Improving farmers' livelihood in rainfed rice-based lowlands of Asia

SM Haefele [1*], G Atlin [1], SP Kam [1], DE Johnson [1]

[1] The International Rice Research Institute, DAPO Box 7777, Metro Manila, Philippines.
* Corresponding author: e-mail: s.haefele@cgiar.org; tel: (63-2) 580-5600

Abstract

About one billion people depend on rainfed lowland rice grown on 46 million hectares in South and Southeast Asia. Farmers in these environments are among the poorest in Asia. Rainfed rice faces various biophysical stresses resulting in low and unstable yields, averaging about 2 t ha^{-1} versus 5 t ha^{-1} in irrigated systems. The most important abiotic constraints to production are frequent droughts, submergence, and unfavorable soil conditions. Our objectives are to present some important characteristics, changes, and developments in this system, and to assess possible consequences for natural resource management and impact-oriented research. Contrary to developments in irrigated systems, the successful introduction of modern rice varieties is rather recent in rainfed environments. Their main advantages are higher yields, better fertilizer response, lower disease susceptibility, and shorter duration. Further varietal improvement for abiotic stress tolerance can be expected as a result of an increased focus on breeding for stress tolerance, including the use of recently discovered major quantitative trait loci. These developments as well as socioeconomic and production technology changes offer considerable opportunities for intensification of rainfed systems. They can also contribute to reduced production risk and provide options for diversification. But, to reach these goals, the variety-driven changes must be accompanied by improved and adapted crop and natural resource management options. Only integrated germplasm-crop management solutions adapted to the production environment can achieve stable production increases and maintain the sustainability of rainfed lowlands. We conclude that rainfed lowlands offer substantial potential for increased productivity. This would not only improve farmers' livelihood, but could also contribute an important share to the rice production increases needed in the near future to compensate for high population growth rates and the loss of prime farmland.

Introduction

Rainfed lowland rice in Asia covers about 46 million hectares or almost 30% of the total world rice area (Maclean et al., 2002) (Figure 1). While this system includes favorable environments with conditions similar to those of irrigated systems, most rainfed lowlands face various biophysical constraints, such as drought, submergence, adverse soil conditions, pests, and weeds. Although these conditions cause generally low productivity, about one billion people depend on rainfed lowland rice in South and Southeast Asia. Because of the low and unstable productivity levels, poverty is severe in communities largely dependent on rainfed rice (e.g., most of eastern India). In drought years, food consumption decreases, indebtedness increases, assets are sold, and household members migrate. Therefore, droughts can have long-term destabilizing effects on poor communities and reduce productivity even in non-drought years because farmers, fearing crop loss, avoid investing (Pandey et al., 2001). Despite the importance of the area and dependent populations, research efforts for rainfed lowlands have been limited. Instead, irrigated ecosystems have been the focus of rice research because of their leading role in rice production. Strategies to transfer approaches and technologies from irrigated to rainfed systems were of limited success, and are only applicable in favorable rainfed environments. However, rice research for rainfed lowlands was more successful during the last two decades, and contributed, together with socioeconomic developments, to considerable changes in rainfed lowland systems. Knowledge of system characteristics as well as of the most important changes and their consequences will be the basis for impact-oriented research and the development of adjusted and sustainable natural resource management options, needed to improve farmers' livelihood in rainfed rice-based lowlands of Asia.

General characteristics of rainfed lowlands

Rainfed lowland rice grows in bunded fields that are flooded for at least part of the season. Apart from bunds, there is no other water control, and drought and/or submergence can limit crop growth at any time. In addition, small to medium topographic differences cause considerable short-range variability in water availability and several important soil factors (e.g., soil texture, soil fertility, toxicities) in most rainfed lowlands (e.g., Oberthuer and Kam, 2000). External input use (e.g., fertilizer, agro-chemicals) is generally low for various reasons, such as high production risk, low fertilizer response due to varietal or soil-chemical reasons, limited financial resources, limited accessibility, or limited knowledge on efficient use. In most rainfed lowlands, a single crop of rice is grown per year, and rice is often the only choice due to at least temporarily flooded soils. In areas with longer rainy seasons and/or where short-duration varieties are used, other crops can be grown after rice (e.g., chickpea, mustard, linseed, mungbean). Mechanization is limited but increasing rapidly in many regions.

