IRRIGATION AND DRAINAGE
Irrig. and Drain. **56**: 335–348 (2007)
Published online in Wiley InterScience (www.interscience.wiley.com) **DOI**: 10.1002/ird.308

INNOVATIVE LAND AND WATER MANAGEMENT APPROACHES IN ASIA: PRODUCTIVITY IMPACTS, ADOPTION PROSPECTS AND POVERTY OUTREACH†

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ABSTRACT

There are no unanimous views regarding the real water-saving effects of land and water management innovations. Some claim that the innovations merely change the prevailing water allocation. However, there is no dispute regarding their land and water productivity impacts. The water productivity improvement ranged from 30% for zero tillage technology to 648% for micro-irrigation technology for beetroot. The land productivity improvement ranged from 4% for bed planting technology to 88% for micro-irrigation technology for watermelon. Aerobic rice varieties are inferior to lowland rice varieties in terms of land productivity but superior in water productivity. In addition, some of the innovations reduce cost of production, improve the quality of produce and entail positive environmental externalities. However, the current level of adoption of these innovations is not satisfactory due to insufficient labour and organic fertilizer availability problems, uncertain irrigation water supply, crop specificity and complexity, lack of capital, high knowledge and technical skill requirements. To realize the potential benefits of these innovations to the poor the following actions are suggested: (1) provision of subsidies; (2) targeted training opportunities; (3) encouragement of private participation in the supply chain of inputs; (4) focus on short pay-back period technologies; (5) strengthening of public research on the systems. Copyright © 2007 John Wiley & Sons, Ltd.

KEY WORDS: micro-irrigation; SRI; adoption; land productivity; water productivity; poverty; Asia

Received 28 November 2006; Accepted 23 January 2007

RÉSUMÉ

Les réponses possibles au problème de manque d'eau impliquent deux actions complémentaires, gestion de l'offre et gestion de la demande. Les approches innovantes de gestion des terres et de l'eau font partie des solutions de gestion de la demande. Il n'existe pas d'opinion unanime sur les véritables effets des innovations en matière d'économie d'eau. Certains disent que les innovations changent simplement la répartition de l'eau ou son mécanisme de transfert. Cependant, il n'y a aucune contestation concernant leurs impacts sur la productivité de la terre et de l'eau. Et, pour certaines des innovations qui font l'objet de cet article, ces impacts sont tout à fait substantiels. L'accroissement de productivité de l'eau va de 30% pour le zéro labour à 648% pour la micro-irrigation de betteraves. La hausse de productivité de la terre va de 4,2% pour la culture en billons à 87,5% pour la micro-irrigation de pastèques. Les variétés aérobies de riz sont inférieures aux variétés de riz de bas fonds en termes de productivité de terre, mais supérieures en productivité de l'eau. En plus de ces effets, une partie de l'innovation réduit le coût de production, améliore la qualité du produit et induit des externalités environnementales positives.

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Cependant, le niveau d'adoption de ces innovations n'est pas proportionné à l'importance des améliorations de productivité qu'elles entraînent. Les contraintes principales d'adoption incluent disponibilité de force de travail, disponibilité d'engrais organique, fiabilité de l'approvisionnement en eau d'irrigation, spécificité de la culture, complexité (de l'innovation), besoin élevé de capital initial, niveau élevé des connaissances et compétences techniques requises. Pour faire en sorte que les avantages potentiels de ces systèmes et technologies innovants aillent un peu plus aux pauvres, les actions suivantes sont suggérées: (1) subventions de démarrage ciblées sur les pauvres; (2) formations ciblées pour que les pauvres augmentent leur compétence et connaissances afin de faire face aux complexités des systèmes; (3) participation privée encouragée dans la chaîne d'approvisionnement des inputs nécessaires aux systèmes (par exemple, machines, instruments et outils); (4) accent sur le développement de technologies à courte période de retour; (5) renforcement de la recherche publique sur les systèmes pour prolonger les améliorations.

MOTS CLÉS: micro-irrigation; adoption; productivité de la terre; productivité de l'eau; pauvreté; Asie

INTRODUCTION

Due to ever-expanding demand, Asia is incurring a vast water deficit. Water tables are now falling in many countries triggered by increasing demand and the introduction of powerful diesel and electricity-driven pumps. Groundwater levels are falling precipitously throughout the northern half of China, and in India (Kendy *et al*., 2003). Competition among the various sectors of the economy for the scarce water is becoming intense. As urban water use for industry, sanitation and drinking rises, farmers are faced with a dwindling share of a shrinking per capita water supply. Brown (2005) rightly claims that neither economics nor politics favours farms; they almost always lose out to cities.

Responses to the water scarcity problems in general follow two complementary tracks: management of water supply such as development of water infrastructure including reservoirs, wells, canals and pipelines, and management of demand. Demand management options mainly focus on improving the productivity and economic efficiency of existing infrastructure. Demand management approaches may conveniently be divided into two subcategories which are also complementary: (1) institutional, organizational and economic policy interventions; and (2) technological innovations. Institutional, organizational and economic policy instruments have been widely implemented with varying levels of success (Vermillion, 1997; Tsur *et al*., 2004). They include forming user organizations, implementation of irrigation management transfer (IMT) and participatory irrigation management (PIM) polices (Vermillion, 1997), water pricing policies (Tsur *et al.,* 2004), and trade policies among countries or regions enhancing virtual water transfer among countries (Fraiture *et al.,* 2004).

