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Agricultural Technology Choices for Poor Farmers in Less-Favored Areas of South and East Asia

John Pender

Environment and Production Technology Division

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE.

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ABSTRACT

During the past several decades dramatic improvement has occurred in agricultural productivity and livelihoods in South and East Asia, stimulated by the Green Revolution and supported by several other factors. Nevertheless, hundreds of millions of rural people in less-favored environments of this region still live in poverty and received limited benefit from the Green Revolution. To address these problems, alternative technological approaches to the conventional Green Revolution technologies are being advocated to address the problems of poor farmers in less-favored areas of Asia, including low external input and sustainable agricultural approaches, organic agriculture and biotechnology. This paper reviews the literature on agricultural technology options in South and East Asia, drawing conclusions concerning technology strategies to reduce poverty among poor farmers in less-favored areas of this region.

Among the main conclusions of the review are the following:

1. There is no technology approach that will work in all of the diverse circumstances of South and East Asia.
2. It is difficult, but not impossible, to identify and promote technologies that will substantially improve the livelihoods of poor people in less-favored areas.
3. Key requirements for technologies to be taken up by farmers and to have a substantial impact on reducing poverty are that the technology is profitable in a relatively short period of time; does not substantially increase risks; and is consistent with farmers' endowments of knowledge, management skill, land, labor, and other assets.
4. New technologies, by themselves, are not sufficient to bring about sustainable rural development and elimination of rural poverty, although they can have a major impact. Effective institutions and a stable and supportive policy environment are also critical.
5. Effective farmers' organizations accountable to poor farmers are a critical need for the success of all technologies in reaching the poor. Such organizations are needed to reduce the costs and improve the effectiveness of technical assistance efforts for all technologies, and are particularly important for technologies that require effective collective action and for increasing smallholders' access to markets for organic and other high value products.
6. Improved methods of technology dissemination are needed to reach poor farmers in less-favored areas. Top down technology transfer approaches that worked well with simple technology packages do not work as well with complex technologies that have to be adapted to local circumstances based on agro-ecological principles and local conditions.

These lessons should give pause to advocates one particular technological approach as the solution for poor farmers in less favored environments of Asia and elsewhere. What farmers need are not technology dogmas but options that can work in their context, combining what is useful from different approaches. This requires a pragmatic approach to learning what works well where and why. In pursuit of such pragmatic options for farmers, research and development programs should not ignore the potentials of traditional farming practices or intensive Green Revolution type technologies, which are well suited to farmers' needs in many contexts.

Key Words: agricultural technologies, low-external input and sustainable agriculture, organic farming, biotechnology, less favored areas, rural poverty, South and East Asia

ACKNOWLEDGMENTS

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1. INTRODUCTION

During the past several decades, dramatic improvement in agricultural productivity and reduction in poverty has been achieved in many of the countries of South and East Asia, stimulated by the success of the Green Revolution and supported by policy reforms, stable macroeconomic conditions, public investments in infrastructure, education and other services, and other factors. Poverty rates have declined dramatically throughout much of this region, and the absolute number of poor also declined in East Asia despite continued rapid population growth. Between 1975 and the early 2000s, the number of poor people from 680 million to 258 million in China and Southeast Asia, and from 470 million to 449 million in South Asia, despite rapid population growth (ADB 2000; ADB 2004).

Despite this progress, hundreds of millions of rural people in less favored environments – areas where rainfed agriculture dominates and that are subject to critical biophysical constraints such as low and uncertain rainfall, steep slopes and poor soils, and/or socioeconomic constraints such as poor access to markets, infrastructure and services – obtained much less benefit from this progress. Poverty rates are still high in many of these areas, productivity growth is slow and in many such areas declining due to land degradation resulting from deforestation, overgrazing of livestock, and increased production on marginal soils with declining use of fallow, limited use of soil and water conservation measures, and limited use of organic or inorganic sources of crop nutrients in many such areas. At the same time, productivity growth has slowed in many irrigated and favorable rainfed agricultural areas as a result of diminishing returns from conventional technologies in these areas and natural resource degradation problems, including salinization, waterlogging and compaction of soils, soil nutrient deficiencies, groundwater depletion, and others. Negative environmental and health consequences have also resulted from the heavy dependence on agricultural chemicals.

As a result of these problems, alternative technological approaches are being advocated, particularly for poor farmers in less favored areas. Among such approaches are low external input and sustainable agriculture (LEISA) approaches, organic agriculture, and biotechnology. The purpose of this paper is to assess the potential of these technology approaches to help improve productivity and natural resource management and reduce poverty in less-favored areas of South and East Asia, and to provide recommendations concerning technology strategies to reduce poverty among poor farmers in these areas.

The paper is organized as follows. In the next section, the setting of agriculture in the South and East Asia and Pacific (SEAP) region is described, considering the biophysical and socioeconomic conditions in different countries and agroecologies, and the common farming systems and cropping patterns found across these domains. The third section reviews the history of agricultural development in the region since the start of the Green Revolution and the problems that have arisen which are stimulating pursuit of alternative technology approaches. The fourth section reviews the literature related to LEISA technologies, organic agriculture, and biotechnology, considering available evidence of adoption and impacts of these approaches, farm and community level constraints and policy and institutional issues affecting adoption and impacts, focusing on poor farmers in less favored areas, and the prospects for the future. The final section offers conclusions and recommendations.

2. AGRICULTURE IN SOUTH AND EAST ASIA

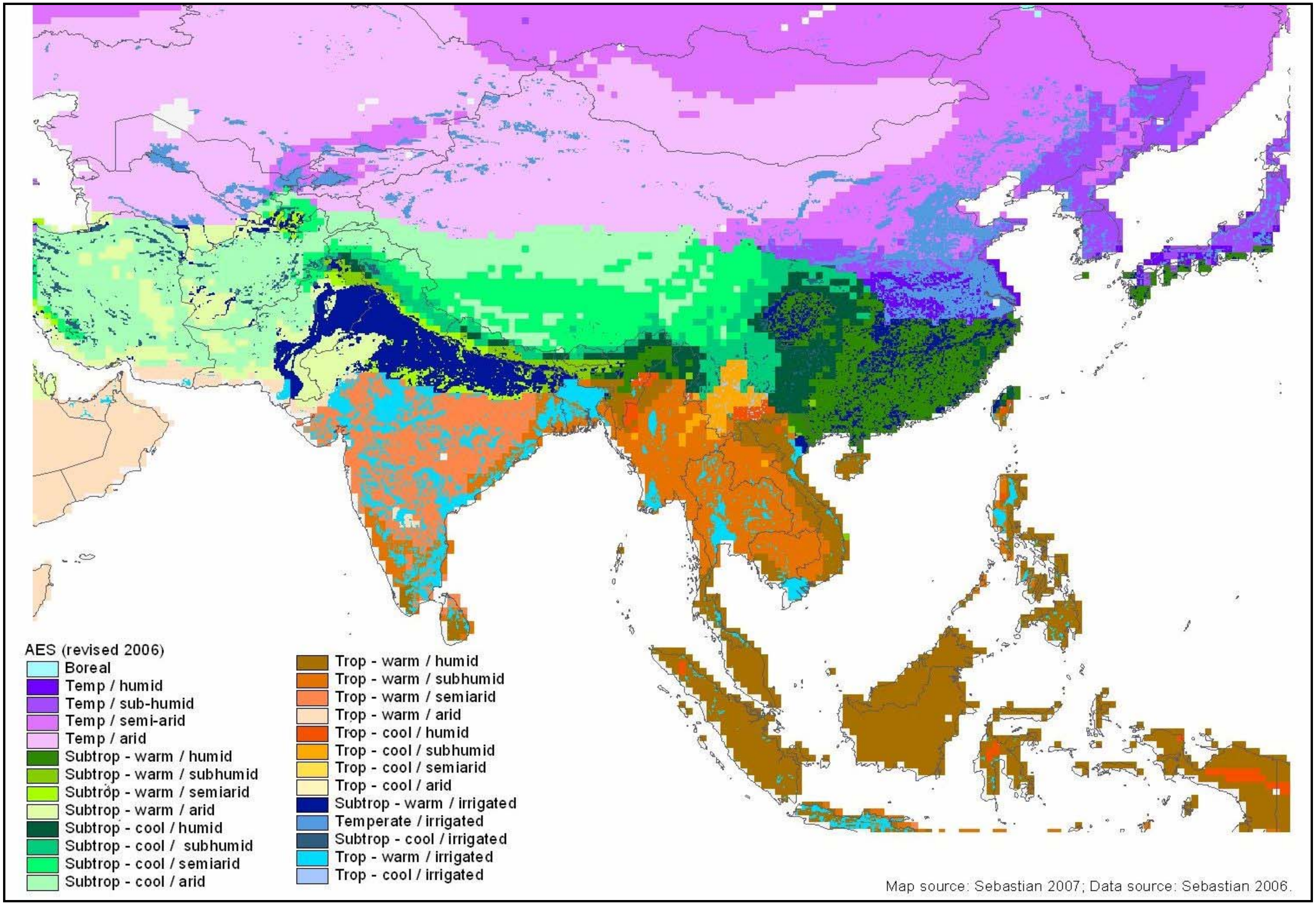
The farming systems in South and East Asia are diverse, as a result of the large diversity in biophysical and socioeconomic environments in this region.

Biophysical Context

The climate in the South and East Asia and Pacific region (SEAP) ranges widely from the warm humid and subhumid tropical climate predominating in the southeastern and southernmost portions of the region, including most of the Philippines, Indonesia, Malaysia, Thailand, Vietnam, southeastern China, Laos, Cambodia, Myanmar, Bangladesh, Sri Lanka and parts of southern and eastern India; to the semi-arid and arid subtropical regions of western India and Pakistan; to the cooler temperate arid and semi-arid zones of western and northern China and Mongolia, to the cold mountain climate of the Himalayas in northern India, Nepal, Bhutan and southern China (Figure 1).[1]

[1] Agro-ecological zones (AEZ) are defined by FAO based on the average annual length of growing period for crops, which depends on precipitation and temperature. The length of growing period is greater than 270 days in the humid zone, 180 to 269 days in moist subhumid zone, 120 to 179 days in the dry subhumid zone, 60 to 119 days in the semiarid zone, and less than 60 days in the arid zone (Dixon, et al. 2001).

Figure 1. Agro-ecological zones in South and Southeast Asia and the Pacific



These variations in climate are largely determined by the latitude and altitude gradients, with cooler climates further north and at higher elevations, and drier climates in the rain shadow to the north and west of the Himalayas. The variability of rainfall is greatest in the drier zones, especially in western China, Pakistan, western and parts of southern India (Figure 2). These are among the most marginal and high risk areas for rainfed agriculture in the region, although there is highly productive irrigated agriculture in the Indus River valley in northwestern India and eastern Pakistan. Most of the Himalayan mountain region of southern China and parts of Nepal and northern India (except in valleys at lower elevations) is also climatically unsuited to agriculture.

The rugged terrain and steep slopes of the Himalayan foothills and steeply sloping upland regions elsewhere are also a major constraint to agriculture in large parts of the region (Figure 3). As a result of steep slopes, intensive rainfall, and land use practices, soil erosion is severe in upland regions of the Philippines, central and eastern China, Vietnam, and large parts of India (Figure 4). Soil erosion (mostly water erosion, but also wind erosion in some areas) is assessed to have had strong to extreme negative impacts on about one third of the agricultural land in the SEAP region (Wood, et al. 2000).

Other forms of soil degradation are also severe in large parts of the region, including chemical degradation (soil fertility depletion, loss of organic matter, acidification, salinization/alkilinization, and pollution) in the southeastern region (especially in Thailand, Cambodia, and Vietnam) and parts of India, and physical degradation (compaction, crusting and sealing, waterlogging, lowering of the soil surface, and aridification) in large parts of eastern China and Bangladesh (van Lynden and Oldeman 1997). Beyond their susceptibility to degradation, the soils in most areas are subject to natural constraints, such as low inherent nutrient status, shallow depth, low moisture holding capacity, acidity and others (Wood, et al. 2000). Only a relatively small portion of the region is considered free of soil constraints to agricultural production (Figure 5), with these more favorable soil conditions being most common in fertile alluvial plains such as the Indo-Gangetic plain.