Because of the environmental limitations for agricultural production and low market value of rice, rainfed lowland rice farmers are generally poor. Average rice yields reached approximately 2 t ha^{-1} in the mid-1990s, but range from 4.6 t ha^{-1} in Korea DPR to 1.5 t ha^{-1} in Cambodia and fluctuate considerably from year to year (Maclean, 1997). Landholdings are mostly small and fragmented, and farmers' education levels are usually low. Although poverty is widespread in rainfed lowlands, poverty levels cover a considerable range depending on biophysical conditions and opportunities for other income sources. Off-farm income in particular can improve farmers' livelihood considerably (e.g., Wijnhoud et al., 2003). The distribution of rainfed lowland rice in Asia is shown in Figure 1. India has by far the largest area of rainfed lowlands, but large areas are also found in Thailand, Bangladesh, Indonesia, Vietnam, and Myanmar. The total area has not changed much over the last two decades, but there have been large increases in Thailand, Cambodia, Indonesia, and Laos, while decreases occurred in Myanmar, Nepal, and the Philippines.

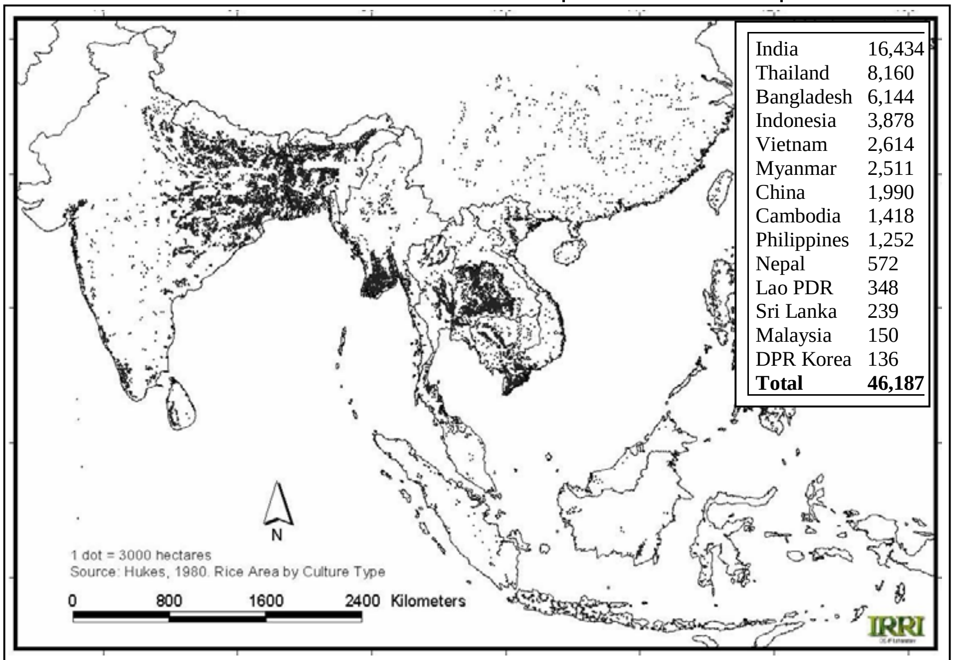

Figure 1: Distribution and area (000 ha) of rice-based rainfed lowlands in Asia. Source: Huke, 1982; Huke and Huke, 1997. Produced by IRRI, GIS unit.

Abiotic stresses in rainfed lowlands

Abiotic stresses constitute the most important constraints to productivity and intensification of rice-based rainfed lowlands. Most rainfed lowlands are situated in the warm subhumid tropics (eastern India, Myanmar, Thailand) and the warm humid tropics (Laos, Cambodia, Vietnam, Bangladesh, Philippines, Indonesia, Sri Lanka, Malaysia). Severe and regular droughts affect mainly eastern India, northeast Thailand, and parts of Myanmar and Laos (Figure 2), but regional weather patterns and topography cause considerable drought-risk variations within and beyond these countries. Drought stress is the most important limitation to production in rainfed lowlands and is estimated to frequently affect about 19 to 23 million hectares (Garrity et al., 1986). About 11 million ha of lowland rice areas are prone to temporary submergence (Huke and Huke, 1997). Further constraints arise from the widespread incidence of problem soils. Common soil constraints in rice-based lowlands include salinity/alkalinity (≈1.3 million ha), Fe toxicity (≈7 million ha), and acid sulfate soils (≈2 million ha) (Garrity et al., 1986; Akbar et al., 1986; Van Bremen and Pons, 1978). Saline and/or alkaline rice soils in coastal or dry inland regions are mainly found in Vietnam, Thailand, Myanmar, India, and Bangladesh. Acid sulfate rice soils are widespread in Vietnam, Thailand, Bangladesh, and Indonesia. Often, stress combinations occur at a site or in a region (Neue et al., 1998). Salinity and alkalinity often induce P and/or Zn deficiency. Soil acidity often occurs together with Al and Fe toxicity, and P deficiency. Garrity et al. (1986) estimated that in northeast Thailand, Laos, and Cambodia, about two-thirds of the rainfed area is characterized by soil acidity, widespread Fe toxicity, low CEC, and low soil N, P, and K reserves.