The range of interventions under technical innovation options, which are the subject of this paper, can be classified as: (1) on-farm soil and water management practices such as zero tillage, mulching, and soil fertility management; (2) improved crop varieties that perform better under low moisture stress environments such as aerobic rice varieties; and (3) water efficient irrigation technologies such as micro-irrigation systems. Because paddy rice production is such a large consumer of water, a whole set of interventions including aspects of both the first and second type of intervention focus on rice production.

Most analysts believe future increases in food supplies and economic prosperity for the rural poor will mainly come from improved productivity of the existing agricultural lands and irrigation infrastructure, since the natural resources base will not support either significant expansion of farmlands or more extensive irrigation (Shah and Strong, 2000). In light of this, researchers, policy makers, NGOs and farmers are increasingly pursuing various innovative land and water management technologies and systems in Asia.

Many advanced agricultural research systems, international agricultural research institutes, national agricultural research and extension systems and NGOs are engaged in development, adaptation and dissemination of innovative land and water management solutions in many parts of the developing world including Asia (Netherlands Water Partnership, 2003).

This paper aims to take stock of the major land and water management technologies and systems being developed, adapted or disseminated in Asia, and analyses their adoption prospects, evaluates their poverty outreach and productivities, and derives research, extension and policy implications or recommendations. Specifically the paper attempts to give answers to the following questions:

1. What are the technical and economic attributes of these innovations across a range of growing environments, farming systems and farmer groups?
2. Can poor farmers readily adopt and benefit from these innovations?

OVERVIEW OF ON-FARM WATER, LAND AND CROP MANAGEMENT SYSTEMS AND TECHNOLOGIES

Many innovative practices under research or being promoted in Asia can be placed in three categories, namely micro-irrigation technologies, resource-conserving agriculture, or alternative rice management systems and technologies (Table I). An analysis of land and water productivity and poverty impacts for each of these types of technologies or management practices can be carried out based on experiences in Asia, primarily India, China and Pakistan.

Micro-irrigation technologies

Increased land productivity, water productivity, improved product quality and reduced cost of production are the hallmarks of micro-irrigation technologies when adopted for production of a variety of vegetables, fruit and cash crops both under fresh and saline waters. Yield advantage in the range of 23.1–87.5% and significant water productivity improvements are possible when shifting to micro-irrigation technology (Table II).

Table I. Selected on-farm land and water management technologies and systems

Technologies or management systems	Examples
Micro-irrigation systems	Micro-drip and sprinkler systems
Resources conservation technologies or conservation agriculture	Surface seeding, zero tillage with inverted T-openers, reduced tillage, etc.
Rice technologies and management systems	The system of rice intensification Alternate wetting and drying Aerobic rice cultivation

Table II. Land and water productivities for selected crops under conventional and drip irrigation systems in India

Crop	Water productivity (kg m^{-3})			Land productivity (t ha^{-1})		
	Conventional	Micro-irrigation	% increase	Conventional	Micro-irrigation	% increase
Banana	3.27	9.02	176	57.5	87.5	52
Grapes	4.96	11.69	136	26.4	32.5	23
Sugarcane	5.95	18.09	204	128.0	170.0	33
Tomato	10.67	26.09	145	32.0	48.0	50
Watermelon	7.27	21.43	195	24.0	45.0	88
Cotton	1.70	6.16	262	2.33	2.95	27
Chillies	0.39	1.46	274	4.233	6.09	44
Papaya	0.06	0.32	433	1.34	2.35	75
Sugar beet	85	132	55			
Sweet potato	6.73	23.37	147			
Beetroot	0.67	5.01	648			
Radish	2.25	10.98	388			
Mulberry	138.6	375	171			

Sources: Sivanappan (1977); Sivanappan *et al.* (1987); Agarwal and Goel (1981); Sivanappan and Padmakumari (1980); Muralidhara *et al.* (1994); Paul and Sharma (1999); Narayanamoorthy (1999); National Committee on the Use of Plastics in Agriculture (1990).

DOI: 10.1002/ird

In addition to enhancing land and water productivity, micro-irrigation technologies reduce cost of production by making possible economies in the use of fertilizer, labour and energy and by reducing the incidence of pests and diseases (Reddy and Reddy, 1995; Narayanamoorthy, 1999, 2003; Sivanappan, 1977; Sivanappan *et al*., 1987; Sivanappan and Padmakumari, 1980; Muralidhara *et al*., 1994; Paul and Sharma, 1999). Another beneficial feature of micro-irrigation is that it allows the use of saline water and marginal lands (Caswell, 1989). The economic return to farmers' investments in micro-irrigation technologies is reportedly substantial, and the magnitude of economic benefits depends on the type of the crop and the type of micro-irrigation technology used (Table III).