Figure 2. Variability (coefficient of variation) in length of growing period

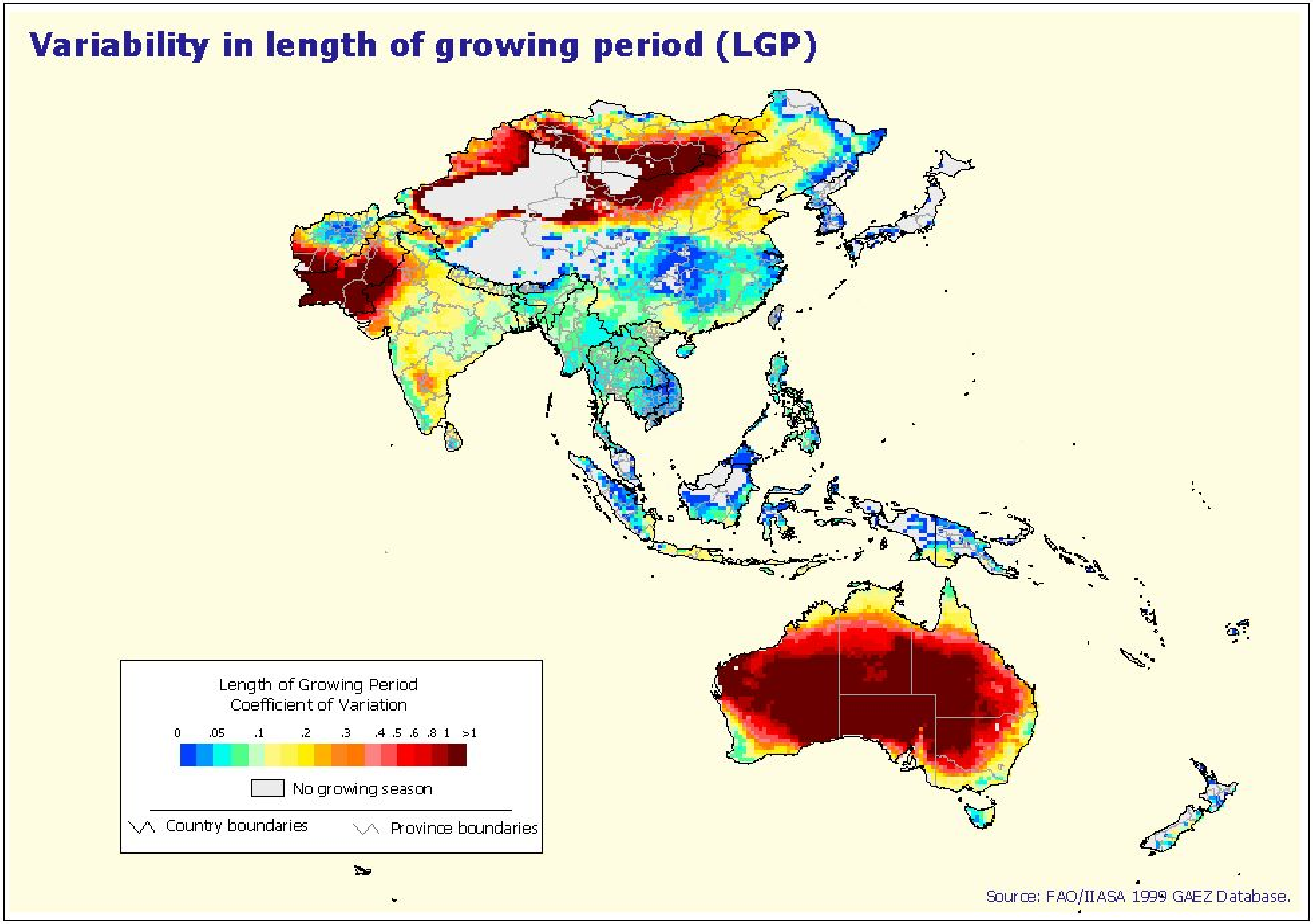


Figure 3. Terrain

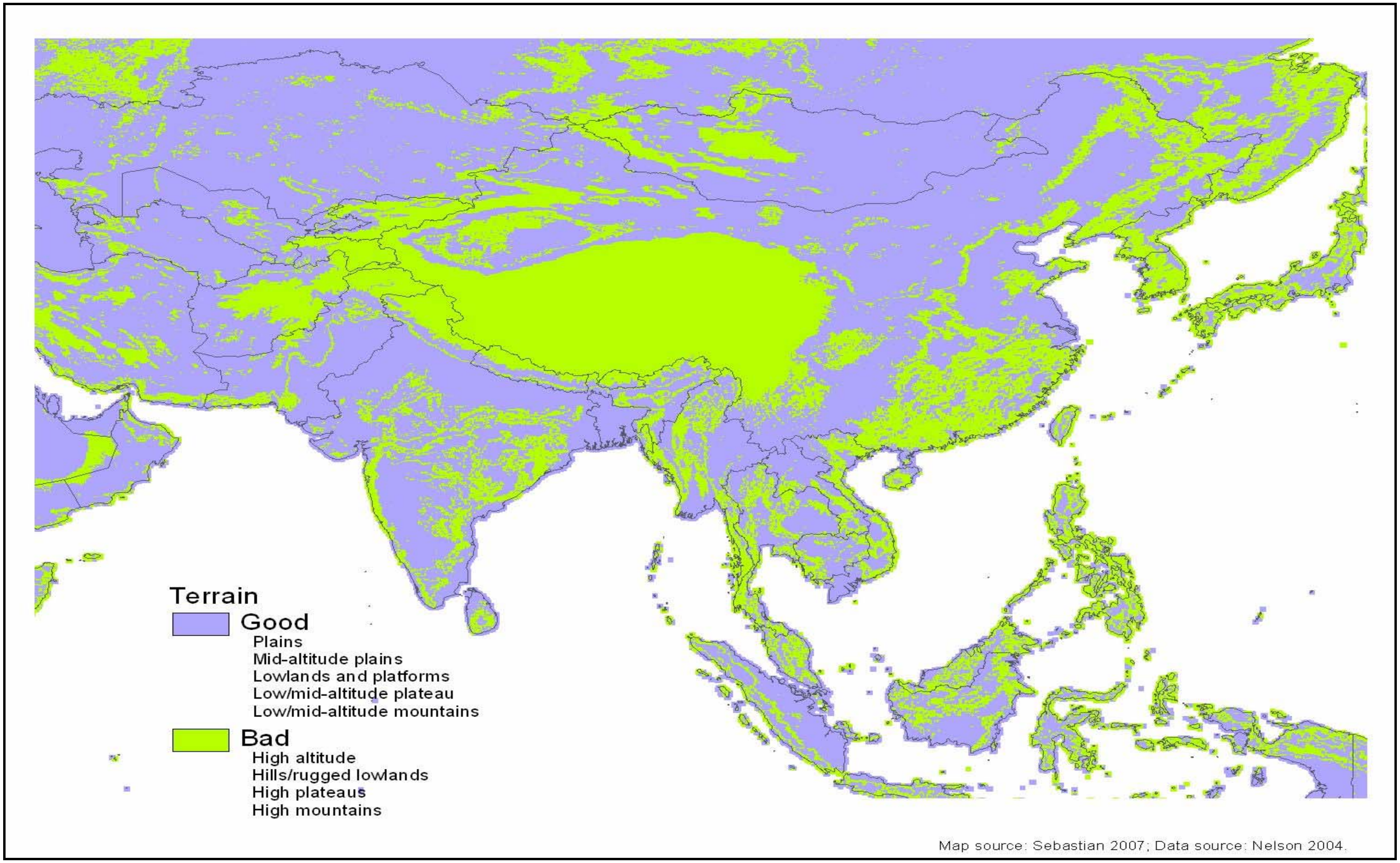


Figure 4. Soil degradation

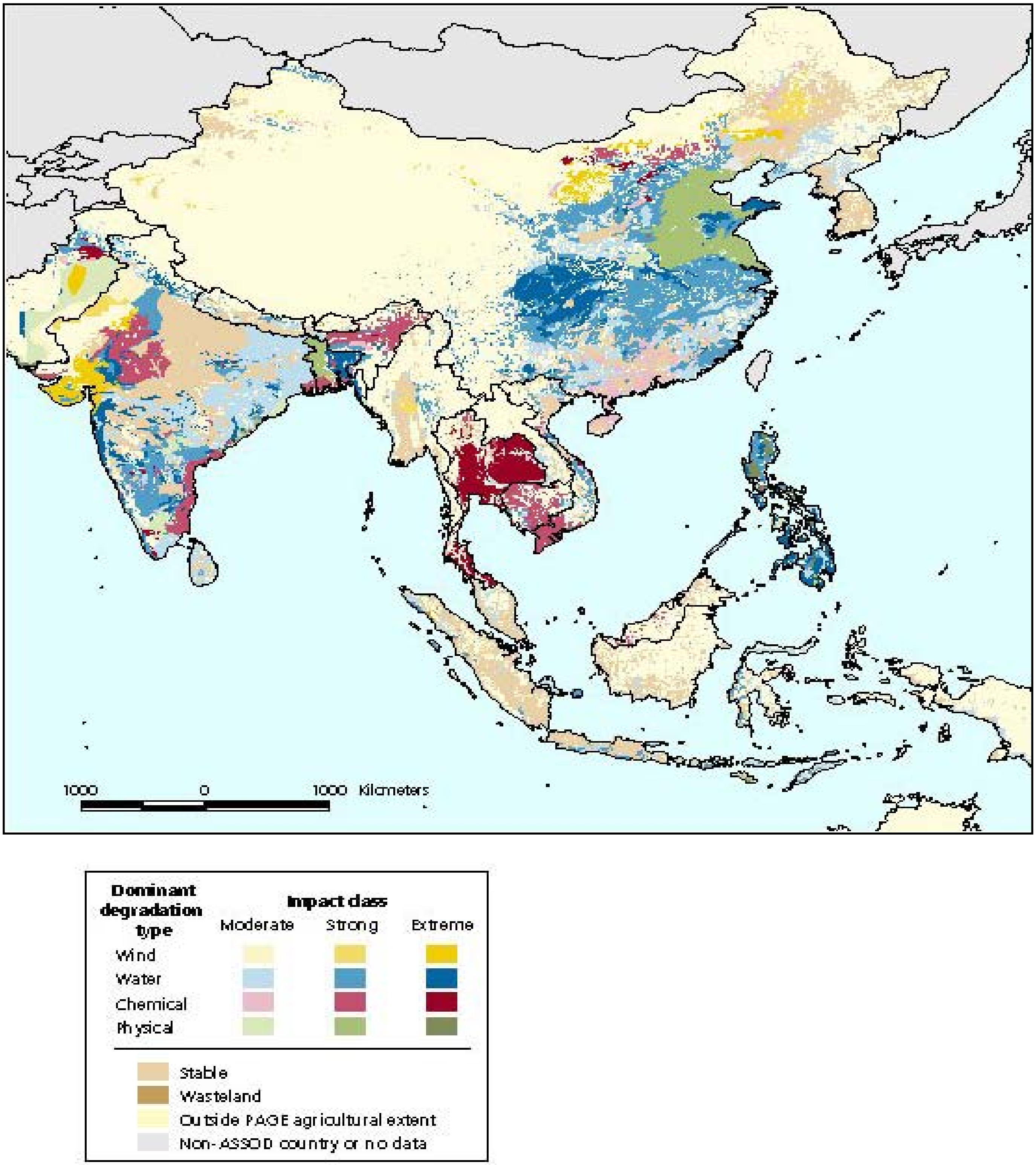
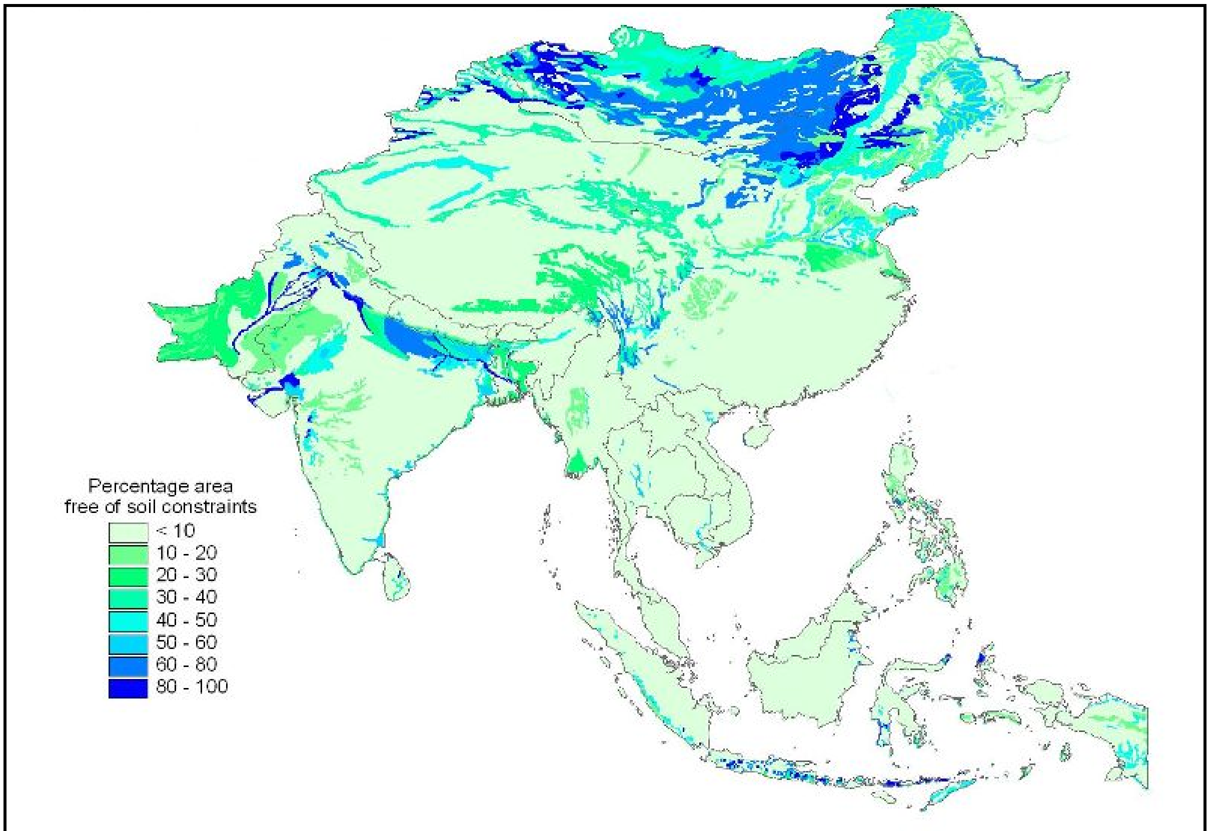


