60 % globally by 2050, relative to 2009 levels. The majority of extra food demand is anticipated to reflect rising population and incomes in Asia. Rising incomes in China are predicted to be a major driver of this demand, accounting for 43 % of the global increase, while India accounts for 13 % [4].

To meet the demands of increasing population, it is essential to double the yields of smallholder farmers in developing countries of the world by improving the input efficiency and reliability of agricultural production. This is possible largely by scaling up best practices of currently available technologies and farming systems. The rural farming communities in developing countries are home to the most hard-working and self-reliant farmers looking for newer technologies for improving crop productivity, their income, and livelihood. A substantial increase in agricultural yield and output is expected to be realized by implementing interventions aimed at speeding up the assimilation and adoption of improved agricultural technologies and management practices of the research stations to the farmers' fields.

In this chapter, we made an attempt to: (1) put forward the importance of weeds and their management in enhancing the needed crop productivity to meet the demands of increasing population, (2) identify the weed management technologies that need special attention in upscaling them to larger numbers of farmers, and (3) list possible means and approaches for enhancing the farmers' knowledge for better weed management in agro-ecosystems of developing countries.

Importance of Weed Management to Attain Optimal Crop Productivity

Global estimated loss potential of weeds in rice, wheat, and maize indicates that weeds account for 46.2–61.5 % of potential losses and 27.3–33.7 % of actual losses caused by all pests together [5]. In most of the farming systems and for most of the crops of smallholder farms in developing countries, large yield gaps were identified [5–12]. Hence, significant scope exists for the improvement of crop yields by identifying and alleviating the constraints. Several studies were conducted to identify constraints causing the yield gaps, and among biotic constraints, the most important constraint in Africa is weeds (Table 17.1). Competition from weeds and shortcomings in weed management were severe in several of the developing nations of Asia and Africa. The shortage of labor is affecting the timely weed management in all cropping systems.

Continuous research efforts are being made to manage weeds in different crops, and cropping systems and technologies are available for managing weeds effectively and economically. A study in India revealed that the overall average gap in weed management practices in rice and wheat crops was 25 % and 25.8 %, respectively [13]. The maximum average technological gap of 31.4 % in wheat crop was found in case of chemical weeding followed by integrated weed management (20.3 %). Waddington et al. [12] observed that among the ten farming systems in South Asia, East Asia, and sub-Saharan (SS) Africa, inadequate farmer knowledge/training of different crops was reported as the major constraint in attaining optimum yields in the following farming systems:

1. SS Africa—cereal-root crop mixed; South Asia—rainfed mixed; South Asia—dry rainfed; East Asia P—lowland rice; and East Asia P—upland intensive mixed farming systems for rice
2. SS Africa—highland temperate mixed; SS Africa—maize mixed; and South Asia—rainfed mixed farming systems for sorghum
3. SS Africa—root crop and SS Africa—agro-pastoral millet/sorghum farming systems for cowpea
4. SS Africa—highland temperate mixed and South Asia—rice for chickpea
5. SS Africa—maize mixed for cassava

The closing of yield gaps signals effective knowledge transfer to farmers for successfully fostering the adoption of effective weed management. The exchange of information between scientists and farmers will be essential to reduce the time lag between development and implementation of more sustainable weed management practices. Hence, there is an urgent need to create awareness on the available and appropriate weed management practices among farmers in developing countries of Asia and Africa to tackle the weed menace and boost the crop production.

Weed Management Technologies that Need Special Attention

Continuous awareness creation and knowledge enhancement of the farming community are needed to benefit from weed management technological innovations. Recently, several technological advances occurred in the field of weed management. Some weed management technologies, about which the farmers' knowledge should be strengthened, include the following.