Encouraged by these positive benefits of micro-irrigation technologies, substantial efforts have been made to disseminate and popularize these technologies in Asia. For instance, the central and state governments of India have encouraged adoption by farmers by providing targeted subsidies. Despite these efforts, however, the percentage of total irrigated area under sprinkler and drip irrigation is 1.6 and 2.8% in India and China, respectively. The corresponding figure for France, Germany and Israel is over 90% (International Programme for Technology and Research in Irrigation and Drainage, 2003). However, in regions where water is very scarce and the labour used in securing it is intensive such as the Rajasthan and Maharashtra states of India, micro-irrigation techniques have been found to be successfully adopted (Dhawan, 2002).

Early adoption studies indicate that micro-irrigation has been most successful in countries where farmers produce high-value crops and have access to markets and groundwater (Sakks, 2001; Shrestha and Gopalakrishnan, 1993). Government canal irrigation water rates are so cheap that farmers who have access to it will not have the incentive to install micro-irrigation systems. In the groundwater sector as the water availability is limited and cost

Table III. Cost–benefit ratio of different drip-irrigated crops

Crop	Spacing (m × m)	Cost–benefit ratio
Coconut	7.62 × 7.62	1.41
Coconut	8.2 × 8.2	1.08
Grapes	3.04 × 3.04	13.35
Grapes	2.44 × 2.44	11.50
Grapes (Anab-e-shahi)	4.6 × 4.6	1.68
Grapes (Thompson Seedless)	4.6 × 4.6	1.57
Grapes		1.76
Banana	1.52 × 1.52	1.52
Banana		2.23–2.36
Orange	4.57 × 4.57	1.76
Pomegranate	3.04 × 3.04	1.31
Pomegranate	4.3 × 4.3	4.23
Mango	7.62 × 7.62	1.35
Mango	10 × 10	1.30
Papaya	2.13 × 2.13	1.54
Sugarcane	—	1.31
Sugar cane	—	1.83–2.05
Vegetables	—	1.35
Oil palm	9 × 9	1.72
Sapota	7.6 × 7.6	2.07
Guava	6.1 × 6.1	1.55
Ber	6.1 × 6.1	1.56
Citrus	6.1 × 6.1	1.99
Coccima India	3 × 3	1.11
Rose	1.2 × 1.2	3.08
Cotton	1.22 × 1.22	1.1–1.82

Sources: Reddy and Reddy (1995); Narayanamoorthy (1997a, b, 1999, 2003); Indian National Committee of the International Commission on Irrigation and Drainage (1994); Verma *et al.* (2004).

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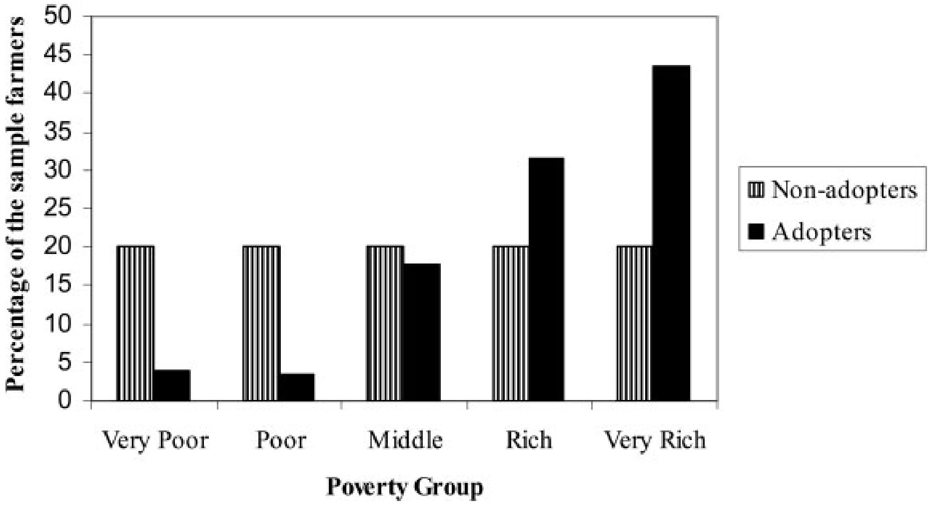

Figure 1. Poverty outreach of micro-irrigation technologies in Gujarat

of water is high, farmers have taken to micro-irrigation and sprinklers. The other major adoption constraints of micro-irrigation are: high capital cost and lengthy and tedious procedures to secure loans and subsidies, inadequate after-sales services from suppliers, acute power shortage and inadequate extension services.

Micro-irrigation technologies are often therefore associated with the capital-intensive, commercial farms of wealthy farmers. The systems used on large farms, however, are unaffordable for smallholders and are not available in sizes suitable for small plots. Recently, these technologies have gone through technical transformations from capital-intensive features to input mode[1] with the idea that this will create significant opportunities for smallholder agriculture. Adoption studies, disaggregated by wealth status, are necessary to determine whether this approach works.

Who are the current adopters of micro-irrigation technologies? The answer to this question may be contextual. However, a recent micro-irrigation adoption study carried out in selected villages of the Gujarat and Maharshtra states of India reveals that the largest proportion of micro-irrigation technology adopters belongs to the relatively rich groups of farmers[2] (Figures 1 and 2).