Figure 5. Area free of soil constraints



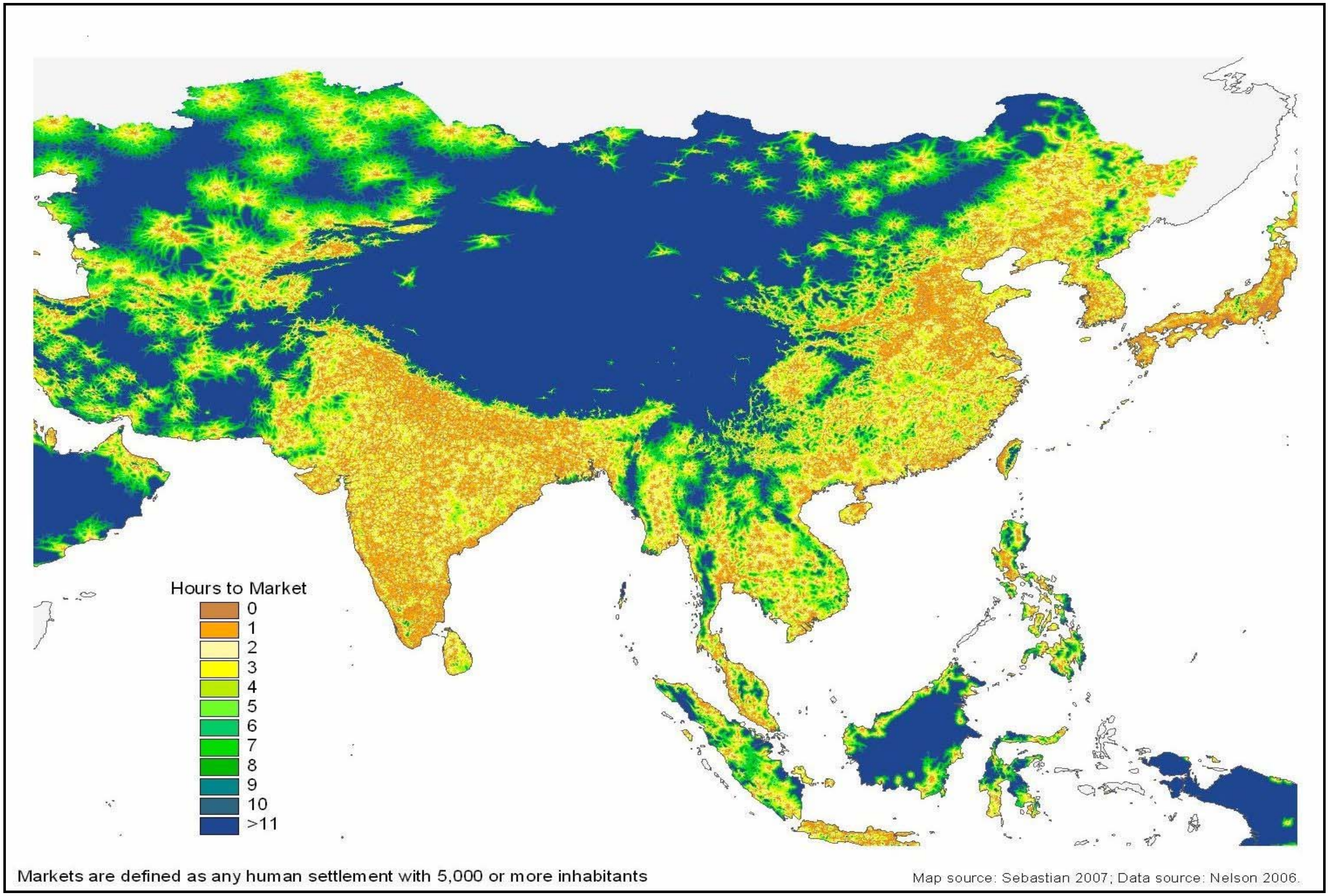
Source: Wood et al. (2000) based on FAO Soil Map of the World (FAO 1995) and the fertility capability classification (FCC: Sanchez et al. 200?).

Socioeconomic Context

The agricultural options available to farmers also depend to a great extent on socioeconomic conditions, such as access to infrastructure and markets, population density, poverty, and policies and institutions. Among the most important factors is access to irrigation, which was an essential component of the Green Revolution. Irrigated agriculture is prominent in northern India and western Pakistan, much of the rest of India, Bangladesh, eastern China, and significant areas of Myanmar, Thailand, Vietnam, the Philippines and Indonesia (especially in Java) (Figure 1). Paddy rice is the dominant crop in the irrigated (as well as rainfed lowland) areas of Southeast Asia, while rice and wheat are the dominant irrigated crops in South Asia.

Urbanization, access to urban markets, ports, roads and other infrastructure determine the market opportunities available to farmers. The pace of urbanization and industrial development in the SEAP region is unprecedented, and this is creating rapidly growing and diversifying markets for agricultural commodities in the region. Access to urban markets is relatively favorable throughout much of India, Bangladesh, Sri Lanka, eastern China, Thailand, Malaysia, the Philippines, Java (Indonesia), and in parts of the other countries (Figure 6). Some of these areas (i.e., in coastal zones) also have favorable access to ports and hence to export opportunities.

Figure 6. Access to markets



Rural population density also influences market opportunities as well as production conditions. More intensive agricultural practices (especially labor intensive practices) are generally found in more densely populated rural areas as a result of small farm sizes and the high labor to land ratio in these areas (Boserup 1965; Ruthenberg 1980). The rural population density is quite high (greater than 200 persons pr square km.) throughout large parts of the region, especially in eastern China, much of India, western Pakistan, Bangladesh, Sri Lanka, and parts of other countries (e.g., Java in Indonesia). Such high levels of rural population density imply that average farm sizes are quite small in these regions, typically no more than one or two hectares (Dixon, et al. 2001). In general, rural population density is higher in areas of greater agricultural potential and urban market access.

Agricultural opportunities and farming systems are also influenced by a host of other factors, including especially access to science and technology, government policies, market and land tenure institutions, development of human capital, local organizational development, and others (Dixon, et al. 2001; Pender, Ehui and Place 2006). We discuss recent changes in several such factors, most of which are more dynamic in nature than the contextual factors discussed above, in Section 3 of the report.

Less Favored Areas

Pender and Hazell (2000) define less favored areas as areas that are limited in potential for agricultural production due to biophysical constraints such as low and uncertain rainfall, steep slopes or poor soils; or that face socioeconomic constraints such as poor access to markets and infrastructure (or both). Considering favorable areas as those having both favorable market access (as defined in Figure 6) and that either have access to irrigation or are in humid or subhumid rainfed areas in relatively favorable terrain for agriculture, we estimate that only 15 percent of the area of the SEAP region is favored, while 85 percent is less favored (Tables 1 and 3).[2]

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[2] These estimates are based on overlaying the agroecological zones shown in Figure 1, terrain zones in Figure 3 and the market access zones shown in Figure 6 (classifying areas within 2 hours of an urban market to be high access areas) within a Geographic Information System (GIS), and calculating the areas of each domain of agroecology, terrain and market access within each country and for the region as a whole. The population share within each domain (reported in Table 2) was estimated by overlaying the map of rural population density from the Global Rural-Urban Mapping Project on these domains using the GIS.

Table 1. Percent of area of each country and SEAP region by AEZ and market access

AEZ class	Market Access	Bangla-desh	Bhutan	Cambo-dia	China	India	Indone-sia	Laos	Malaysia	Mongolia	Myanmar	Nepal	Pakistan	Philip-pines	Sri Lanka	Thailand	Vietnam	SEAP region
Irrigated - suitable terrain	**High**	59.9	0.1	2.3	5.9	28.2	2.2	0.7	0.5		3.0	9.6	20.0	6.2	7.6	11.1	12.0	**9.7**
	Low	7.0	0.6	0.8	3.0	2.4	0.9	0.5	0.0	0.0	2.3	2.2	5.3	1.3	4.0	2.3	3.9	**2.4**
Irrigated - less suitable terrain	**High**	1.1		0.1	2.7	4.6	1.5	0.2	0.3		0.4	3.2	0.5	5.3	2.8	2.5	2.8	**2.4**
	Low	0.1	0.3	0.0	1.5	0.7	0.4	0.1	0.0	0.0	0.3	0.9	0.4	2.4	1.2	1.0	0.6	**1.0**
Favorable rainfed - suitable terrain	**High**	15.8	1.6	26.9	4.3	6.4	6.7	7.7	13.6		9.0	4.3	0.9	5.1	19.6	22.5	7.3	**5.6**
	Low	7.0	28.4	39.4	9.3	5.3	56.8	65.3	33.4		48.0	24.6	2.4	24.9	15.8	24.2	35.0	**15.7**
Favorable rainfed - less suitable terrain	**High**	4.8	1.2	8.0	5.4	2.8	4.7	6.0	12.3		7.2	2.3	0.6	17.1	17.9	14.4	12.7	**5.0**
	Low	4.3	62.7	22.4	7.4	5.0	26.3	19.6	39.9		29.6	30.7	2.2	37.7	16.1	22.1	25.6	**10.8**
Semiarid rainfed - suitable terrain	**High**				3.1	19.2	0.0			0.6		2.6	0.6		8.5			**4.7**
	Low				9.0	4.4	0.2			25.5		8.5	1.5		6.5			**7.2**
Semi-arid rainfed - less suitable terrain	**High**				1.3	9.7	0.1			0.0		1.0	0.4					**2.2**
	Low		5.3		13.2	4.6	0.2			9.1	0.0	7.9	3.2					**8.0**
Arid rainfed - suitable terrain	**High**				0.1	2.5				1.5			4.7					**0.8**
	Low				15.5	3.1				54.5			39.0					**14.0**
Arid rainfed - less suitable terrain	**High**				0.0	0.3				0.1			1.6					**0.1**
	Low				18.4	0.8				8.6		2.2	16.4					**10.3**
Total	**High**	**81.6**	**2.8**	**37.3**	**22.8**	**73.7**	**15.2**	**14.5**	**26.6**	**2.2**	**19.6**	**23.0**	**29.4**	**33.8**	**56.4**	**50.5**	**34.9**	**30.5**
	Low	**18.4**	**97.2**	**62.7**	**77.2**	**26.3**	**84.8**	**85.5**	**73.4**	**97.8**	**80.4**	**77.0**	**70.6**	**66.2**	**43.6**	**49.5**	**65.1**	**69.5**

We classify areas within 2 hours of an urban market (population of 5,000 or more) to be high market access; areas further from urban markets as low market access.

Source: Sebastian (2007) based on data represented in Figures 1, 3, and 6.