Table 17.1 Estimated smallholder farm yield gaps and an initial breakdown of yield losses associated with four categories of constraint for five food crops in Asian and African farming systems. The contribution of weed competition to yield gap is given in the parenthesis under the column biotic stresses. (Source data: [12])

Crop	Region	Farming system	Highest small-holder farmyield[a] (t/ha) (SD)	Average small-holder farmyield (t/ha) (SD)	Small-holder yield gap (t/ha) (SD)	Yield losses by constraint category (percent of total yield gap)[b]			
						Socio-econozmic	Abiotic	Biotic (weeds)	Manage-ment-related
Wheat	Sub-Saharan Africa	Highland temperate mixed	4.14(1.51)	2.02(1.11)	2.12(0.69)	28	20	19 (6)	32
	South Asia	Highland mixed	3.80(1.62)	2.05(0.99)	1.76(0.89)	23	30	21 (5)	27
		Rice–Wheat	4.81(1.16)	2.46(0.74)	2.38(0.89)	20	28	20 (6) (6)	31
		Rainfedmixed	4.96(1.11)	2.39(0.57)	2.54(0.80)	20	28	22 (7)	28
		Dry Rainfed	5.32(0.99)	2.16(0.42)	3.10(0.72)	23	30	18 (5)	30
	East Asia Pacific	Lowland rice	8.18(2.32)	5.12(1.76)	3.06(1.00)	20	29	20	30
		Upland intensive mixed	7.81(3.43)	3.99(1.51)	3.82(3.02)	24	30	17	29
		Temperate Mixed	8.74(1.71)	5.84(2.67)	3.13(0.98)	20	34	20	27
	Crop mean		5.97	3.25	2.74	22	29	20	29
Rice	Sub-Sahara Africa	Root crop	4.54(1.85)	2.88(1.36)	1.72(1.01)	38	18	25 (5)	18
		Cereal–root cropmixed	4.83(2.31)	2.74(1.31)	2.09(1.34)	51	14	16 (3)	19
	South Asia	Highland mixed	4.70(1.60)	2.52(0.57)	2.18(0.59)	27	29	21 (9)	23
		Rice	6.98(1.69)	3.74(1.17)	2.85(1.16)	27	25	22 (6)	26
		Rice–Wheat	6.23(1.29)	3.12(1.44)	2.76(0.82)	26	26	20 (6)	27
		Rainfedmixed	5.04(1.12)	2.95(0.65)	2.09(0.99)	27	22	19 (7)	31
		Dryrainfed	6.58(1.77)	3.88(1.53)	2.57(0.76)	27	24	23	26
	East Asia Pacific	Lowland rice	8.95(2.72)	5.93(2.02)	2.94(1.20)	28	21	17	35
		Upland intense mixed	9.94(1.20)	6.88(1.27)	3.05(1.23)	25	29	19	27
		Temperate mixed	10.35(1.11)	6.85(0.74)	3.54(0.99)	29	24	23	24
	Crop mean		6.81	4.15	2.58	31	23	21	26

Table 17.1 (continued)

Crop	Region	Farming system	Highest small-holder farmyield[a] (t/ha) (SD)	Average small-holder farmyield (t/ha) (SD)	Small-holder yield gap (t/ha) (SD)	Yield losses by constraint category (percent of total yield gap)[b]			
						Socio-econozmic	Abiotic	Biotic (weeds)	Manage-ment-related
Sorghum	Sub-Saharan Africa	Highland temperate	3.44(1.28)	1.80(0.58)	1.64(1.44)	15	25	28 (7 + Striga: 5)	29
		Cereal–root crop mixed	2.93(1.44)	1.13(0.55)	1.80(1.18)	23	23	26 (6 + Striga: 8)	24
		Maize-mixed	2.30(1.67)	1.09(0.78)	1.23(1.34)	30	29	19 (7)	22
		Agropastoralmillet/sorghum	2.15(1.33)	0.66(0.37)	1.50(1.12)	24	32	18 (Striga: 5)	27
	South Asia	Rainfedmixed	3.11(1.50)	1.62(0.31)	1.69(1.36)	23	25	22 (4)	30
		Dryrainfed	4.47(1.27)	1.85(0.65)	2.86(1.27)	27	30	20 (6)	23
	Crop mean		3.07	1.36	1.78	24	27	22	26
Cowpea	Sub-Saharan Africa	Root-crop	0.80(0.45)	0.38(0.19)	0.41(0.48)	31	16	31 (4)	21
		Cereal–root crop	0.97(0.62)	0.54(0.43)	0.50(0.42)	22	21	37	21
		Cropmixed Maize mixed	1.36(0.90)	0.42(0.41)	0.92(0.77)	27	25	28 (4)	20
		Agro pastoral-millet/	1.63(1.14)	0.62(0.52)	1.01(0.81)	21	21	30 (7)	29
	Crop mean		1.19	0.49	0.71	25	21	32	23
Cassava	Sub-Saharan Africa	Rootcrop	22.67(11.21)	13.77(6.26)	8.24(5.81)	32	23	22 (5)	24
		Cereal–rootcropmixed	21.35(12.66)	12.88(2.27)	9.00(5.91)	31	20	23 (5)	26
		Maizemixed	19.87(7.32)	8.74(3.78)	12.22(5.14)	25	20	25 (4)	29
		Lowlandrice	40.00(7.07)	21.00(1.41)	19.00(5.66)	15	25	25	35
		Uplandintensive	27.13(17.26)	15.80(3.89)	19.20(5.98)	28	27	17 (5)	28
	Crop mean		26.20	14.44	13.53	26	23	22	28