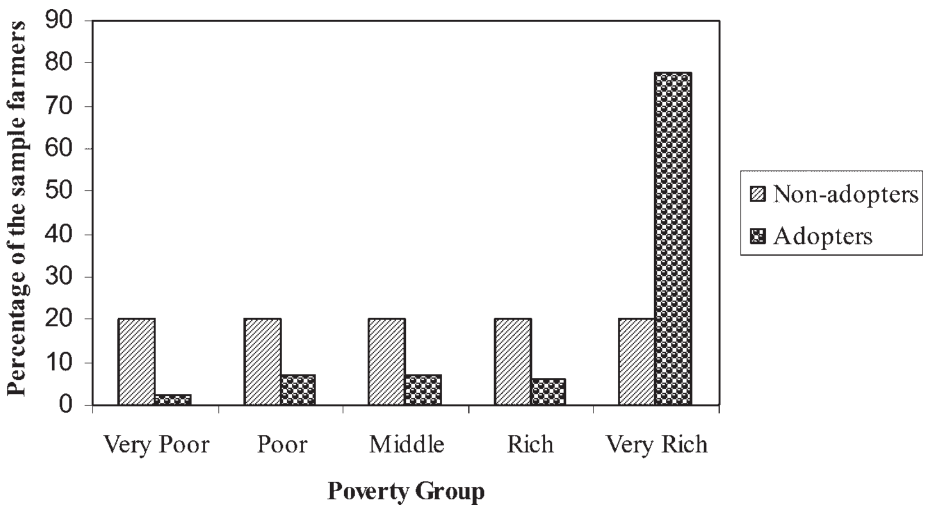

Figure 2. Poverty outreach of micro-irrigation technologies in Maharashtra

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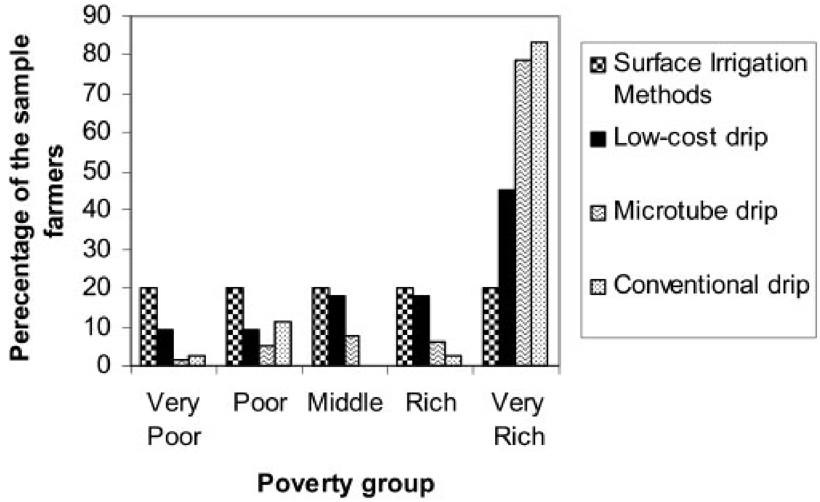

Figure 3. Poverty outreach of micro-irrigation technologies by type in Maharshtra

By design, the bars for non-adopters are expected to be equal in size across the poverty groups, and if the probability of adoption of micro-irrigation technologies is equally likely among the different groups of farmers, the distribution of adopters would have followed a similar pattern to that of non-adopters. However, this is not true in the present case. In Gujarat, the current micro-irrigation adopters are somewhat evenly distributed among the middle, rich and very rich groups (see Figure 1). The slight difference in the pattern of poverty group-by-micro-irrigation adoption interaction between Gujarat and Maharashtra may be because many NGOs are operating in Gujarat. However, in both Maharashtra and Gujarat, the poor and the very poor categories are the least represented in the adopters' sample.

The above, is perhaps, quite as per expectations. We have noted before that a majority of micro-irrigation technologies available today are most appropriate for capital-intensive rich farmers. However, a comparison of adoption rates for different technologies would reveal a more nuanced understanding of the adoption behaviour. Different micro-irrigation technologies appeal differently to different groups of farmers. This can be assessed by visualizing how much adoption of the different kinds of micro-irrigation technologies deviates from that of the traditional irrigation method (see Figures 3 and 4). The most commonly reported view is that low-cost