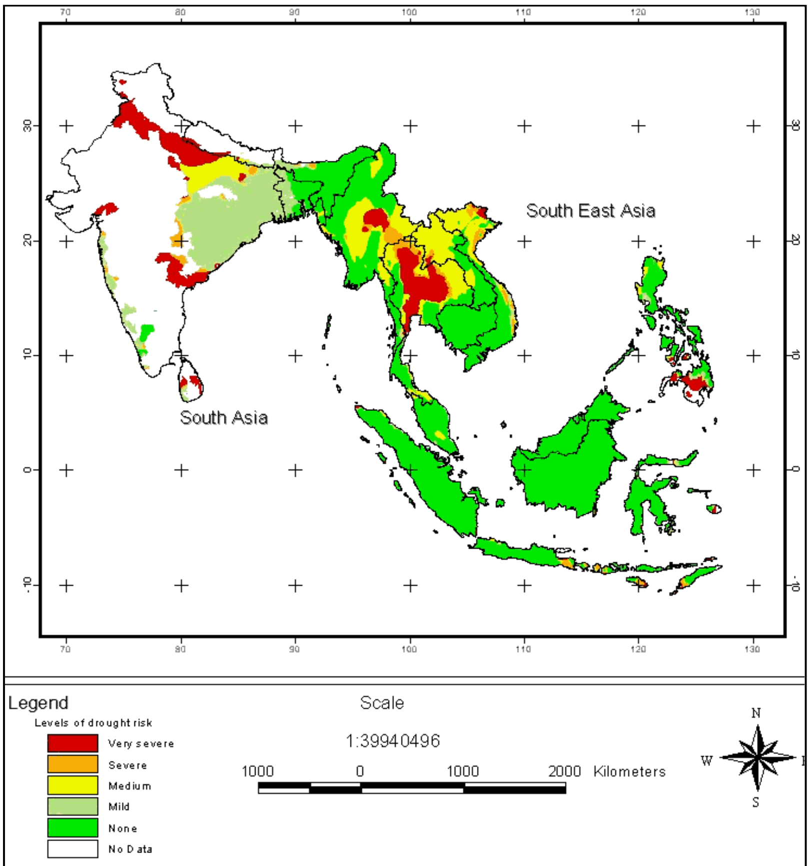

Figure 2: Areas of drought risk in South and Southeast Asia. Adapted from Kam et al. (2000).

The need to intensify rainfed lowland systems

Although population growth rates are declining, absolute increases in population are today at the highest level in history. The poor especially rely on rice as their main food source, and, although the main share of total rice production will continue to come from irrigated systems, there are indications that irrigated systems alone will not be able to supply the additional amount needed in the near future (Rosegrant and Svendsen, 1993; Pingali et al., 1997). Average yields in irrigated systems are gradually approaching economically viable and sustainable yield targets, which might be one important reason for decreasing yield growth rates (Dawe and Dobermann, 1999). Apart from hybrid rice, no technology promising substantial increases in potential yields is in sight. Limited land and water resources, costs, and environmental concerns make substantial rice-area increases very unlikely. Productivity increases in rainfed environments could help to close the gap between future demand and supply, reduce the pressure on irrigated systems, and on land and water resources, and have a considerable impact on poverty reduction in rural Asia. Studies in India concluded that the marginal returns from government investments in technology and infrastructure are the highest in rainfed areas (Fan and Hazell, 1997). Increases in marginal productivity from improved varieties and management are greater in low-potential than in high-potential rainfed areas.

Opportunities for intensification

Rice-based lowland systems worldwide have undergone considerable changes in recent decades. Important elements of change include a much-improved access to markets for inputs and outputs, more opportunities for off-farm income, new farming technologies (varieties, inorganic fertilizer, agro-chemicals, machinery), and better access to information. These elements influence specific regions in multiple ways and varying degrees, which cannot be summarized here. Instead, we concentrated on two developments having major implications for rice-based rainfed lowlands.