Table 2. Percent of rural population of each country and SEAP region by AEZ and market access

AEZ class	Market Access[1]	Bangla-desh	Bhutan	Cambo-dia	China	India	Indo-nesia	Laos	Malaysia	Mongolia	Myanmar	Nepal	Pakistan	Philippines	Sri Lanka	Thailand	Vietnam	SEAP region
Irrigated - suitable terrain	**High[1]**	70.1	0.1	9.5	20.6	44.0	15.7	1.6	2.7		11.4	21.7	48.9	12.6	4.7	16.0	38.7	**31.6**
	Low[1]	7.8	1.3	1.8	8.3	2.7	2.5	1.1	0.1	0.1	6.8	4.8	8.7	1.3	2.1	2.8	5.7	**5.6**
Irrigated - less suitable terrain	**High**	0.8		0.5	7.7	4.7	11.3	0.4	1.1		1.2	7.7	1.1	7.3	2.1	2.9	7.8	**5.9**
	Low	0.1	0.2	0.0	4.4	0.6	1.3	0.2	0.1	0.0	0.6	1.2	0.4	2.2	0.7	0.8	0.9	**2.2**
Favorable rainfed - suitable terrain	**High**	15.0	3.4	56.2	8.4	9.1	19.7	12.6	32.1		20.3	5.5	2.3	7.6	22.8	31.4	7.7	**10.4**
	Low	4.3	46.1	17.0	14.2	3.4	22.5	54.8	20.6		26.4	25.4	4.8	13.7	13.3	17.0	12.5	**10.6**
Favorable rainfed - less suitable terrain	**High**	1.4	2.1	9.6	11.0	3.0	16.0	8.3	22.2		12.3	4.1	1.2	25.6	36.8	13.9	11.7	**8.2**
	Low	0.5	44.6	5.3	10.4	2.1	10.4	21.0	21.2		20.9	14.1	3.0	29.7	11.3	15.2	15.0	**7.7**
Semiarid rainfed - suitable terrain	**High**				3.8	16.5	0.0			2.8		3.2	0.6		4.1			**7.1**
	Low				4.7	2.9	0.3			46.4		8.0	1.6		2.2			**3.0**
Semi-arid rainfed - less suitable terrain	**High**				2.0	7.3	0.1			0.1		1.4	0.5					**3.3**
	Low		2.2		1.9	1.8	0.2			16.0	0.0	2.9	2.6					**1.5**
Arid rainfed - suitable terrain	**High**				0.0	1.0				1.2			4.3					**0.6**
	Low				1.8	0.6				24.8			12.4					**1.5**
Arid rainfed - less suitable terrain	**High**				0.0	0.2				0.7			0.9					**0.1**
	Low				0.9	0.0				8.0		0.1	6.6					**0.7**
Total	**High**	**87.3**	**5.6**	**75.8**	**53.4**	**85.9**	**62.8**	**22.9**	**58.0**	**4.7**	**45.2**	**43.6**	**59.9**	**53.0**	**70.4**	**64.2**	**66.0**	**67.2**
	Low	**12.7**	**94.4**	**24.2**	**46.6**	**14.1**	**37.2**	**77.1**	**42.0**	**95.3**	**54.8**	**56.4**	**40.1**	**47.0**	**29.6**	**35.8**	**34.0**	**32.8**

[1] We classify areas within 2 hours of an urban market (population of 5,000 or more) to be high market access; areas further from urban markets as low market access.

Source: Sebastian (2007) based on data represented in Figures 1, 3, and 6.

This definition of less-favored areas includes sloping uplands and mountain areas, semi-arid and arid rainfed areas, and areas with favorable biophysical conditions (i.e., with access to irrigation or humid/subhumid climate in flat terrain) that are remote from markets. Except for the last category (remote areas with favorable biophysical conditions), this definition of less-favored areas is consistent with the definition used by IFAD in its assessment of rural poverty in Asia and the Pacific region (IFAD 2002). This last category represents about 19 percent of the land area and 24 percent of the rural population of the SEAP region (Tables 2 and 3), and is included in the definition of less-favored areas because, as in the other categories of less-favored areas, the Green Revolution bypassed many of the farmers in these areas and problems of poverty are severe in many of these areas.

Table 3. Favored and less-favored areas by country and SEAP region

	Favored Areas		Less Favored Areas							
Country	**Irrigated or humid/subhumid, favorable terrain and market access**		**Poor access (otherwise favorable)**		**Semi-arid rainfed lands**		**Irrigated or humid/subhumid with unfavorable terrain (uplands and mountains)**		**Arid lands**	
	% area	% rural pop.	% area	% rural pop.	% area	% rural pop.	% area	% pop.	% area	%pop
Bangladesh	75.7	85.1	14.0	12.1	0.0	0.0	10.3	2.8	0.0	0.0
Bhutan	1.7	3.5	29.0	47.4	5.3	2.2	64.2	46.9	0.0	0.0
Cambodia	29.2	65.7	40.2	18.8	0.0	0.0	30.5	15.4	0.0	0.0
China	10.2	29.0	12.3	22.5	26.6	12.4	17.0	33.5	34.0	2.7
India	34.6	53.1	7.7	6.1	37.9	28.5	13.1	10.4	6.7	1.8
Indonesia	8.9	35.4	57.7	25.0	0.5	0.6	32.9	39.0	0.0	0.0
Laos	8.4	14.2	65.8	55.9	0.0	0.0	25.9	29.9	0.0	0.0
Malaysia	14.1	34.8	33.4	20.7	0.0	0.0	52.5	44.6	0.0	0.0
Mongolia	0.0	0.0	0.0	0.1	35.2	65.3	0.0	0.0	64.7	34.7
Myanmar	12.0	31.7	50.3	33.2	0.0	0.0	37.5	35.0	0.0	0.0
Nepal	13.9	27.2	26.8	30.2	20.0	15.5	37.1	27.1	2.2	0.1
Pakistan	20.9	51.2	7.7	13.5	5.7	5.3	3.7	5.7	61.7	24.2
Philippines	11.3	20.2	26.2	15.0	0.0	0.0	62.5	64.8	0.0	0.0
Sri Lanka	27.2	27.5	19.8	15.4	15.0	6.3	38.0	50.9	0.0	0.0
Thailand	33.6	47.4	26.5	19.8	0.0	0.0	40.0	32.8	0.0	0.0
Vietnam	19.3	46.4	38.9	18.2	0.0	0.0	41.7	35.4	0.0	0.0
SEAP region	**15.3**	**42.0**	**18.1**	**16.2**	**22.1**	**14.9**	**19.2**	**24.0**	**25.2**	**2.9**

Source: Author's calculations based on data in Tables 1 and 2.

Favored areas are more densely populated than less-favored areas, and contain 42 percent of the rural population in the region, even though they comprise only 15 percent of the area of the region, while 58 percent of the rural population lives in less-favored areas (Tables 2 and 3). Most of the favored areas are irrigated areas, mainly in India and China, but with significant areas in Bangladesh, Pakistan, Sri Lanka, Thailand and the Philippines. The remaining favored areas are mainly in the subhumid and humid lowland areas of Bangladesh, Sri Lanka and Southeast Asia.[3] The less favored areas are highly diverse, including the steeply sloping upland areas of the humid and subhumid zones of Southeast Asia and the Pacific, the Himalayas, the semi-arid and arid rainfed region of central and western India and Pakistan, the arid and semi arid regions of western China and Mongolia, and areas of poor market access in all agro-climatic zones and terrains. About one-fourth of the land in the SEAP region is in arid areas unsuited for agriculture, but less than 3 percent of the rural population lives in these areas.

Poverty in Less-Favored Areas

It is commonly believed that poverty is more severe in less favored areas than in favored areas, although the evidence for this has been questioned (Renkow 2000). In general, evidence is limited on the spatial distribution of poverty in most countries of Asia, although the evidence available indicates that a large portion of the poor live in less-favored areas. A large part of Asia's rural poor are concentrated in the hills and mountain regions of Bhutan, Cambodia, China, India, Indonesia, Laos, Myanmar, Nepal, Pakistan, Thailand, the Philippines, and Vietnam (IFAD 2002). Nearly one-fourth of Asia's 250 million absolute poor live in sloping areas, and the majority live in rainfed cropping areas (Ibid).

For India, Fan and Hazell (1999) report that 84 percent of the rural poor in 1993 lived in rainfed areas, and a more recent study (Fan, et al. 2003) found that the rural poor are increasingly concentrated in rainfed areas, with a relatively equal proportion in high

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[3] If soil constraints and degradation were taken into account, some of these favored areas could also be classified as less favored. For example, severe soil chemical degradation in otherwise favorable areas of Thailand and physical degradation in irrigated areas of eastern China (see Figure 3) likely reduce the productive potential of these areas.

vs. low potential rainfed areas. There is a high degree of variability in the incidence of rural poverty across states in India, ranging from 15 percent in Punjab to 66 percent in Bihar in 1993/94 (IFAD 1999). There is also substantial variation within states. For example, in Maharashtra poverty incidence ranges between 24 percent and 38 percent in the coastal and western regions to 62 – 66 percent in the northern and eastern regions (Ibid.). In the Himalayan belt, the largest increase in poverty between 1987/88 and 1993/94 occurred in West Bengal, followed by Assam Hills, Arunachel Pradesh and Manipur (Ibid.). Most of these areas are dependent on rainfed agriculture, some have suffered from political unrest and many contain a large number of ethnic minorities.

In Pakistan, the incidence of food-poverty in 1990-91 was highest in rural areas of the South Punjab region, in contrast to low poverty rates in the neighboring Punjab region of India (IFAD 2002). The high poverty in the Punjab region of Pakistan is attributable to highly unequal access to land, indicating that poverty is also affected by other factors besides agricultural potential and access to markets and infrastructure.

In China, poverty is far greater in the low potential remote upland areas (IFAD 2002). Almost all of the 65 million people officially recognized as income-poor in the late 1990s lived in remote and mountainous rural areas (UNDP 1997). Although the proportion of households below the national poverty line is less than 1 percent in urban areas of Beijing, Shanghai, Tianjin and Guangdong, it is 20 percent or more in Inner Mongolia and Qinghai (de Haan and Lipton 1998). One study found that more than 60 percent of the rural poor live in low-potential areas, and that the share of the national total living in such areas has increased since 1986 (Fan et al., 2002).

A poverty map for Vietnam based on a household survey conducted in 1992 and 1993 shows that poverty is concentrated in the northern uplands and in the northern part of the central highlands (Minot 2000). These are hilly areas far from large cities and the coast, and that have large ethnic minority populations. More recent evidence confirms that although poverty declined rapidly between 1993 and 2002 throughout Vietnam, poverty remains highest (with incidence of poverty above 50 percent) in the northwest and central highlands (Swinkels and Turk 2004). There was wide variation in poverty rates within poor provinces. For example, in the northern uplands region, poverty rates range from 6 percent in Quang Ninh to nearly 80 percent in Lai Chau. The incidence and depth of poverty in greatest among ethnic minorities in Vietnam (their poverty rate was nearly 70 percent in 2002), particularly those living in the northern mountains (Ibid). Among the key factors contributing to poverty in these upland regions, besides (but related to) less favorable agro-ecological conditions and poor access to markets and infrastructure, are small farm sizes, dependence on forest land and consequent land tenure insecurity, low education, limited access to health care, and low public spending on investments and services in these areas (Ibid.).

Recent poverty mapping work in Bangladesh found that the pockets of high poverty incidence coincide with ecologically poor areas, including the low-lying depression area (called *hoar*) in the northeast, the drought prone area on higher land in the northwest, several *upazila* (subdistrict administrative level) on the fringes of major rivers, and several of the southeastern *upazila*, including the Chittagong Hill Tract (Kam, et al. 2005). Despite the importance of some agro-ecological conditions in explaining poverty in Bangladesh (especially prevalence of highland, low or very low-lying land and heavy soils), socioeconomic factors, especially education, but also access to infrastructure (roads, irrigation and electricity) and landlessness are the strongest predictors of poverty (Ibid.).

In a study of poverty and environment linkages in Cambodia and Lao People's Democratic Republic, Dasgupta, et al. (2003) found a positive association (correlation = 0.30) between poverty incidence and areas with steep slopes across provinces in Laos, with high incidence of poverty especially in the northern upland region. In Cambodia, by contrast, poverty is concentrated more in flatter lowland areas (Ibid.).

In Indonesia, there is high concentration of poverty in Java, particularly in the limestone hills of Central and East Java (IFAD 2002). Poverty is also extremely prevalent on Madura in areas far from urban centers, and in fishing villages along the coast of West and East Java (Ibid.). In the Philippines, the incidence of poverty is 61 percent in the uplands compared to 50 percent in the lowlands (Ibid.).

Impacts of Investments in Less-Favored Areas

The work of Fan and colleagues has shown that many types of public investment in more marginal agricultural areas of India and China has a larger impact on poverty reduction than comparable amounts of investment in more favorable environments (Fan and Hazell 1999; Fan, et al. 2000; Fan, et al. 2004). In India, Fan and Hazell (1999) classified rural districts as either irrigated (if more than 25 percent of cultivated area was irrigated), high potential rainfed or low potential rainfed (based on their agro-ecological characteristics), and investigated the impacts of various types of investments (use of high yielding varieties (HYV's), education, and access to roads, markets, irrigation, and electricity) (Table 4).

Table 4. Impacts of investments in different areas of India

Investment	Units	Irrigated areas	High potential rainfed areas	Low potential rainfed areas
Impacts on value of agricultural production (1990 prices) per unit of investment				
HYV's	Rps/ha	63	243	688
Roads	Rps/km	100,598	6,451	136,173
Local markets	Rps/number	-276,745	7,808,112	-4,794,073
Canal irrigation	Rps/ha	938	3,310	1,434
Private irrigation	Rps/ha	1,000	-2,213	4,559
Electrification	Rps/ha	-546	96	1,274
Education	Rps/ha	-360	571	902
Impacts on rural poverty (persons lifted out of poverty per unit of investment)				
HYV's	Persons/ha	0.00	0.02	0.05
Roads	Persons/km	1.57	3.50	9.51
Local markets	Persons/number	-2.62	537.8	-313.7
Canal irrigation	Persons/ha	0.01	0.23	0.09
Private irrigation	Persons/ha	0.01	-0.15	0.30
Electrification	Persons/ha	0.01	0.07	0.10
Education	Persons/ha	0.01	0.23	0.01

Source: Fan and Hazell (1999)

For most investments (except access to local markets and canal irrigation), the impacts of a unit of investment on agricultural production and poverty reduction were largest in the low potential rainfed areas. Fan and Hazell (1999) argued that higher marginal returns to investments in lower potential zones was due to diminishing marginal returns to investments in the higher potential zones, where the levels of investment have been much higher. Using the same data and model as Fan and Hazell (1999), Fan, et al. (2000) conducted a similar analysis for more disaggregated rainfed zones (Table 5) (ranked in decreasing order of land productivity in Table 5), taking into account the costs as well as the impacts of the investments (enabling estimation of benefit-cost ratios of investments).