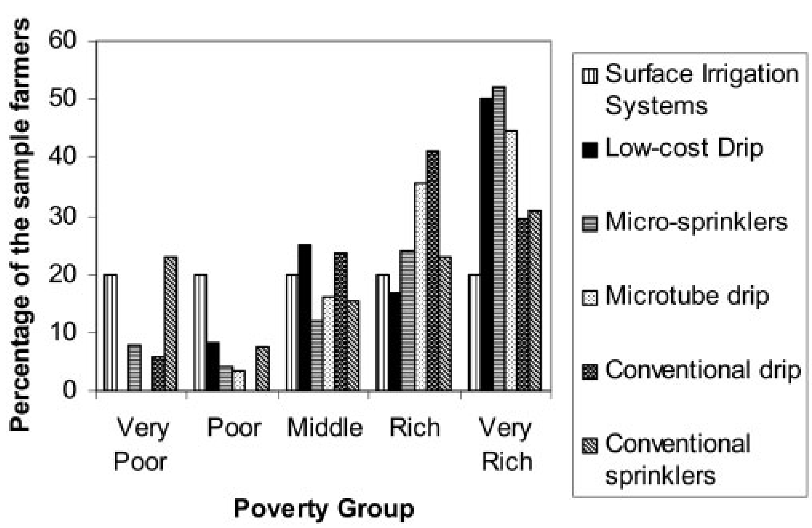

Figure 4. Poverty outreach of micro-irrigation technologies in Gujarat

DOI: 10.1002/ird

micro-irrigation technologies (low-cost drip such as Pepsee, easy drip, and micro-sprinklers) are easily accessible to poor farmers by virtue of their low initial capital requirements. However, this study shows that the relatively rich and very rich farmers represent the highest proportion of the low-cost drip technology adopters in both Maharashtra, and Gujarat. In the case of Gujarat, none of the very poor farmers have accessed low-cost drip technologies.

Adoption behaviour is thus more complex than is commonly perceived. The premise is that the low-cost technologies act as ‘‘stepping stones’’ for first-time users, irrespective of their income category. Therefore, once demonstrated, the rich are as likely to adopt low-cost technologies as the poor. The conventional (capital-intensive) micro-irrigation technologies offer high returns to large capital investments over a period of five to eight years. However, farmers are either unable to adopt these technologies by virtue of lack of investible capital (in the case of poor and very poor farmers) or are hesitant to allocate a significant amount of capital to a new technology about which they are not sure. Efforts by the government to remove the capital barrier by offering subsidies also does not seem to have helped as accessing these subsidies tends to be tedious and fraught with high transaction costs (Shah and Keller, 2002).

Low-cost technologies reduce the *payback period* of the investments and even though they have a shorter lifespan (a *Pepsee* system usually lasts one or two seasons as against the conventional drip systems which last for 5–8 years), they act as the perfect stepping stones for first-time adopters. It is not surprising therefore that an analysis of farmers who discontinue the use of low-cost micro-irrigation technologies after a couple of years reveals that three-quarters of them move on to the conventional drip systems (Verma *et al*., 2004).

Resource conservation technologies

The rice–wheat cropping system is the predominant farming system in the Indo-Gangetic plains of Bangladesh, India, Nepal and Pakistan, and the Yangtze River Valley of China. It covers about 13.5 million ha in South Asia and an estimated 10 million ha in the central areas of the Yangtze River Valley of China (Hobbs and Gupta, 2003). The rice–wheat systems of South Asia are facing a myriad of problems including: stagnating or even declining yield, declining soil organic matter, emergence of new weeds, pests and diseases, paucity of irrigation water, soil erosion resulting from soil tillage and problems of late wheat planting and poor plant stands. As a solution to these problems various resource-conserving technologies are being promoted. The conservation technologies include reduced tillage, zero tillage with inverted T-openers, bed planting, surface seeding, laser levelling, non-puddling for rice (Hobbs *et al*., 2000). These technologies specifically target problems of late wheat planting and poor plant stands, which limit yields under rice–wheat rotations.

Research shows resource-conserving technologies offer considerable potential for improving the sustainability and productivity of wheat in the rice–wheat system of South Asia (Gupta *et al*., 2002). These include raising input-use efficiency, cutting costs, providing various environmental benefits, and ultimately improving farmer livelihoods and helping to reduce poverty. The specific advantages include reduced labour, seeds, fertilizers, pesticides, fuel and water usage and less pollution of groundwater and greenhouse gas emissions. Study findings from Pakistan suggest that small-scale cultivation and resource conservation technologies such as the bed and furrow method, zero tillage technology and precision land levelling, lead to water saving by 20–30%, labour saving by over 30% and crop yields increase by 15–20% – these factors reduce cost of production and improve returns to farming (Jehangir *et al.,* 2004).

In Haryana, India, surveys and crop cuts have shown that zero tillage produces 400–500 kg ha^{-1} more grain than the traditional systems. This is attributed to earlier, timely planting, fewer weeds, better plant stands and improved fertilizer efficiency because of placement with a seed drill. The water productivity of the resource-conserving technologies is also substantial (Table IV).

Initially the adoption of these technologies remained very limited, scattered and patchy. Lately, farmer responses to these technologies have been very favourable. The area under resource- conserving technologies has risen from 100 000 ha in 2001 to 500 000 ha in 2002–3 wheat season with significant gains in Pakistan’s Punjab, north-west India, Sindh province in Pakistan and the eastern Gangetic plains. The main adoption constraints include initial

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Table IV. Land and water productivity of selected resource-conserving technologies

Technologies	Yield (kg ha^{-1})	Water productivity (kg m^{-3})
Zero tillage	4188	1.43
Bed planting	4134	1.81
Laser levelling	4764	1.67
Normal planting	3968	1.10

Source: Hobbs and Gupta (2001).

high cost of specialized planting equipment and the completely new dynamics of a conservation farming system, requiring high management skills and a learning process by the farmers.