Varietal improvement for rainfed lowlands: Varietal improvement for rainfed environments was slow compared to the development in irrigated systems. During the 1950s and 1960s, rice breeders focused on irrigated and favorable rainfed environments. A detailed classification system of rainfed environments as a basis for breeding efforts was only developed in 1982 (Khush, 1984). Other reasons for the slow breeding progress include(d) the failure to recognize the importance of rice quality in a system in which most rice produced serves for consumption, breeding under favorable conditions strongly contrasting with conditions in farmers' fields, the high level of heterogeneity within and across fields and seasons in rainfed production environments resulting in large genotype x environment interactions that limit the effectiveness of selection (e.g. Atlin, 2001), and an environment frequently characterized by multiple stresses. Therefore, traditional varieties and improved varieties of the traditional type are still widespread in rainfed environments. Contrary to common belief, they are often susceptible to various diseases, to drought, and to submergence (Mackill, 1986), and even some of the most successful improved varieties have these short-comings. A famous example is the variety Mahsuri (released in 1965), one of the most widely grown rice cultivars in the world (Mackill et al., 1996). Mahsuri has stable yields even on poor soils and excellent grain quality, but is not suited for intensification (low yield potential; no fertilizer response; prone to lodging; susceptible to diseases, drought, and submergence; long duration). Similarly, most of the rainfed area in northeast Thailand is grown to improved but traditional-type varieties (e.g., KDML105, RD6). They fulfill a high grain quality standard and are tolerant of multiple stresses, but they show little input response, are prone to diseases and lodging, and have a low yield potential.

Improved modern-type varieties (i.e., short to medium duration, height ≤ 1.3 m, high yield potential, good fertilizer response), required for the intensification of rainfed lowlands, became available only more recently. Instrumental to this success was the recognition that improved varieties for stressful rainfed environments can be developed if selection and variety evaluation are done under conditions similar to those experienced in farmers' fields (Atlin and Frey, 1990), and if farmers' needs, preferences, and opinions are taken into account in the selection process (Joshi and Witcombe, 1996). A very successful case of the development and adoption of such improved rainfed varieties has occurred in the Lao PDR (see details below), where improved varieties (e.g., TDK 1) that are substantially more productive than traditional varieties under both traditional and intensified crop management have been rapidly taken up by rainfed lowland farmers (Pandey, 2001; Shrestha, 2004). A similar success has been achieved in Chhattisgarh State (eastern India) with the drought-tolerant yet input-responsive variety Mahamaya (Shrivastava, pers. communication). But, in both cases, the variety adoption process happened in the last ten to fifteen years only and farmers, extension services, and researchers are still testing complementary natural research management strategies that will permit farmers to exploit the full potential of the new varieties.

Another opportunity is offered by marker-assisted breeding (MAB). MAB can be used to improve existing widespread and accepted varieties in a programmed and incremental manner by introgressing genes conferring tolerance of stresses. With present technology, MAB is most likely to be effective for quantitative trait loci (QTLs) controlled by stress tolerance genes with large effects. Advances in biotechnology make the transfer of defined QTLs into widely used varieties a viable and fast breeding strategy and could allow combining tolerances for multiple stresses (e.g., Mackill 2004). Major QTLs for abiotic stress tolerance identified in rice are *Sub1* (submergence tolerance; Xu et la., 2000), *Saltol* (salinity tolerance; Bonilla et al., 2002), *Pup1* (P-deficiency tolerance; Wissuwa et al., 1998), and two QTLs for Al-toxicity tolerance (Nguyen et al., 2003; not yet fine-mapped). Promising major QTLs were also identified for Zn-deficiency tolerance, (Wissuwa, pers. communication) and Fe-toxicity tolerance (Wan et al., 2003), but further research is needed to evaluate their effectiveness under field conditions.