Table 5. Disaggregated impacts of investments in different zones of India

Zone	HYV	Roads	Canal irrigation	Electricity	Education
Impacts on agricultural production (rupees per rupee invested)					
Irrigated areas	4.64	26.80	2.76	0.86	0.22
Rainfed zones*					
1	0.00	38.38	4.90	1.18	0.10
2	26.14	8.29	6.27	10.02	1.54
3	7.50	102.83	3.17	5.15	0.09
4	0.00	29.94	3.63	0.80	2.50
5	0.86	37.88	2.19	1.28	0.86
6	12.87	135.85	3.51	1.09	1.07
7	29.80	100.47	6.96	4.44	0.94
8	0.41	137.28	7.81	4.28	2.41
9	5.30	82.53	1.95	2.92	10.55
10	9.21	9.14	0.14	6.90	6.76
11	0.02	2.57	2.53	0.16	11.93
12	10.67	50.88	2.71	5.78	1.10
13	0.00	113.29	0.00	31.42	12.37
Impacts on poverty (persons lifted from poverty per 1 million rupees invested)					
Irrigated areas	0.76	8.02	0.46	1.56	0.48
Rainfed zones*					
1	0.00	25.69	1.00	12.47	1.09
2	32.56	55.07	0.55	26.37	3.83
3	0.97	35.84	0.05	11.20	2.16
4	0.00	35.98	0.00	7.15	7.01
5	0.72	39.75	1.85	4.10	1.24
6	13.43	165.35	0.44	5.65	3.01
7	5.44	18.34	8.82	8.97	3.36
8	0.17	0.00	0.98	3.33	3.02
9	1.21	25.29	1.85	2.37	3.73
10	3.39	1.02	0.00	11.82	5.76
11	0.00	2.60	0.48	0.03	2.54
12	0.00	1.75	1.88	26.21	8.93
13	0.00	6.06	12.43	1.68	0.66

Notes: Returns are expressed in constant 1994 prices. HYV = high yielding variety; the number 0.00 indicates statistically insignificant or negative.
* Rainfed zones ranked by land productivity (1 = highest, 13 = lowest).

Source: Fan, et al. (2000)

They found very high benefit cost ratios for many investments (especially for investments in rural roads, with estimated B/C ratios exceeding 100 in many cases) in many zones, including several of the lower potential rainfed zones. Investments in rural roads in several low potential zones also had the largest estimated impacts in reducing poverty.

In a similar analysis using data from China, Fan, et al. (2004) estimated that marginal benefit/cost ratios exceed one for all investments considered (agricultural research and development (R&D), irrigation, roads, education, electricity, and telephone service), with B/C ratios as high as 12 (for education in coastal regions) (Table 6).

Table 6. Impacts of investments in different areas of China

Investment	Coastal	Central	Western
Impacts on total rural GDP (yuan per yuan invested)			
R&D	5.54	6.63	10.19
Irrigation	1.62	1.11	2.13
Roads	8.34	6.90	3.39
Education	11.98	8.72	4.76
Electricity	3.78	2.82	1.63
Telephone	4.09	4.60	3.81
Impacts on poverty reduction (no. of poor reduced per 10,000 yuan invested)			
R&D	3.72	12.96	24.03
Irrigation	1.08	2.16	5.02
Roads	2.68	8.38	10.03
Education	5.03	13.90	18.93
Electricity	2.04	5.71	7.78
Telephone	1.99	8.10	13.94

Source: Fan et al. (2004)

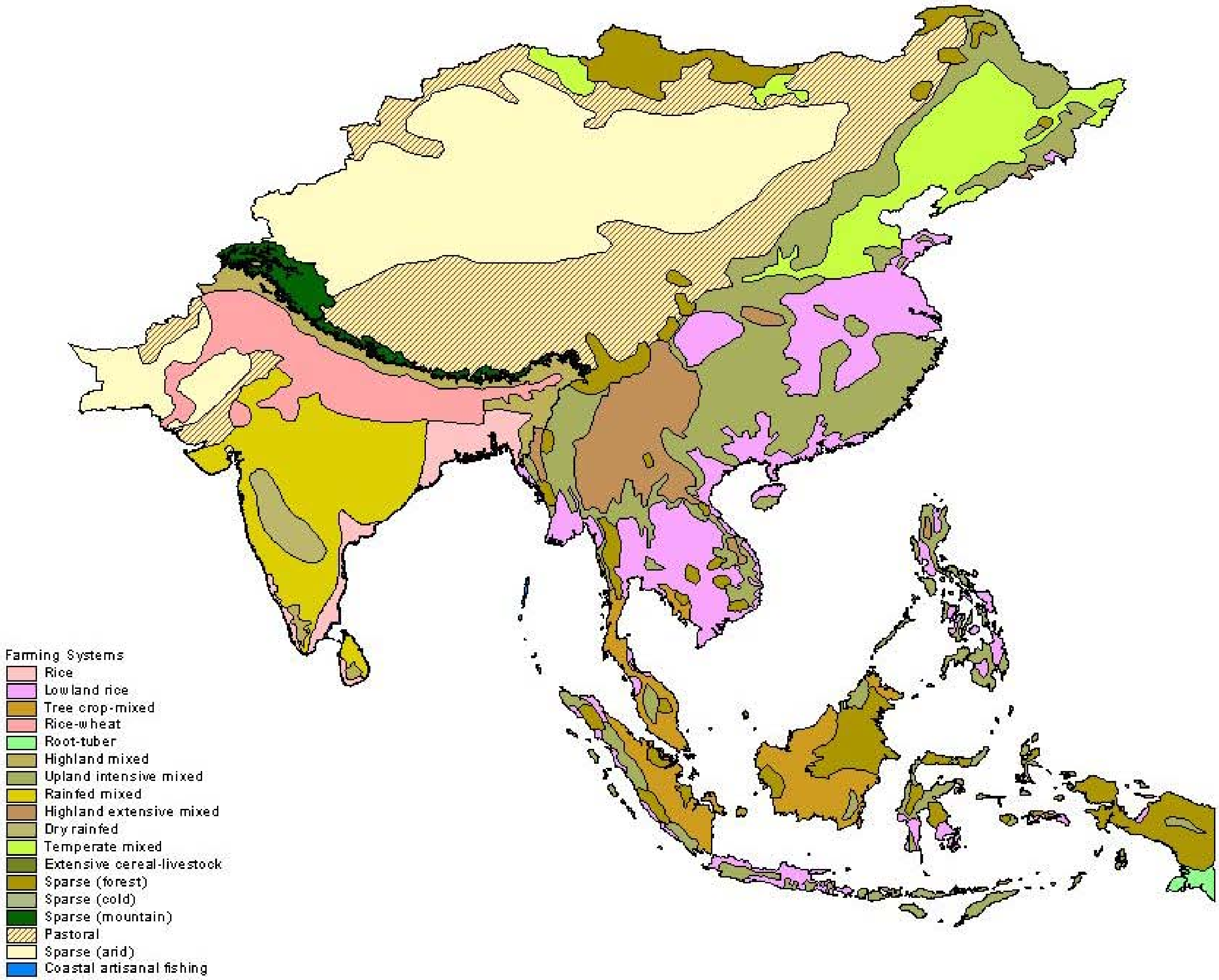
The pattern of returns varied across the regions of China, with the highest marginal returns to agricultural R&D and irrigation in western China, the highest marginal returns to investments in roads, education and electricity in the coastal region, and the highest returns to telephone service in the central region. The marginal impacts of all investments on poverty was greatest in the western region, however, because of the higher concentration of poverty and relatively limited amount of investment that has occurred in that region.

Thus, it is clear that there are large numbers of poor people in less-favored areas of these countries, and that investments in these areas may have more impact in reducing poverty than comparable investments in favored areas, even if the relative incidence and depth of poverty between favored and less-favored areas is not yet clear in most countries.

Farming Systems

As a result of the large diversity in agro-ecologies and socioeconomic conditions in the SEAP region, there is also a large diversity in farming systems. FAO has classified 21 farming systems in this region (Dixon, et al. 2001). The locations of these systems are shown in Figure 7.

Figure 7. Farming systems in East, South and Southeast Asia



Source: FAO, based on Dixon, et al. (2001)

In South Asia, the most important farming systems are the rice-wheat, rainfed mixed, rice, highland mixed, dry rainfed, and pastoral systems. According to FAO, more than 95 percent of the agricultural population[4] (more than 700 million people) and more than 80 percent of the total land area of South Asia are in these six systems (Ibid.). The most important farming systems in East Asia and the Pacific include the lowland rice, upland intensive mixed, temperate mixed, highland extensive mixed, pastoral, and tree crop mixed systems. These systems account for 94 percent of the agricultural population (more than 1.0 billion people) and nearly 70 percent of the total land area of the East Asia and Pacific region. The major features of these systems are summarized in Table 7.

[4] The agricultural population is defined as all persons depending for their livelihood on agriculture, hunting, fishing or forestry. This includes all persons actively engaged in agriculture and their non-working dependents (Dixon, et al. 2001).

Table 7. Major farming systems in SEAP region

Region	Farming System	Agro-Ecological Zone	Total Pop. (Million)	Agric. Pop. (Million)	Agric. Pop. Density (#/Ha)	Bovine Pop. Density (#/Ha)	Cultivated Percent of Area	Irrigated Percent of Cultivated Area	Principal Livelihood Strategies	Relative Poverty	Main Household Strategies For Reducing Poverty
South Asia	rice-wheat	dry-subhumid tropics/ subtropics	484	254	2.6	1.2	64	77	irrigated rice, wheat, vegetables, livestock (incl. dairy, off-farm activities	moderate-extensive	diversification off-farm income intensification
	rainfed mixed	dry subhumid/ moist semiarid tropics	371	226	1.5	0.9	59	16	cereals, legumes, fodder crops, livestock, off-farm activities	extensive (varies seasonally)	diversification intensification off-farm income exit agriculture
	rice	humid tropics	263	130	3.6	1.4	61	45	wetland rice (two seasons), vegetables, legumes, off-farm	extensive	diversification off-farm income intensification exit agriculture
	highland mixed	moist subhumid cool subtropics	82	53	0.8	0.7	29	16	cereals, livestock, horticulture, seasonal migration	moderate-extensive	exit agriculture diversification off-farm income
	dry rainfed	semi-arid tropics	45	30	1.7	na	53	36	coarse cereals, irrigated cereals, legumes, off-farm	moderate	diversification intensification off-farm income
	pastoral	semi-arid and arid subtropics	27	21	0.4	0.2	12	67	livestock, irrigated cropping, migration	moderate-extensive (drought induced)	exit agriculture off-farm income

Table 7. Major farming systems in SEAP region (continued)

Region	Farming System	Agro-Ecological Zone	Total Pop. (Million)	Agric. Pop. (Million)	Agric. Pop. Density (#/Ha)	Bovine Pop. Density (#/Ha)	Cultivated Percent of Area	Irrigated Percent of Cultivated Area	Principal Livelihood Strategies	Relative Poverty	Main Strategies For Reducing Poverty
East Asia	lowland rice	humid and moist subhumid tropics/ subtropics	825	474	2.4	0.3	36	46	rice, wheat, maize, pulses, sugarcane, oil seeds, vegetables, livestock, aquaculture, off-farm	moderate	diversification off-farm income
	upland intensive mixed	uplands in humid/ subhumid tropics/ subtropic/ temperate	530	314	1.0	0.2	24	24	rice, wheat pulses, maize, sugarcane, oil seeds, fruits, vegetables, livestock, off-farm	extensive	off-farm income diversification exit agriculture
	temperate mixed	moist/dry subhumid temperate	247	162	1.6	0.1	31	39	wheat, maize, pulses, oil seeds, livestock, off-farm	moderate	off-farm income diversification exit agriculture
	highland extensive mixed	high altitude humid/ subhumid subtropics	na	47	0.5	0.2	9	20	upland rice, pulses, maize, oil seeds, fruits, forest products, livestock, off-farm	moderate	exit agriculture off-farm income diversification
	pastoral	semi-arid/arid temperate	na	42	0.1	na	4	20	livestock, irrigated crops in suitable areas	extensive (drought induced)	exit agriculture off-farm income
	tree crop mixed	humid/ moist subhumid tropics	48	30	0.4	0.2	21	11	rubber, oil palm, coconuts, coffee, tea, cocoa, spices, rice, livestock, off-farm	moderate	diversification off-farm income intensification

Source: Adapted from Dixon, et al. (2001)

South Asian systems

The rice-wheat system of South India is located in northern Pakistan and India, stretching from the Indus irrigation area in Sindh and Punjab across the Indo-Gangetic plain to northeast Bangladesh.[5] This system is predominantly in the dry-subhumid AEZ. Access to markets and roads is generally good in this system. This system is one of the cradles of the Green Revolution, and experienced dramatic increases in productivity as a result. A summer paddy rice crop is followed by irrigated winter wheat, and sometimes vegetables. The agricultural population density is quite high (260 agriculturally-dependent persons per square km, or 2.6 per ha), resulting in small average farm sizes (typically less than 1 ha). Livestock are a key component of the system, being used for traction and puddling in paddy production, for milk, and other purposes. Off-farm activities are also important in many households' livelihood strategies, especially for smaller farmers and landless households who work in other farmers' fields as well as pursuing non-agricultural opportunities.