One pertinent question is whether poor farmers, like wealthy farmers, can equally adopt the technologies. Unlike micro-irrigation, it appears that these technologies are scale neutral and that farmers from all social classes can benefit from the many advantages these systems bring to wheat cultivation. For instance, a survey conducted in 2000 in Haryana showed that 24% of the zero tillage adopters owned a tractor, while the rest used service providers, indicating a high degree of adoption by poorer farmers (Hobbs and Gupta, 2003). The average farm size of adopters ranged from 0.8 to 20.2 ha, again indicating that the technologies were adopted across a range of wealth classes.

Rice technologies and management systems

The system of rice intensification. The system of rice intensification (SRI) first developed in Madagascar and now being tested in many countries including 14 in Asia, is an example of a land and water productivity-enhancing approach. The components or elements that constitute SRI practice are:[3] (1) transplanting an 8–15- day-old rice plant within 15–30 min of uprooting at wider spacing than usual; (2) reducing the use of inorganic fertilizer and increasing the use of organic matter; (3) using a mechanical weeder instead of herbicide; and (4) avoiding the usual practice of flooding of rice fields and reducing the amount of water used in the paddy cultivation process. Some proponents claim that SRI will revolutionize the method of rice production, while others see it as a fad. For instance, in Thailand and Laos, the SRI effect has not been seen as dramatically as in other countries such as Cambodia, Myanmar, Indonesia, the Philippines, India and China.

Yield and productivity advantages of SRI are often cited (see Table V and Figure 5). In addition, SRI can result in about 90% savings in seed, reduced demand for agrochemicals, less risk of lodging, improved seed quality and milling ratio, reduced date of maturity and more straw yield (Namara *et al.*, 2003; Sinha and Talati, 2004).

Table V. Comparison of yield between SRI and conventional method of rice production

Item	Paddy yield (kg ha^{-1})			Straw yield (kg ha^{-1})		
	SRI	[a]*N*	Conventional	*N*	SRI	Conventional
Farmers' report (India)	5267	106	3995	106	5068	3368
Farmers' report (Cambodia)	2289	400	1629***	100	—	—
Farmers' report (Sri Lanka)	5524	60	3836**	60	—	—
Actual measurement (India)	5713	40	4398**	40	5535	3743***
Actual measurement (Sri Lanka)	6365	12	4,778*	12	—	—

*, **, ***, means the yield differences are significant at 10%, 5%, and 1% level of probability.
[a]Sample size.
Sources: Sinha and Talati (2004); Namara *et al*. (2003); Anthofer (2004).

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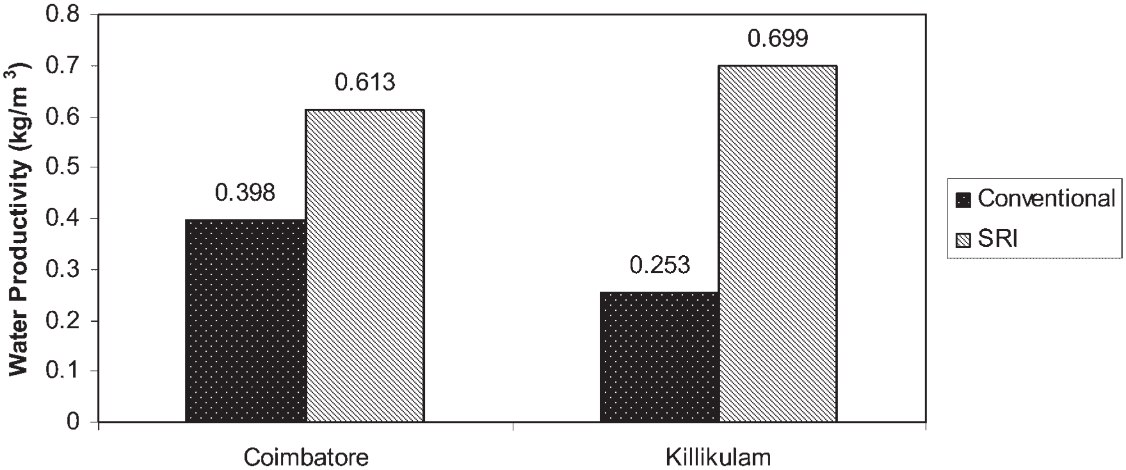

Figure 5. Water productivity comparisons (Source: Thiagrajan *et al*., 2002; Jothimani and Thiagrajan, 2005)

Studies in Sri Lanka, Cambodia and India show that SRI is economically viable and improves the factor productivities of land, water, labour and capital (Table VI).

It also has positive environmental externality as it significantly reduces the demand for agrochemicals. However, the rate of adoption of the system varies from country to country. It is increasingly popular in some states of India and Cambodia. The constraints to the adoption of SRI are context-specific; however, the following are often cited: labour shortage, availability of organic fertilizer, reliability of irrigation water supply, lack of consensus and divergent views about the potential of the system and its scientific basis.