Dry direct seeding in rainfed lowlands: The rising wage rate, increasing availability of chemical weed control methods, and the need to intensify rice production systems are considered to be the major driving force for the adoption of direct-seeding technologies in Asia (Pandey and Velasco, 2002). In comparison with transplanting, dry direct-seeded rice can be established earlier because there is no need to accumulate enough soil moisture for soil puddling. Labor needs for establishment are much reduced and spread more evenly during the season, and earlier establishment combined with the absence of transplanting shock cause an earlier crop maturity. Especially when combined with modern short-duration varieties, dry direct seeding enables a better use of early rains, reduces late-season drought risk, and can add the possibility of a second, post-rice crop. Direct seeding is not a new technology in rice-based systems, but increasing labor costs in some areas coupled with the availability of herbicides increased its attractiveness as a means for system intensification. Pandey and Velasco (2002) estimated the total direct-seeded area in irrigated and rainfed lowlands (no separate estimates for rainfed lowlands are available) at about 29 million ha, or only 14% of lowland rice. Provided weeds can be controlled, yields of direct-seeded rice are reported to be identical to or only slightly lower than those of transplanted rice (e.g., Pandey and Velasco, 2002; Johnson et al., 2003). Changing management practices, however, are likely to result in weed population shifts and problematic weeds may cause serious problems unless effective management strategies are applied. Weeds are the major constraint of direct-seeded rice and practicable, efficient, and sustainable weed management options for direct-seeded systems are one of the most important research issues in direct-seeded rainfed lowlands. If such options were available, the advantages of direct seeding, especially when combined with modern-type varieties, could reward higher external input-use practices. In some regions, additional intensification through diversification (i.e., a second crop made possible by the reduced growth duration of direct-seeded rice) could increase farmers' livelihood and reduce their risk susceptibility even further (Singh et al., 2000; Sharma et al., 2004).

Intensification and some consequences for natural resource management

As indicated above, there are opportunities for intensification of rainfed lowlands, but the related system changes require adjusted resource management options to maintain the sustainability of the system. This is outlined below for some nutrient management issues, but is equally true and important for other management components (e.g., crop, pest, and disease management, etc.).

An example of the successful introduction of modern-type varieties in rainfed lowlands can be found in Laos (Table 1). The introduction of improved varieties started only around 1990, initially based on improved traditional-type varieties from northeast Thailand, and from 1993 onward, increasingly based on improved modern-type varieties released locally. After ten years, the majority of farmers used improved varieties on at least part of their farm. The combination of improved varieties and increasing inorganic fertilizer use led to considerable yield increases, highest for improved modern-type varieties. But current fertilizer doses (organic and inorganic) are still very low, and the sustainability of the described system change is unclear. Table 2 shows partial nutrient balances for four different nutrient management scenarios in farmers' fields in Laos. The balances account for nutrient removal with the crop and applied nutrients only, but they can be used as an indicator for sustainability. The partial balance for all scenarios without substantial inorganic fertilizer use was negative for N, P, and K, but use of the improved variety and

Table 1: Varieties, inorganic fertilizer use, and average yields in rainfed lowlands, southern and central Laos. Based on Pandey (2001) and Shrestha (2004).

	1990	1995	2001
Planted area (%):			
traditional varieties	95	79	25
improved varieties, traditional-type	5	21[a)]	46
improved varieties, modern-type	0		29
Farmers using			
inorganic fertilizer (%)	-	60	93
Average yield (t ha^{-1})			
traditional varieties	-	1.3	1.4
improved varieties, traditional-type	-	1.5[a)]	1.9
improved varieties, modern-type			2.3

[a)] average for improved traditional and modern-type varieties organic fertilizer reduced nutrient losses despite higher yields. A positive N and P balance resulted from the recommended inorganic fertilizer dose, but the K balance remained negative because of the dominant use of 16-20-0 NPK fertilizer. Biological N fixation of 20-40 kg N ha^{-1} was described for rainfed lowlands (Greenland, 1997), but it is unknown whether weathering of minerals could compensate for the anticipated P and K losses. Many rainfed lowlands have been cultivated for less than 50 years (total rice area increased from 87 million ha in 1948 to 154 million ha in 2000), and even their capacity to maintain current yields without increased nutrient inputs is uncertain. Balances given in Table 2 might be extreme because of the participating farmers' very low nutrient input use, but negative N and K balances in Lao were also estimated by Linquist and Sengxua (2001). They showed that the common practice of applying N and P only led to frequent yield limitation by K deficiency within a few cropping seasons, thereby reducing the efficiency of N and P applications. Wihardjaka et al. (1998) reported negative K balances in Central Java. Medium inorganic fertilizer inputs and low average yields resulted in slightly positive partial NPK balances for most farmers in a study in northeast Thailand (Wijnhoud et al., 2003), but Vityakorn (1989) concluded that the biophysical sustainability of rice-based rainfed lowlands in Thailand might be limited to lower paddies due to nutrient leaching from higher positions. Particularly in Southeast Asia, widespread low indigenous nutrient supplies in rainfed lowlands offer little buffering capacity for nutrient management imbalances. In these systems, residue recycling might have an especially important role in reducing nutrient losses and maintaining soil fertility. But increasing opportunity costs of labor make organic fertilizers less attractive in many rainfed environments (Pandey, 1998).