Poverty and food insecurity are widespread in the wheat-rice system, mainly among landless agricultural workers and sharecroppers. Irrigation is common, supporting a crop of wheat during the dry season after the monsoon rice crop. With the development of improved varieties of both rice and wheat during the Green Revolution, together with use of irrigation and fertilizer, there have been remarkable increases in production in this system. However, yield growth has declined and in some places yields are stagnating in this system. In recent years, there has been widespread adoption of minimum tillage in this system with very positive results (this issue is discussed in more detail in the subsection on low external input and sustainable agriculture (LEISA) technologies in section 4). The drier western parts of the system in Pakistan are more mechanized, and the timing of planting wheat after rice is critical due to temperature and moisture constraints. The system has expanded over time into areas where groundwater is less accessible, and because of unreliable water supply, farmers have to transplant rice at the onset of the monsoon. To maintain flexibility, they plant slow maturing rice varieties, which often leads to late sowing of wheat and low yields.

Resource management problems are significant constraints to productivity in the rice-wheat system. Soil fertility is declining due to unbalanced use of mineral fertilizer. Poor irrigation management in the drier western areas is causing buildup of salinity and sodicity in the soil, while rapid expansion of tubewells and subsidized electricity rates have contributed to declining groundwater tables in some areas such as Western and Central Uttar Pradesh. In parts of Gujarat and

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[5] This discussion of farming systems draws heavily from Dixon, et al. (2001).

Rajasthan, some irrigation dependent farmers are being forced to switch to rainfed crops due to groundwater depletion. Efforts to address such resource management problems are critical to maintain and improve the productivity of this system.

The rainfed mixed farming system occupies most of India and Sri Lanka. The climate in this system ranges from moist semiarid to dry subhumid. There is relatively poor market access in sizable areas of this system. The dominant crops include cereals (some rice where irrigation is available, and maize, pearl millet and sorghum under mostly rainfed conditions), pulses, oilseeds, sugarcane, and some vegetables and fruits. Irrigation is not commonly available in this system; only about 16 percent of cultivated area is irrigated. Livestock are also important in this system, providing much of households' cash income, and fodder crops are also important as a result. Dairy production is not common, though is increasing in areas with good market access. The agricultural population density (1.5 persons per ha) is lower than in the rice-wheat system, but still implies small farm sizes (typically two or three hectares) on average. Agriculture is mostly subsistence oriented, with limited use of modern technologies, as most areas are poorly served by infrastructure and services, such as roads, irrigation, and agricultural extension, and are remote from markets. Where irrigation is used, it is mostly provided by traditional "tanks" (ponds) or shallow dug wells with low capacity. As a result of unfavorable climate and access conditions and reliance on production of low value subsistence crops using limited inputs, agricultural productivity is low and growing slowly in this system and a large proportion of households live in chronic poverty, aggravated by drought-induced transient poverty. Farmers are quite vulnerable to the vagaries of the weather in this rainfed system. Despite production risks and lack of market access, farmers are adopting higher value commodities such as dairy and vegetables where irrigation is available, while oilseeds production has been stimulated by production subsidies (Gulati and Kelley 1999). Land degradation, including soil fertility depletion as well as erosion, is a serious concern, as is increasing scarcity of water. Increasing water availability and conservation (both for domestic use and agriculture) through small scale irrigation, water harvesting and soil and water conservation measures are likely to be essential for increasing uptake of improved technologies, increased productivity and poverty reduction in this system.

The rice farming system is found in humid tropical areas of eastern and coastal southern India, Bangladesh and coastal areas in southern Sri Lanka. Wetland rice is the dominant crop, and is invariably cultivated during the wet season, while in the dry season, a second rice crop, or another less water-demanding crop such as coarse grains, oilseeds, legumes or vegetables is grown. About 45 percent of the cultivated land is irrigated, mainly in the second season, with supplementary irrigation used in the monsoon season. Besides rice, other cereals, vegetables and legumes are grown, mainly in the dry season. Livestock are important in rice production, as is dairy production since most of this system is in areas of good market access. Aquaculture is widely practiced in southern parts of this system. Access to extension services is generally good in this system. Most farmers use high levels of fertilizer and are aware of improved seeds, although uptake of improved seeds is limited in some cases by lack of high quality certified seeds, poorer taste of some new varieties, their lower tolerance to early or late transplanting, and sometimes only marginal increase in yield compared to local varieties. Although wetland rice yields are high due to sufficient moisture and intensive use of fertilizer, yield growth has stagnated, due to diminishing returns to such inputs, land degradation (including waterlogging, soil erosion and salinization) and low rice prices that limit the profitability of high levels of costly inputs. Shortages of groundwater are also increasingly of concern, limiting the use of tubewells in some parts of this system. Depletion of groundwater and high levels of chemical input use have reduced the quality of drinking water in some areas, including widespread arsenic poisoning in Bangladesh. Population density is highest in this farming system of any in the SEAP region (3.6 persons per ha), leading to very small average farm sizes (often less than one hectare). The farm size distribution is bimodal, with many tenants and sharecroppers farming very small areas, and some larger farms of as much as 5 to 10 ha or more. Off-farm income is particularly important for such small farmers and landless households. Poverty is extensive, especially among these households.

The highland mixed farming system occupies highland areas in the foothills of the Himalayas in northern Pakistan, northern India and large parts of eastern India, and most of Nepal and Bhutan. Some highland farming is also found in higher elevation zones of southern India and in Sri Lanka. The climate in these highlands is cool with a fairly long growing period (moist subhumid). A wide variety of crops is grown in this system, including various cereals, legumes, vegetables and fruits. Irrigation is not common (only 16 percent of cultivated area is irrigated), and a large portion of the land is not cultivated (less than 30 percent of the land is cultivated). Consistent with this, the agricultural population density is relatively low (0.8 persons per ha). However, farm sizes are generally quite small, typically less than one hectare in size, as there are substantial areas unsuited to agriculture (e.g., forest areas). Encroachment into forest areas is common in this system, and lack of land tenure security is a result. In most cases, indigenous tribal communities have lived in these areas for thousands of years practicing shifting cultivation. A large proportion of the global indigenous population resides in this farming system. Immigration from more densely populated lowland areas is contributing to more sedentary forms of agriculture, pressures on the resources, severe problems of deforestation and soil degradation, and to a lack of social cohesion in many of these areas. At the same time as immigration is occurring from lower elevations, many of the local youth are migrating out in search of better opportunities elsewhere. This has both positive and negative impacts on highland communities, providing a source of income (through remittances) and reducing population pressure, but also reducing the stock of human capital and labor. Many of these areas are remote and have little access to services and markets, making it difficult to intensify or diversify agricultural production. Adoption of improved inputs is low in staple crop production, hence improvement in productivity has also been slow. A critical need is to address problems of deforestation and soil erosion, which are severe in many highland areas. In areas with better access to markets and services, farmers are diversifying into higher value commodities, such as apple production in Himachal Pradesh, citrus in eastern Nepal, and potatoes in northern Pakistan. In Nepal, some projects have successfully promoted improved livestock management using zero grazing/stall feeding on a pilot basis, helping to reduce pressure on common grazing lands, recycle nutrients to the soil, increase income, improve children's school attendance and increase labor availability. Poverty is moderate to extensive in this farming system, with variations likely due largely to differences in access to markets and services. Continued diversification of agriculture into higher value and resource conserving practices is likely to be a key pathway for agricultural development and poverty reduction in this farming system.

The dry rainfed farming system is located within the rainfed mixed farming system in the western Deccan plateau of south India. The climate in this zone is semi-arid, and subject to substantial uncertainty in the amount and distribution of annual rainfall, as well as to a short growing season. Although the climate is drier than in the surrounding rainfed mixed system, the availability of irrigation is greater (36 percent of cultivated area is irrigated), helping to reduce farmers' vulnerability where irrigation is available. The main crops include coarse cereals (pearl millet and sorghum), oilseeds and legumes under rainfed conditions and paddy rice and vegetables where irrigation is available and where market access is favorable (especially for vegetables). Agricultural population density (1.7 per ha) is similar to that in the rainfed mixed system, resulting in similar farm sizes on average. Poverty varies substantially across households depending upon whether they have access to land, irrigation and markets. For those with less access to these assets, off-farm income is particularly important. Water scarcity and land degradation are major concerns in this farming system, as in the surrounding rainfed mixed system.

The pastoral system is located in semi-arid and arid regions of northwestern India (mainly in Rajasthan) and parts of Pakistan. Transhumant pastoralism is the main livelihood strategy in this system, combined with irrigated cropping of rice, wheat and other food and fodder crops on limited areas. The cultivated area is only 12 percent of the total area in this system, but two-thirds of this area is irrigated due to the dry conditions. Off-farm income and income from migration are also important sources of livelihood. Agricultural (including pastoralists) population density is relatively low (0.4 persons/ha), but increasing population and livestock pressure is a concern for the management of grazing lands. Poverty depends largely on the size of the herd owned by households, and households are vulnerable to the impacts of drought upon the survival and value of their herds.

East Asian and Pacific systems

The lowland rice system is found in all countries of East Asia and the Pacific (excluding Mongolia), but the largest areas are in Thailand, Vietnam, Myanmar, central eastern and southeastern China, the Philippines and Indonesia. This is the most important farming system in East Asia, directly employing an agricultural population of nearly 500 million people, and providing the major source of food security for all of the countries in the region. This system is found in humid and subhumid tropical and subtropical areas at low elevations. As in the rice-wheat and the lowland rice systems of South Asia, the Green Revolution had a major impact in this farming system. Rice production is highly intensive in much of this system, with two or three crops per year in many areas, depending on the availability of sufficient rainfall or irrigation. Variations in cropping intensity also depend on population density and farm sizes, which range from typical sizes of several hectares in central Thailand to as small as 0.2 hectares in the Red River Delta of Vietnam. Rice yields average more than 3 tons per hectare in this system, though with large variation. Much higher yields are seen in China (e.g., up to 8 tons per hectare in Jiangsu Province) as a result of high use of high yielding varieties and fertilizer (both inorganic and organic). Winter wheat is the second most important crop in this system in central-eastern China. Other crops found in this system, in descending order of area occupied, include vegetables, oilseeds, maize, root crops, soybeans, sugarcane, cotton and fruits. Livestock are a less important source of income, but are still important in most areas for draft power, meat, manure, income and as a form of savings. Aquaculture is practiced in many areas, with farmers raising fish in paddies as well as farm ponds. Off-farm income is also important for many households, especially where farm sizes are very small.

Major concerns in the lowland rice farming system include declining soil fertility as a result of unbalanced nutrient inputs and continuous cropping, land fragmentation, inefficient use of water resources, excessive use of agricultural chemicals and attendant pollution and health problems, inferior seed quality in many areas, poor post-harvest management, limited farm diversification, and lack of local capacity for agricultural processing. Poverty is generally moderate compared to other farming systems, though there is still severe poverty in many areas in this system, especially where land is very scarce.