Is SRI equally appealing to all groups of farmers including the poor? There is no unanimous answer to this question. However, a study from Sri Lanka indicated that SRI is more likely to be adopted by rich and poor farmers than the middle farmers (Figure 6). This can probably be explained by the labour intensity of SRI. Poor farmers with low landholdings often have excess labour at their disposal and find SRI attractive by virtue of its low cash intensity. The rich, in conditions where labour markets exist, can hire labour. In central India's tribal homelands, and in similar conditions – where paddy cultivation is central to rural livelihood systems, where land productivity is abysmally low, and where labour is the biggest asset of the poor tribal farmers – SRI holds out a big promise that needs to be vigorously explored (Phansalkar and Verma, 2005).

Alternate wetting and drying or intermittent irrigation. In response to the increasing scarcity and competition for fresh water, many Asian countries are currently experimenting with methods for reducing the irrigation water used for producing rice. One such practice is the alternate wet and dry irrigation (AWDI) method. In this system of irrigation, rice fields are not kept continuously submerged but they are allowed to dry intermittently

Table VI. Economics of the SRI vis-à-vis convention system of rice cultivation

Country	Net benefits		% increase
	SRI	Conventional	
Cambodia*	209	120	74.2
Sri Lanka	162	80	102.5
India*	139	82	69.5

*The figures for Cambodia and India are gross margins, i.e. returns over variable costs.
Source: Namara *et al*. (2003); Anthofer (2004); Sinha and Talati (2005).

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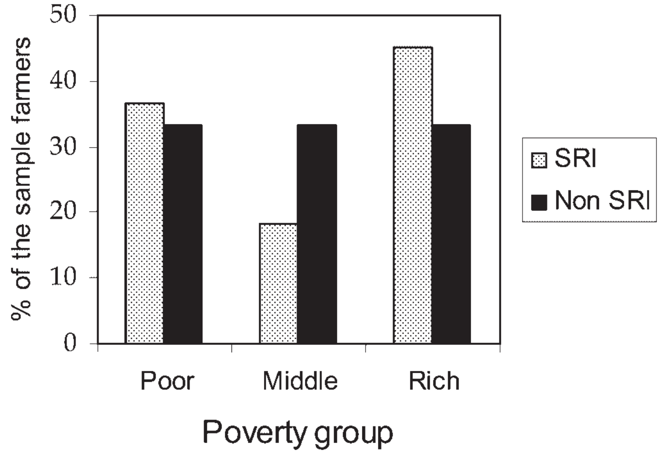

Figure 6. An assessment of the poverty outreach of SRI among Sri Lankan farmers

beginning 30 days after transplanting and farmers irrigate only when their fields are either just saturated (no standing water) or dry (Moya *et al*., 2001).

Research on irrigation water-saving techniques in general and AWDI in particular, has been done in China, India and Indonesia in response to sharp increases in the demand for water for industry, domestic, hydropower generation and agriculture (Li, 2001; van der Hoek *et al.*, 2001; Belder *et al*., 2002; Gani *et al*., 2002). The major conclusions from these experiments is that higher or comparable rice yields could be obtained without continuously flooding fields (Table VII), with the additional advantages of energy saving, nutrient use efficiencies and controlling vectors of malaria and Japanese encephalitis.

Even though the yield effect of AWDI is not that substantial, its economic significance to farmers could be considerable. For instance, in some regions of China the farmers who adopt it were able to work for longer in cities because the irrigation interval is longer and the irrigation events are less. Moreover, AWDI resulted in low irrigation duty.

Until recently, however, the idea of AWDI was not widely accepted by the irrigation community. Traditional concepts and habits, a high risk of lodging with AWDI and lack of training and guidance slowed the adoption process (Moya *et al*., 2001). In China, water-saving irrigation systems including AWDI techniques have been applied on more than 3.5 million ha of rice fields. Such systems are now also becoming a standard management practice in certain irrigation systems of India. However, application of AWDI systems needs a sound irrigation system and reliable water supply. In the advent of supply uncertainty, farmers may be reluctant not to flood their paddy fields when water is available.

Aerobic rice cultivation. Unlike the practices discussed above, which are mainly based on agronomic and water management principles and the use of mechanical technologies, the concept of aerobic rice cultivation is

Table VII. Land and water productivity impacts of AWDI

Country	Water saving	Yield improvement	Source
India	10–77%	20–87%	Van der Hoek *et al.* (2001)
India	56%	4.7%	Thiagrajan *et al*. (2002)
China	27–37%	4–6%	Shi *et al*. (2002)
China	13–16%	Ns	Belder *et al*. (2002)
China	80–90 mm	1–25%	Cabangon *et al*. (2001)

Ns = no significant yield difference.