Table 2: Partial nutrient balance (in kg ha^{-1}) for different nutrient management scenarios in farmers' fields in rainfed lowlands, Laos (adapted from Nivong et al., 2004).

Variety:		traditional	improved modern-type		
Organic fertilizer:		farmers' practice		recommended dose	
Inorganic fertilizer:		farmers' practice		none	recom. dose
Grain yield		2270	2790	3130	4170
Straw yield		4330	4120	4280	5310
Nutrient removal	N	-27.0	-28.1	-31.8	-44.0
(with grain and	P	-7.5	-7.2	-8.1	-10.8
1/2 the straw)	K	-35.4	-33.8	-33.2	-40.5
Input inorganic	N	4.5	7.1	0.0	66.0
fertilizer	P	0.4	0.7	0.0	10.8
	K	0.0	0.0	0.0	4.0
Input organic	N	1.0	2.1	10.0	10.0
fertilizer	P	0.3	0.6	3.0	3.0
	K	1.0	2.1	10.0	10.0
Balance	N	-21.5	-18.9	-21.8	32.0
	P	-6.8	-5.9	-5.1	3.0
	K	-34.4	-31.7	-23.2	-26.5

Improvement of varietal stress tolerance might have further important implications for natural resource and crop management practices. Where nutrient fixation is the main limiting factor, increased uptake efficiency would contribute to a better use of indigenous resources. Further, yield increases and yield stabilization due to increased abiotic stress tolerance would make external input use a more attractive and profitable option for farmers. Higher uptake efficiency contributes directly to the better use of applied nutrients and reduced losses from the system. Improved plant nutrition may also contribute to a higher tolerance of multiple stresses (abiotic and biotic) frequently occurring on problem soils. For example, there are strong indications of positive interactions between plant nutrient status and yield performance under drought (e.g., Katyal et al 1997). But, especially in fragile environments, such changes must be analyzed with care. In saline environments, the use of tolerant germplasm could increase salinity if appropriate management is not applied simultaneously. Salinity-tolerant varieties cannot replace resource-caring management practices, and increased salinity tolerance could result in increased salinity if farmers pay less attention to salinity-controlling practices. Improved tolerance of nutrient deficiencies has other implications. P- as well as Zn-deficiency tolerance is achieved by increased access and uptake of indigenous supplies. Where low absolute indigenous supply rather than fixation (low solubility) of nutrients in the soil is the limiting factor, rapid nutrient depletion by tolerant genotypes may give them only a temporary advantage.

Conclusions

The successful development of improved modern-type rice varieties as a basis for intensification of rice-based rainfed lowlands was much delayed because of the complex demands of this environment. But the increased use of adjusted breeding methodologies and participatory approaches led to the more frequent and successful release of improved modern-type varieties for rainfed environments, and molecular breeding tools could even accelerate this process. However, such varieties have become widespread only within the last 10 to 15 years, and improved and adjusted natural resource management practices could now have considerable impact.

Changes in rainfed environments and available technologies go far beyond the introduction of improved varieties and we could only highlight some major changes. Yet, the touched-upon issues of improved varieties, direct seeding, and external input use are key elements for the intensification of rainfed lowlands. Improved modern-type varieties are a prerequisite for any attempt to increase productivity in rice-based rainfed lowlands. Where these are not available or accepted by farmers, further progress in breeding efforts is required first. Direct seeding offers a substantial potential for intensification, risk reduction, and diversification, but effective and sustainable weed management options are obligatory for technology acceptance. And, finally, any sustainable intensification in most rainfed environments will depend on inorganic fertilizers, even if organic residues might have a more important role in the generally poorer soils in rainfed lowlands than in irrigated systems. As with other crop/resource management issues, it must be admitted that existing fertilizer recommendations for most rainfed environments are still blanket recommendations, mostly ignoring the high spatial and temporal variability of water availability, topographic influences on soil fertility, and varietal differences. As can be expected, farmers do not use such recommendations but rather develop their own rules for fertilizer use (e.g., Wijnhoud et al., 2003). To address this situation and the complexity of rainfed systems, flexible resource management options and decision support tools must be developed to increase farmers' and extensionists' ability to make decisions according to their environment and needs. Interdisciplinary approaches, including significant contributions from extensionists and farmers, will be instrumental for this objective. With such technologies, sustainable productivity increases and substantial poverty reduction are realistic goals in many rainfed environments.

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