Like the lowland rice system, the upland intensive mixed farming system is found in all countries of East Asia and the Pacific (excluding Mongolia), in widely varying climatic conditions, ranging from the humid tropics in the southeast to subhumid temperate zones in northeastern China. More than 300 million rural people (27 percent of the agricultural population of East Asia and the Pacific) depend on this system for their livelihoods. In the uplands of Southeast Asia, the soils are gently to steeply sloping, are generally of low fertility, highly erodible, acidic, and subject to severe phosphorus deficiency, aluminum toxicity and low cation exchange capacity (Garrity 2002). This system is the most heterogeneous of all farming systems in the region, with a wide variety of crops grown depending upon local biophysical and socioeconomic conditions. Major crops grown in this system include paddy and some upland rice (the dominant food staple in the warmer and more humid areas in the southeast), wheat (dominant in the cooler and drier areas in the north), maize, pulses, sugarcane, oilseeds, fruits and vegetables. Most crop production is rainfed, with only about one-fourth of the cultivated area irrigated. Livestock are an important component of the system, most of which are raised under extensive conditions, although more intensive practices are found in China, particularly for pigs and poultry. Cultivated area accounts for only about one fourth of total land area in this system, with significant areas used for livestock grazing, as well as scattered forests throughout the system. In general, agricultural research and extension efforts throughout the region have neglected farmers in these upland systems for a variety of reasons (remoteness, complexity of the farming system, lack of irrigation, lack of perception of their importance) and many of the efforts that have occurred had a narrow commodity focus and failed to achieve large impacts on productivity or farmers' incomes. Access to infrastructure such as roads and other rural services such as credit are also generally limited in this system. Land tenure insecurity is also an important constraint affecting many farmers in this system. Deforestation is a major problem, caused by large timber companies and government agencies as well as population pressure of small farmers, and together with unsustainable farming practices on much of the sloping areas, contributes to serious problems of soil erosion in many areas. Adoption of soil and water conservation measures is limited, despite serious soil erosion problems. Poverty is extensive throughout much of this farming system, especially in areas remote from markets and services.

The temperate mixed farming system is found mainly in central-eastern and northeastern China and in some areas of Mongolia. The climate is subhumid temperate, but colder in the northern parts of the system in northern China and Mongolia. There are two main subsystems: the Loess Plateau subsystem in central-eastern China, in which two crops per year are common; and the Northern subsystem in which only one summer crop can be grown due to the severe winters. The agricultural population is about 160 million, with an average density of 1.6 persons per ha, but population density is substantially greater and farm sizes much smaller in the Loess Plateau subsystem. In the Loess Plateau, maize, rice, cotton, soybeans and sweet potato are the main summer crops, while wheat and rapeseed are the main winter crops. Crops are grown under both irrigated and rainfed conditions, with a cropping intensity of about 150 percent. Wheat yield averaged 4 tons/ha in 1999 in this region, having grown rapidly since the advent of the Green Revolution as a result of heavy use of both inorganic and organic fertilizers and improved seeds. In the northern subsystem, wheat and other cereals are grown, as well as some cold resistant vegetable crops such as potatoes and cabbage. Livestock, including cattle, small ruminants, pigs and poultry are important in both subsystems, raised under more extensive conditions in the northern subsystem, especially in Mongolia. Pigs and poultry are raised under much more intensive conditions in China. Off-farm activities are also important in this system, especially in China where market access is generally favorable and urban incomes and market demand have been growing very rapidly. Among the impacts of this is rapidly growing demand for livestock products, which is also stimulating demand for maize as a feed grain. As a result, maize area (as well as yields) have been increasing, while wheat area is declining (although offset by rapidly growing yields). Poverty is generally moderate, and labor constraints are a concern in China as a result of substantial emigration to urban areas. As a result, the need for small scale mechanization is increasing. Other concerns in this system include unbalanced application of soil nutrients, with limited application of potassium causing soil fertility concerns, and depletion of groundwater in some areas.

The highland extensive mixed farming system is found at high altitudes in southwestern China, northern and eastern Myanmar, northern Thailand, Laos, central and northern Vietnam, and parts of the Philippines. The climate is humid and subhumid cool tropical and subtropical. These areas are in many cases above the upland intensive mixed system, and have poorer resource endowments and less favorable access. Most of these areas are remote from markets and have poor access to infrastructure and services. The agricultural population dependent upon this system is nearly 50 million. The agricultural population density is lower than in many other systems (0.5 persons per ha), with extensive areas of forest within the system. Both permanent and shifting cultivation are practiced in this system, with shifting cultivation coming under increasing pressure as population growth leads to declining fallow periods. Major crops include upland rice, maize, pulses, oilseeds, and fruits. Irrigation is used on about one-fifth of the cultivated area. Livestock are also an important source of income, as are forest products and off-farm activities. Problems of land tenure insecurity, lack of social cohesion and land degradation are likely at least as severe in most of these areas as in the upland intensive areas. Poverty is moderate to severe in these areas, depending on the remoteness of the community from markets and services.

The pastoral farming system is found in semiarid and arid temperate zones in western China and much of central and northern Mongolia. Agricultural population density is very low in this system (less than 0.1 person per ha), while access to markets and services is generally poor. Transhumant pastoralism is the main livelihood strategy, with farmers grazing mixed herds of camels, cattle and small ruminants. Only 4 percent of the area is cultivated. Drought and cold tolerant crops such as barley are grown for subsistence under rainfed conditions, while wheat, potatoes, pulses and cotton are grown in irrigated areas. Poverty is severe and households are highly vulnerable to the impacts of drought and severe winters.

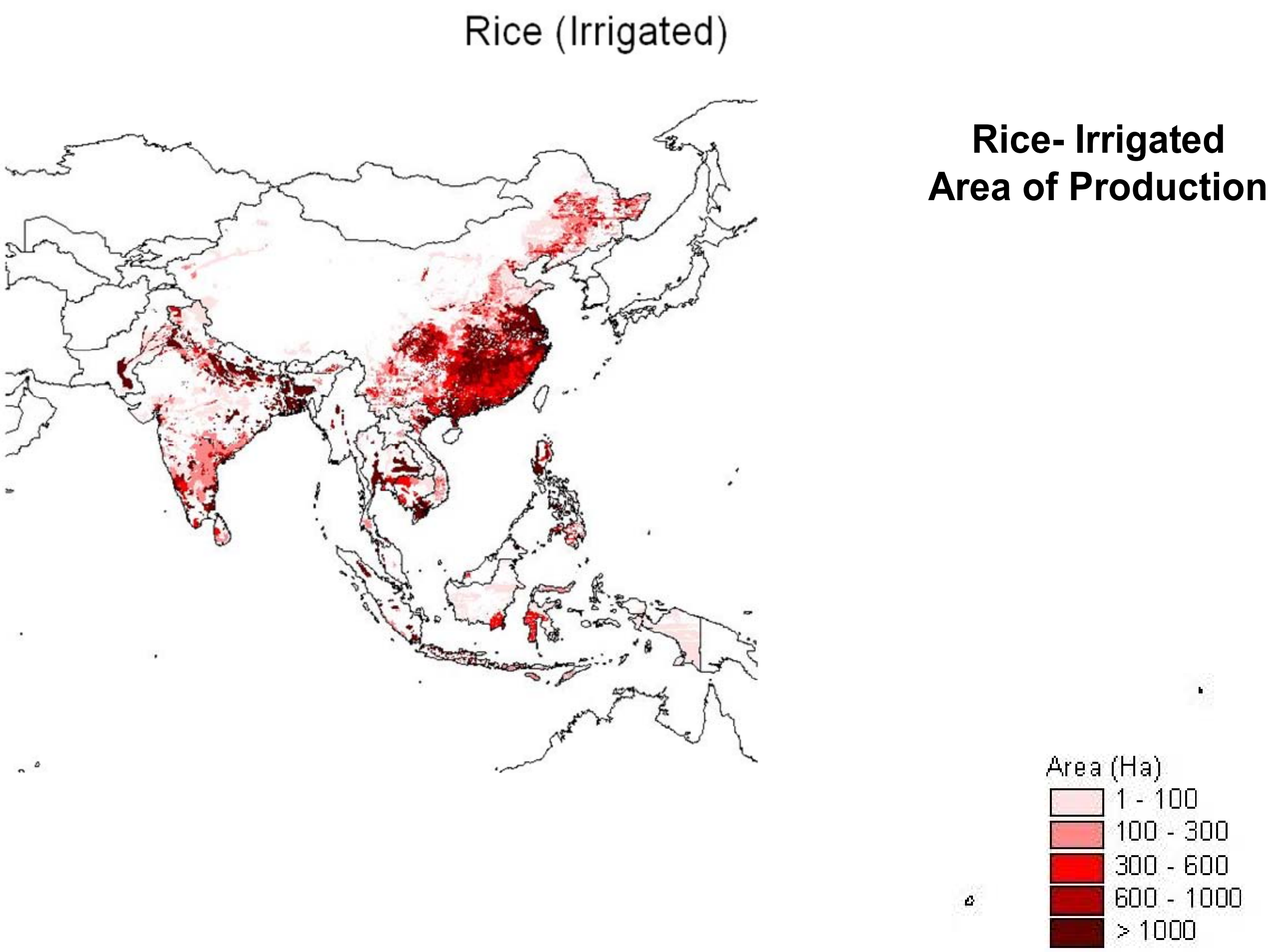
The tree crop mixed farming system is found in humid and moist subhumid tropical areas mainly in Thailand, Malaysia, and Indonesia, with smaller areas in Cambodia, the Philippines, Vietnam, southern China and Papua New Guinea. The soils are generally acidic with low inherent fertility, which limits potential for rice production in these areas. The dominant crops in this system are industrial plantation crops, especially rubber, oil palm and coconuts, with coffee and tea at higher elevations. This system is based on large private estates established beginning in the 19th century, but there are now large numbers of smallholder farmers producing industrial crops as well. Agricultural population density is low (about 0.4 persons per ha), but substantial areas are occupied by large estates, so farm sizes in the smallholder sector are generally no more than 2 or 3 hectares in size. Market access is favorable as a result of infrastructure developed to serve the needs of the estate sectors. Smallholder farms usually produce rice or maize for their food needs, and a variety of spices are produced. Large livestock are not very important in this system, but small ruminants are common. Off-farm activities are important to smallholders and landless people, particularly employment in the estate sector. Poverty is moderate as a result of high value agriculture and high demand for labor. A key concern is low productivity in the smallholder sector, due in part to smallholders' lack of access to technologies used in the estate sector and lack of attention given to them by government extension agencies. Small farmers also lack access to credit and to alternatives in marketing plantation crops, and development of cooperatives is weak. Declining long term trends of international market prices for many plantation crops is also a major concern.

Cropping Patterns and Level of Agricultural Technology

To get a clearer picture of the farming systems and level of agricultural technologies used in the SEAP region, we consider new evidence on the amount and location of crop production by production system. The estimated locations of rice production in the SEAP under different production systems/levels of technology are shown in Figures 8 to 11. These maps were generated by IFPRI using a spatial allocation model to estimate crop production by pixel (You and Wood 2004).[6] Four production systems/technology levels were defined: high input irrigated production, high input rainfed production, low input rainfed production and subsistence production. High input production is based on improved high-yielding varieties and high levels of inorganic fertilizer and other purchased inputs, and production is mainly for the market. Low input production uses mainly traditional cultivars and limited amounts of purchased inputs. In the case of food production, low input production is largely for home consumption, though sales are also often significant. Subsistence production uses no purchased inputs and is primarily for home consumption.

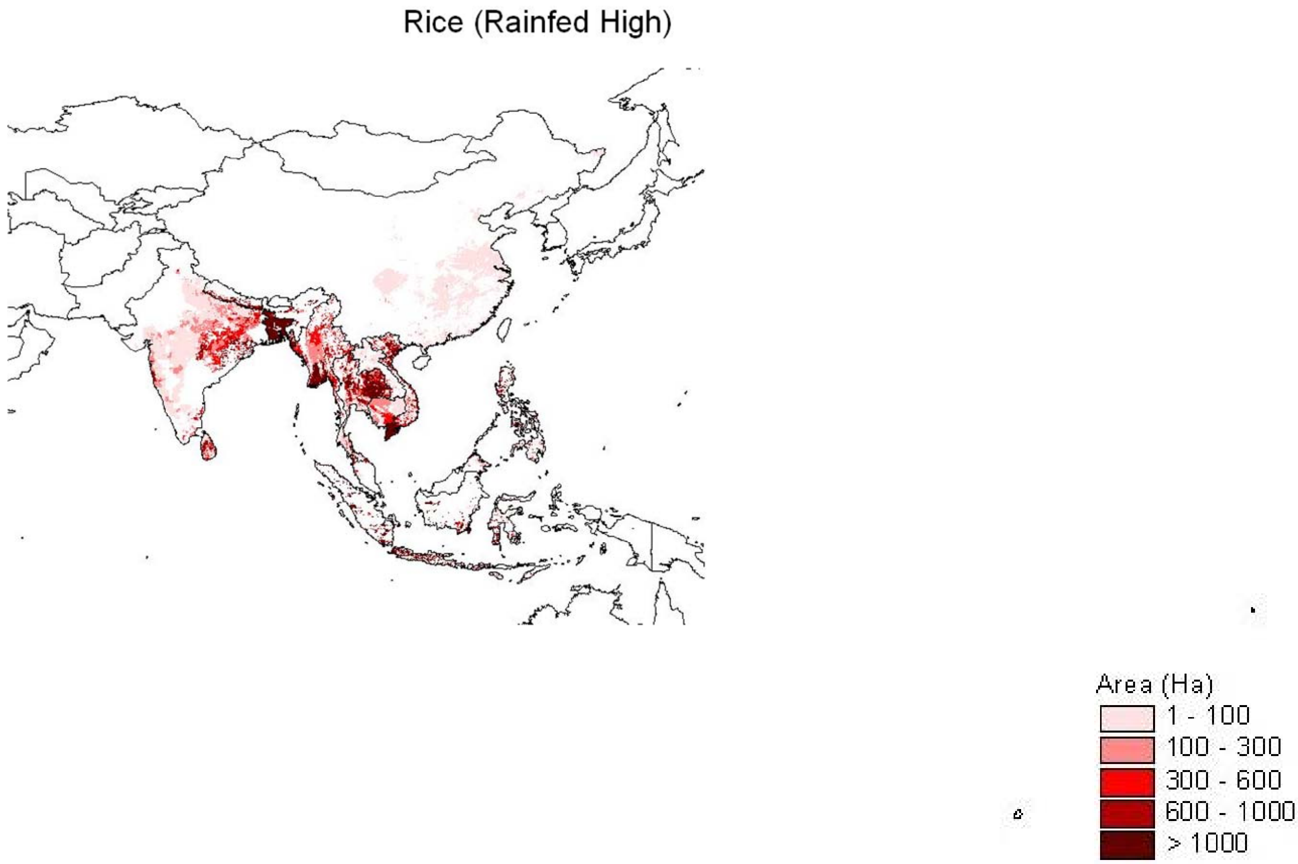
[6] The model combines available crop production statistics in each country with mapped information on farming system characteristics, satellite-derived land cover data, biophysical crop suitability assessments, and population density data, using a cross entropy method that makes optimal use of the best available information (You and Wood 2004). Pixels are typically 25 to 100 square km in size.