SD standard deviation

[a] The highest farm yield, average farm yield, and yield gap estimated by panelists in the round 1 questionnaire were adjusted independently by respondents during round 2. Thus, in some cases the reported average yield plus the yield gap does not sum to the highest farm yield

[b] Initial (round 1) percent estimate for four categories of constraint

Best Management Practices in Integrated Weed Management to Reduce Weed Menace

Farmers' knowledge on the ecology of weeds, weed seed production, prevention, or minimization, and ecological integrated weed management during the critical period of crop–weed competition must be enhanced [14, 15]. Farmers should be made aware of emerging problems, such as weedy rice, and the proper ways and means of managing them in an integrated manner. Weedy rice, and its development as an important problem, is associated with lowland rice ecology of eastern Uttar Pradesh and the adjoining parts of Bihar of India as in many parts of the developing countries. The stale seedbed-technique should be an effective strategy to exhaust the existing seed bank and the use of hybrid seeds to solve seed contamination problem. This will help facilitate the adoption of zero-tillage (ZT) in direct-seeded rice in the region. Like any other technology, the practicalities may get in the way forward. If we look at the whole system, the use of pre-seeding herbicides can be an efficient tool, which can lead to flexibility in respect of using or not using post emergence herbicides. This also makes it possible to boost the early crop canopycover.

Proper Application and Use of Herbicides and Other Weed Management Tools

Herbicides are becoming increasingly popular in developing countries because of the increasing cost and non-availability of manual labor used traditionally for hand weeding by the farming community. Herbicide use provides a pro-poor technology for both rainfed and irrigated crop production in developing countries, where farmers are striving to cut production costs and increase crop output as well as income. There are five key recommendations that will improve spray efficiency: (1) selecting the correct nozzle, (2) using appropriate pressure, (3) using multiple boom nozzles, (4) avoiding adverse weather conditions, and (5) keeping up with technologies [16]. Another key to keeping up with herbicide application education is understanding new spraying techniques. Farmers must be well trained in the proper use of herbicides and other best weed management practices to effectively control weeds and avoid the development of resistance in weeds.

Innovative channels are being used to deliver improved weed management knowledge to farmers, including primary schools in Tanzania and the herbicide supply chain in Bangladesh [17]. A series of training workshops on herbicide application techniques were organized in India and Nepal in 2000 [18]. The workshops focused on teaching the participants how to use and fabricate multiple-nozzle booms, the importance of flat-fan nozzles, calibration, drift avoidance, and applicator safety. These workshops helped in improving the efficiency of herbicides and also facilitated a major shift from application of herbicides by mixing in sand and broadcasting to the adoption of recommended spraying method.