DOI: 10.1002/ird

Table VIII. Land and water productivity of aerobic and lowland rice varieties in northern China

Data source	Cropping pattern	Rice type	Yield (t ha^{-1})	Irrigation water productivity (grain kg^{-1} water)
On-station experiment	Single rice	Lowland rice	7.5	0.5
	Single rice	Aerobic rice	6.0	1.6
	Wheat–rice	Lowland rice	7.5	0.6
	Wheat–rice	Aerobic rice	5.3	2.3
On-farm experiment	—	Aerobic rice	5.2	1.8
	—	Lowland rice	7.5	0.6

Source: Huaqi *et al*. (2002).

based on improving the genetic potential of the rice plant to grow in aerobic soil conditions. Aerobic rice varieties are specifically suited to uplands, where rice is sown in non-puddled fields, without bunds, without irrigation, and without pounded water. In this environment water is the major yield-limiting factor and the farmers are among the poorest.

On-station and on-farm trial results from northern China indicate that even though newly developed aerobic rice varieties yield about double that of traditional upland rice varieties, they still produce 20–30% less than lowland varieties grown under flooded conditions (Table VIII). However, the advantage is found in the irrigation water productivity of aerobic rice varieties, which is considerably higher than that of lowland varieties. Consequently, the net economic returns per ha to aerobic rice cultivation is lower but the net returns per unit of water used is twice as high as that of lowland rice. Thus, aerobic rice is an attractive alternative to lowland rice in areas where water is the limiting factor such as northern China and eastern India.

In China, there is an estimated area of 190 000 ha of land under aerobic rice cultivation (Huaqi *et al*., 2002). However, a concerted research effort is still needed to make aerobic rice varieties a viable alternative to the traditional upland varieties. Many problems such as weeds, insects and rat damage may also need to be tackled to enhance aerobic rice varieties adoption among the target farmers (Castaneda *et al*., 2002).

CONCLUSIONS AND IMPLICATIONS

The technologies and systems of production presented here are under research in many countries of Asia. Results from experimental studies and farmers' experiences have shown their potential benefits for the adopting farmers and society in general. First, they either significantly improve crop yields or give equal yields relative to conventional systems or technologies. Second, they enhance field-level water productivity. Third, some of the systems reduce the cost of production due to savings in seed, fertilizers, pesticides, fuel, etc. Fourth, they contribute to household food and nutritional security. This is particularly true for low-cost micro-irrigation technologies that enable farm families to grow vegetables, otherwise either missing in their normal diet or needed to be bought from the market. Fifth, they have positive environmental externalities such as reduced pollution of groundwater, reduced greenhouse gas emissions, reduced erosion, etc. Sixth, they have positive human health effects directly through improvements in nutrition and indirectly through effects on human diseases. Seventh, some of the technologies (e.g. the system of rice intensification) reduce risk to farmers. Lastly, they may spur further investment and employment opportunities in the area.

The potential benefits of these innovative land, crop and water management practices and technologies can only be realized if they are adopted in practice over the spectrum of farmers, i.e. poor and rich farmers alike. Some of the technologies are scale neutral (resource-conserving technologies) and may even self-select the poor (the system of rice intensification). Some of them can be redesigned to make them pro-poor (e.g. micro-irrigation technologies). Others, such as resource conservation technologies, can be made more pro-poor through efficient institutional arrangements or efficient rental markets for the much-needed machinery for their successful adoption.

DOI: 10.1002/ird

The nature of the adoption constraints to wider dissemination of these systems and technologies could be specific to each and every one but also there are general ones that are applicable to all. Empirical studies have shown the following to be some of the adoption constraints: labour shortage, organic fertilizer availability, irrigation water supply uncertainty, crop specificity, complexity, capital intensity (Namara *et al*., 2003; Sangar *et al*., 2004), demand knowledge and technical skill of farmers, market access and marketing efficiency (Shah and Keller, 2002). These technologies bring about completely new dynamics into farming systems, demanding significant change from the business-as-usual scenario and therefore require high management skill and a learning process on the part of farmers.

To further unlock the potential benefits of these innovative systems and technologies, the following actions are suggested: (1) initial targeted subsidy schemes for the poor; (2) targeted training opportunities for the poor to enhance their skill and knowledge so that they can cope with the complexities of the systems; (3) encouraging private participation in the supply chain of the needed inputs for the systems (e.g. machines, implements and tools) or establishing an integrated services provision (ISP) system along the lines suggested by Hussain and Perera (2004); (4) focus on developing low payback period technologies; and (5) strengthened public research on the systems for further improvement.

Wider adoption opportunities may come from larger-scale interests, such as irrigation system or basin priorities, or public health, that drive policy decisions with respect to promotion of technologies. If these driving forces are combined with knowledge of how to better target the poor in design and dissemination, there is great potential.

NOTES

[1] An example of this transformation can be seen in the widespread popularity of *Pepsee* systems in central India. For details about *Pepsee* systems and their adoption and spread, please see Verma *et al*. (2004).

[2] The sample farmers were divided into quintiles (i.e. very poor, poor, middle, rich and very rich) based on a poverty score assigned to each of the sample households, which in turn was derived from the household's asset positions, level of income, socio-economic characteristics and demographic structures, etc. These household characteristics were pooled together using principal component analyses to assign a unique poverty index to each household. The lower the score, the poorer the household relative to all others with higher scores.

[3] For descriptions and definitions of SRI see http://ciifad.cornell.edu/sri/index.html

ACKNOWLEDGEMENTS

The authors would like to acknowledge the anonymous reviewer of the paper.

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