Similar effort was made recently in Africa [19] on:

1. The production of farmer-to-farmer instruction videos on efficient and safe use of herbicides and on the use of an affordable, hand-operated, rotary weeder
2. Testing two rotary weeder types against best weed management practice and hand weeding
3. Training local blacksmiths in manufacturing locally adjustable rotary weeders
4. Enhancing weed science capacities in Tanzania by training R&D professionals and agronomy/weed science students in accessing and using relevant information and tools for developing optimal weed management strategies

Herbicide Resistance Management

Over the past several years, there was a steady increase in herbicide resistance, that is, the evolved capacity of a previously herbicide-susceptible weed population to withstand a herbicide and complete its life cycle when the herbicide is used at its normal dose in an agricultural situation [20]. Several important weeds have evolved resistance in developing countries, having an important economic impact on specific crops, which were reviewed by Valverde [21]. The most recent information on the occurrence of herbicide-resistant (HR) weeds may be found on the website www.weedscience.org, maintained by Herbicide Resistance Action Committee of Weed Science Society of America (WSSA).

Herbicide resistance was the most serious problem in wheat in the rice–wheat cropping system during the early 1990s. Efforts on herbicide resistance management before 1996–1997 were concentrated around alternate crops [22]. The problem of resistance was so serious that farmers in the state of Haryana (India) started sowing sunflower to exhaust the seed bank of *Phalaris minor* Retz. (wild canary grass). Crop rotation was possible only in a small area and farmers needed a viable technology for herbicide-resistance management.

Emergence of very heavy population during the early phases of crop cycles can be prevented with the use of ZT technology. ZT in wheat reduces the emergence rate of *P. minor* compared to conventional tillage [23]. In a study conducted by Franke et al. [23] at farmers' fields in Haryana, correlating the number of germinable *P. minor* seeds in soil with the number of *P. minor* seedling emerged, it was found that ZT reduced the emergence rate of first flush of *P. minor* by 50 % (Fig. 17.1a). The rate of emergence of second and third flushes was also lower in ZT plots compared to conventionally tilled plots (Fig. 17.1b, c). The first flush of *P. minor* is more damaging to the crops compared to later flushes, and ZT was found relatively more effective in reducing the first flush than other flushes.

ZT made it possible to achieve three major objectives, leading to create competition in the favor of crop. The objectives are optimum plant population, seeding at a time that is not conducive to *P. minor* emergence, and accurate fertilizer placement. Reduced population of this weed does not mean that the *Phalaris* problem will be solved by ZT alone. It also does not mean that farmers will stop using herbicides. Long-term trials at five sites in different villages indicate that farmers can skip her-

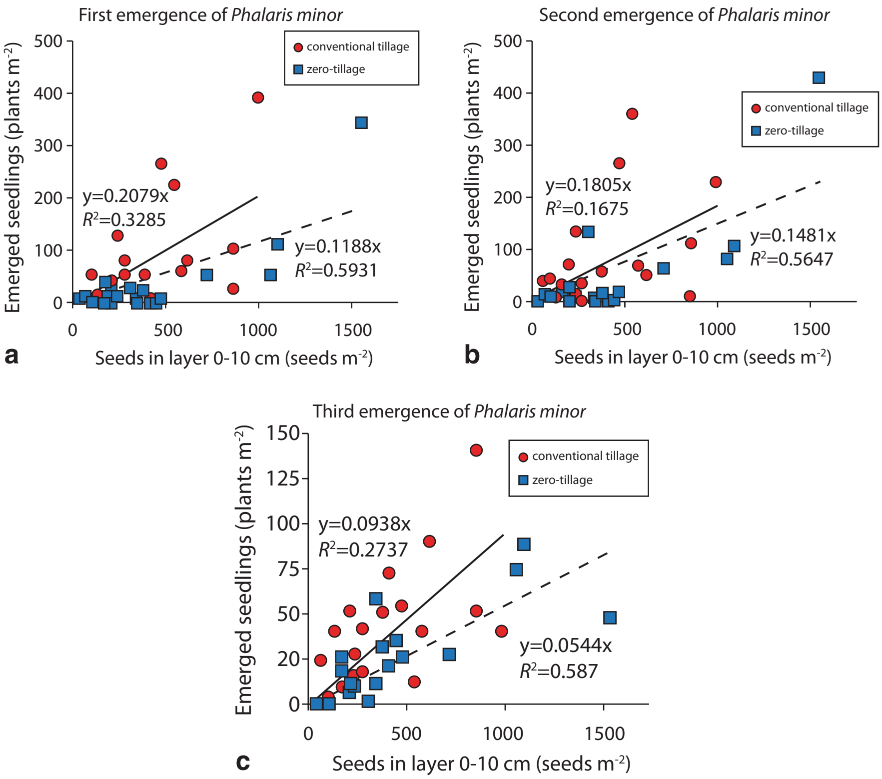

Fig. 17.1 Emergence rate of the first (**a**), second (**b**), and third (**c**) flush of *Phalaris minor* under conventional (●, *solid line*) and zerotillage (□, *dashed line*) in wheat. (Source: [23])

bicide once in 3–4 years. There is a constant danger that this weed will constantly evolve resistance to new herbicides. Using herbicides alone is not a long-term solution for managing resistance. Details of resistance development and its management using integrated approach with focused attention on ZT have been published [22, 23].

It is possible to continuously use effective weed management tools by the adoption of weed management strategies aimed at the prevention of herbicide resistance of weeds. Best management practices suggested by Norsworthy et al. [24] are applicable to developing countries also.

Management of Herbicide-Resistant Crops

Genetically modified crops have become extremely popular since their introduction in 1996. Currently, they are grown on more than170-mha area in 29 countries involving more than 17 million farmers of whom about 15 million are smallholder

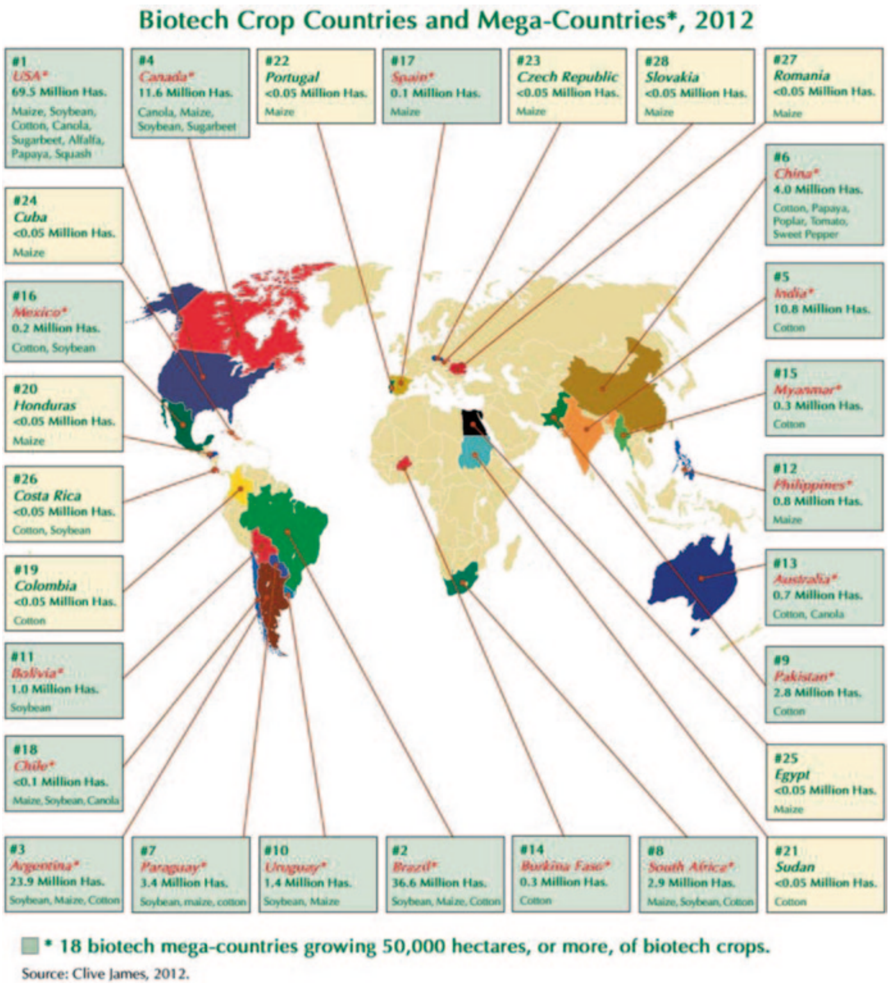

Fig. 17.2 Biotech-crop-growing countries. (Reprinted with permission from James, Clive. 2012. Global Status of Commercialized Biotech/GM Crops: 2012. ISAAA Brief No. 44.ISAAA: Ithaca, NY. http://www.isaaa.org/resources/publications/briefs/44/executivesummary/)

and resource-poor farmers (Fig. 17.2). Tolerance to herbicides is the most predominant trait, contributing nearly 70 % of the total area. India with 10.8 mha and China with 4.0 mha are ranked fifth and sixth, respectively, in terms of total area under genetically modified crops. Pakistan, Philippines, Australia, and Myanmar are a few other countries that are growing genetically modified crops. Glufosinate-resistant soybean, corn, cotton, and canola are now commercialized in certain countries, and, in the near future, crops resistant to the herbicides 2,4-D, dicamba, hydroxyphenyl pyruvate dioxygenase (HPPD) inhibitors, and possibly to the PPO-inhibiting herbicides are expected to reach the marketplace [25]. Further, transgenic crops with resistance to more than one herbicide mode of action (i.e., stacked traits) have also been commercialized in recent times. As new HR crops become available, management of novel HR weeds will be a major challenge. However, the introduction of HR crops also prompted concerns about potential transfer of herbicide resistance to weed populations via crop-to-weed gene flow [26–30].

Clearfield rice, an imidazolinone (IMI)-resistant rice derived from conventional breeding technique, has been in cultivation in Malaysia mainly for managing weedy rice [31]. The possible evolution of resistance to ALS-inhibiting herbicides in weedy rice and the risk of weedy rice acquiring resistance to herbicide following introgression of resistant gene from the HR rice are the major concerns that need to be addressed adequately. In the near future, transgenic crop technology would be brought to the farming community in most of the developing countries as well [32]. Farmers need to be adequately trained on proper use of the HR cultivars before their introduction in developing countries.

Ways to Strengthen Farmers' Knowledge and Ability to Manage Weeds Ecologically, Economically, and Effectively

Effective Extension

In order to ensure that farmers are equipped with the knowledge of the best weed management technologies to optimize long-term agricultural productivity, effective extension should be available. Effective extension would enable increased rates of adoption of improved weed management technology by the farming community. The essential ingredients for an effective extension were summarized in another context [33] that are applicable to weed management also. They are:

- Building the credibility and trust in extension officers by avoiding short-term funding, rapid staff turnovers, and staff who are inexperienced or lack technical farming expertise.
- Recruiting high-caliber personnel on the ground as extension agents who should ideally have authority and technical expertise, be perceived by farmers as similar to them, have a local profile; possess good communication skills; have personal relationships with landholders, and be able to acknowledge and empathize with the problems and circumstances of landholders.
- The use of multiple methods—for example, print articles, verbal presentations, group extension, and advertisements—enhances effectiveness.
- Although group extension work is useful, one-on-one on-farm advice is critical.
- Counseling assistance may aid extension in some circumstances, as those in the most difficult circumstance are also often reluctant to seek help. Integration of counseling with extension programs may help identify those in need of assistance.
- Extension efforts should be based on farmers' needs.

Farmers' Participatory Evaluation of Weed Management Technologies

As farming is risky, farmers' willingness to adopt improved weed management technology depends on demonstrated benefits of the technology. If the benefits are demonstrated with farmers' participation, the chances of farmers' adoption and thus receiving the benefits would be greater.

Implementation of improved weed management technologies will be knowledge-intensive, and, as a result, there is a need for better linkage between farmers and agricultural researchers in order to couple the farmers' location-specific experience with scientists' subject expertise. This linkage should involve information flowing in both directions during research and in extension. As the research is being designed and conducted, interaction between farmers and researchers will help ensure that the location-specific land, soil, and climate conditions are taken into account. To increase the adoption rate of existing and new technologies, farmers should be fully involved in the development of the technologies. Thus, the farmers' participatory process of evolving technologies is one of the ways to strengthen the knowledge of farmers.

Partnership with International Institutes

Weed management is a complex process and it needs combined efforts from several organizations (national and international) for enhancing the farmers' knowledge. The partnership between the state, non-state organizations (private sector), and global scientific research organizations is essential to achieve dissemination of new technologies to the end users and to achieve faster progress [34]. Partnership between these organizations is critical to let cost-efficient weed management technologies disseminate to the end users. Each of the organizations have their own strengths and could complement each other's efforts in taking research from laboratory to field with new institutional mechanism as well as enabling policies. Partnership with global scientific organizations could lead to faster progress as well as behavioral/attitude (work ethics as well as commitment) changes among state actors (bureaucrats and policy makers) as was observed in the Bhoochetana project implementation by ICRISAT and the Government of Karnataka in India [35].

Involving Women in Technology Development Transfer

Women are very actively involved in rice farming and rice processing in both Asia and Africa. Thus, the technology development and extension should have a gender focus in order to ensure that research is effective and efficient. This will greatly enhance the efficiency and impact of research as well as reduce gender inequalities in access to technologies. One recent example that proves it is the rapid adoption of

NERICA varieties across the African continent through the participatory variety selection work involving female and male farmers [36]. Participatory learning and action research methods have facilitated wide adoption of improved technologies for inland valley swamp development in Côte d'Ivoire, Mali, Ghana, and Madagascar.

There is a need to present research knowledge in formats that are easily digested by farmers and other prospective users. Africa Rice has acquired some experience in the use of videos in conveying certain messages to farmers and provoking village-level discussions on issues related to rice cultivation and rice processing. These videos have been translated into 33 local African languages [37–39].

Involving the Private Sector

Technological popularization among the farmers should be a convergent process involving farmers, private sector, department of agriculture officials, university staff, and the scientists from national institutions. Involvement of the private sector would enable the sector to make sure the availability of different components of integrated weed management, such as improved competitive cultivars-adopted to specific locations, herbicides, location-specific mechanical weeders, and other implements and inputs. Involvement of different private sectors with farmers would not only ensure higher production by the farmers through effective weed control but also ensure better marketing of the produce by the farming community.

Farmer Field Schools

The farmer field schools (FFS) training approach was based on active participation of farmers sharing knowledge with each other. Farmers learn new concepts through the experiential learning cycle in a process of learning by doing. The FFS facilitators help farmers to learn from practical experience. Since the initiation of the first FFS in 1989/1990 in Indonesia for educating farmers on the principles of "integrated pest management" for managing major outbreaks of the brown plant hopper, the concept has spread to other Asian countries [40]. This concept may be used for improving the farmers' knowledge of weed management.

Utilizing Information Technology

Most developing countries have started using Internet-based information technology (IT). India, in particular, now has Internet connectivity down to the district level throughout the country. Organizations, such as ITC and Mahindra ShubhLabh Services, have "e-centers" to assist farmers. Many of the agricultural universities have Web sites incorporated with weed management technologies. The information can be accessed by extension staff and passed on to farmers. In addition to existing communication and knowledge dissemination systems, IT may be used simultaneously for transferring knowledge and enriching farmers technologically. Several organizations are incorporating technological information within the new information systems. CAB International manages a wide range of information resources of existing agricultural information through publications, CD-ROMs, and research studies. The National Innovations Foundation (NIF) in India has been established to build linkages between excellence in formal scientific systems and informal knowledge systems [41]. The rapid extension of the Internet, mobile phones, and other communication networks will provide new opportunities. But, in certain developing countries, such progress is not there. However, in the future they will need to use IT to effectively pass on the weed management technology to the farming community.

Conclusion

In these current days of enormous challenges—including climate change, soil degradation, and resource scarcity—there is an urgent need for capacity building of the farming community to combat the menace caused by ever-adapting dynamic weeds. Enhancing farmers' knowledge with timely, relevant, and accurate technological information from time to time is crucial. For strengthening the knowledge of farmers on effective weed management, it is essential to have a networking of weed scientists and other people interested in weeds for rapid knowledge and information sharing among each other.

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