Figure 8. Areas of intensive irrigated rice production



Source: IFPRI crop production allocation database, You and Wood (2004)

Figure 9. Areas of high external input rainfed rice production



Source: IFPRI crop production allocation database, You and Wood (2004)

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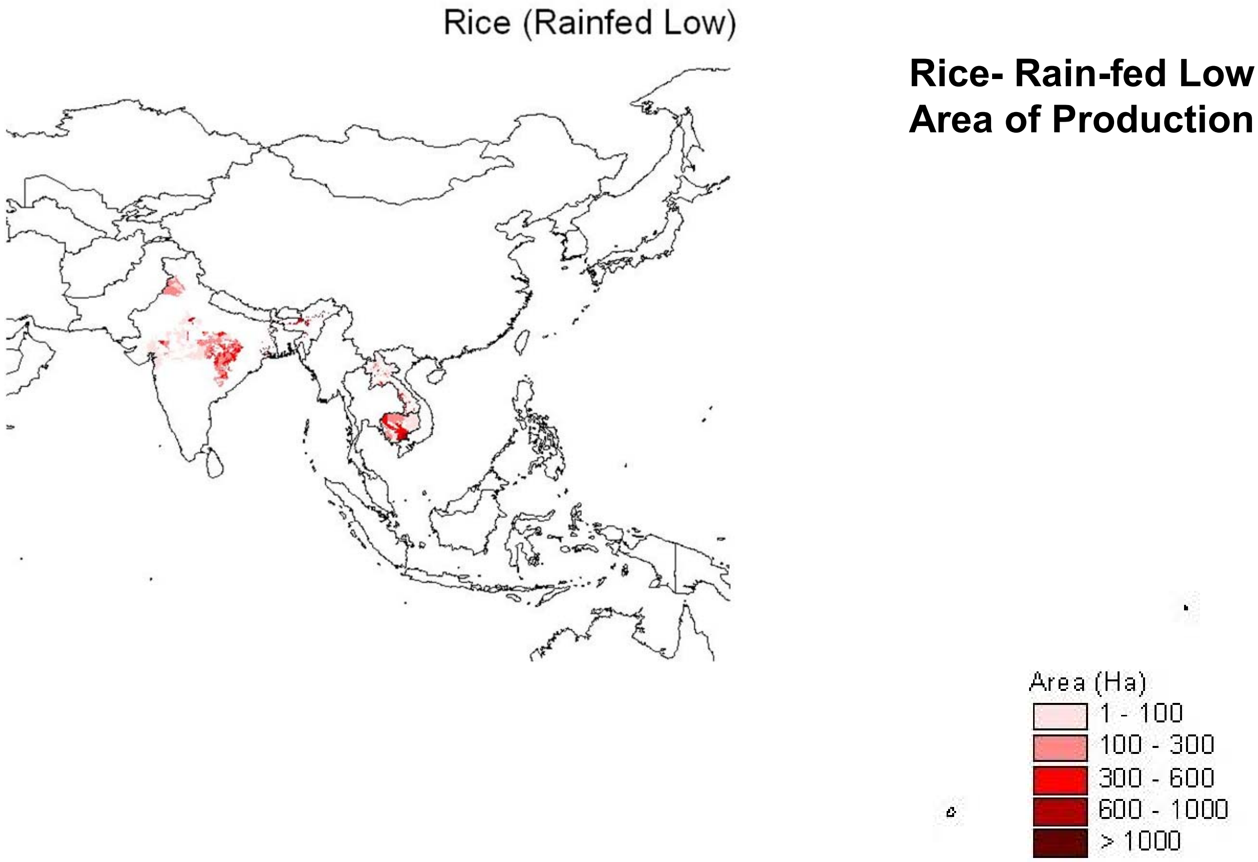
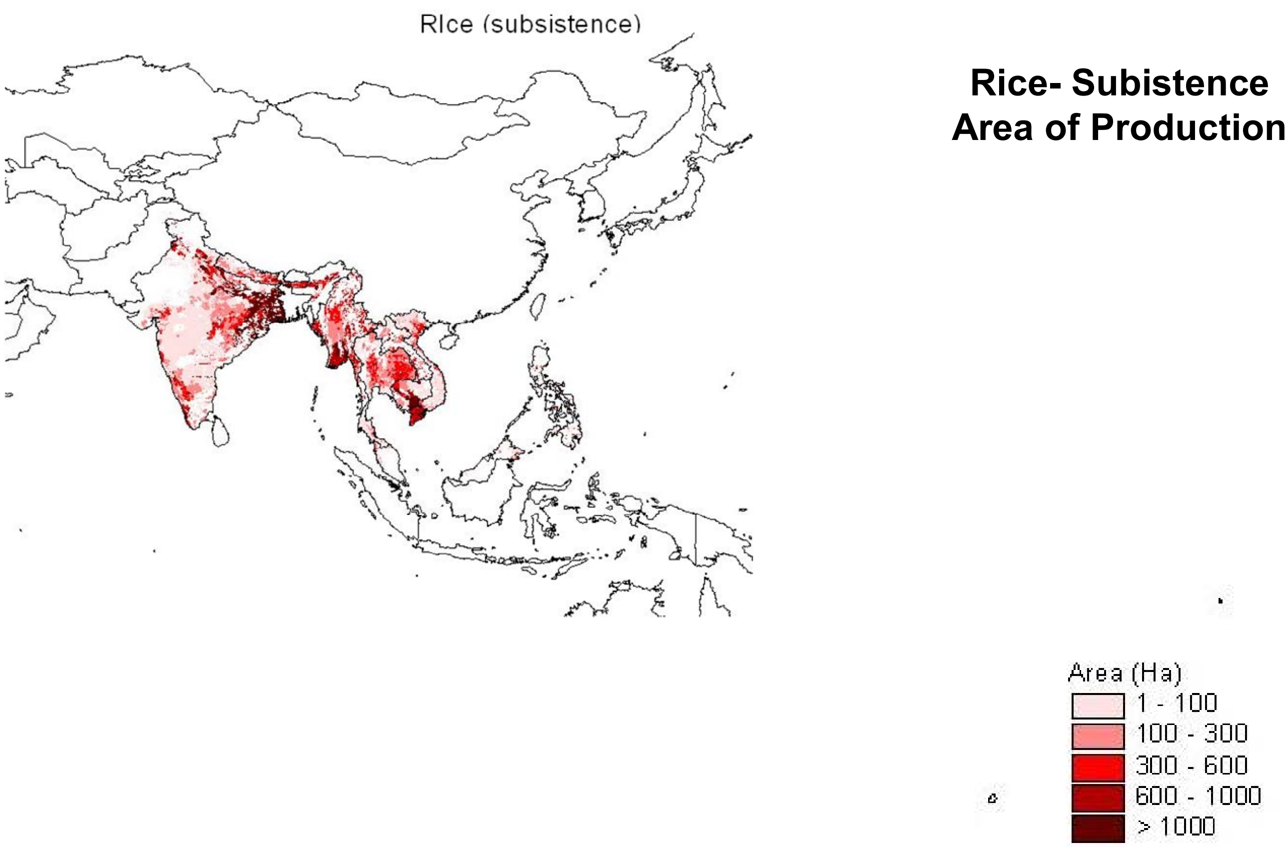
Figure 10. Areas of low external input rainfed rice production



Source: IFPRI crop production allocation database, You and Wood (2004)

Figure 11. Areas of subsistence rainfed rice production



Source: IFPRI crop production allocation database, You and Wood (2004)

Irrigated high input rice production is concentrated in eastern China and significant parts of Thailand, Vietnam, the Philippines and Indonesia in the East Asian lowland rice system, in northern India and parts of Pakistan in the South Asian rice-wheat system, and in eastern India, Bangladesh and Sri Lanka in the South Asian rice system. Irrigated rice is also found to a lesser extent in all other countries of the SEAP region, except Mongolia. High input rainfed production is found in most of the same countries, except China, where irrigated rice is dominant. Large areas of high input rice production are also found in Myanmar. Subsistence rainfed production is most common in Laos, Cambodia and Myanmar. For the SEAP region as a whole, about 20 percent of the total harvested crop area of major crops is irrigated paddy, 7 percent is rainfed paddy grown using high inputs and 6 percent is rainfed paddy grown under low inputs or subsistence production (Table 8).[7]

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[7] The percentages shown in Table 8 are based on the same crop allocation model used to generate Figures 7 to 15. The percentages are the percentage of gross harvested area for the 20 most important crops, including cereals (rice, wheat, maize, sorghum, millet, barley), pulses (beans and others), oilseeds (soybeans, groundnuts and other), root crops (cassava, sweet potatoes, and potatoes), cotton, coffee, bananas, sugar cane, and sugar beets. Multiple cropping adds to the gross harvested area (e.g., if 1 hectare of rice is harvested for three seasons, this is counted as 3 harvested hectares). Areas of other crops, including fruits, vegetables, spices and some plantation crops (e.g., rubber, oil palm, tea) were not estimated.

Table 8. Percent of area of each country and SEAP region by crop and technology level

Crop	Tech level[1]	Bangla-desh	Bhutan	Cam-bodia	China	India	Indo-nesia	Laos	Malay-sia	Mong-olia	Myan-mar	Nepal	Paki-stan	Phili-ppines	Sri Lanka	Thai-land	Viet-nam	SEAP Region
Paddy rice	I	44.0	31.3	12.5	22.8	13.9	24.1	19.5	8.8		7.7	12.3	12.3	24.8	52.6	31.3	38.1	19.5
	RH	36.4		14.2	0.1	3.1	21.6	5.6	4.8		21.1	19.2		18.2	28.0	30.6	25.2	7.0
	RL			17.8		1.1		16.7										0.6
	RS			44.6		8.4	5.0	41.8	1.5		19.2	6.8		7.6		6.9	7.0	5.3
Wheat	I	2.2			10.4	13.7				95.3	0.6	14.6	39.7					10.9
	RH	2.9			7.4	0.5										0.01		2.6
	RL		3.2		0.4	0.8							3.6					0.6
	RS		3.2			1.4					0.2	1.3						0.6
Maize	I				8.7	1.0	1.4				0.3	1.4	4.1				1.4	3.4
	RH	0.04		0.7	11.2	1.0	10.2	2.0	0.5		0.4	16.3	0.9	24.8	2.4	6.3	6.2	5.6
	RL		0.5		0.2	1.0		0.5			1.0							0.5
	RS		45.3	2.9		1.3	2.8	2.4	0.1		0.6	2.7		6.2		1.6	0.8	1.0
Millet	I				0.1	0.6							0.6					0.3
	RH	0.6			0.7	3.5							1.7		0.7			1.7
	RL		0.1			0.8						0.06						0.3
	RS		6.2		0.1	1.8					1.8	6.3						0.9
Sorghum	I				0.1								1.3					0.1
	RH	0.01			0.5								0.7		0.02	0.5		0.2
	RL					5.8												2.3
	RS					0.06										0.06		0.03
Barley	I	0.02			0.02	0.3							0.4					0.1
	RH				0.7								0.2			0.05		0.2
	RL		0.02			0.04						0.01						0.02
	RS		1.9			0.1				1.0		0.7				0.01		0.06
Pulses	I	0.1			0.1	2.1	0.1				2.4		4.4					1.2
	RH	3.3											4.0		2.3	1.7	1.8	0.4
	RL			0.8	0.5	7.4		0.2			15.2	3.8		0.3				3.6
	RS			0.8	2.4	4.5	1.4	0.2			6.0	3.8		0.3		0.2	0.2	2.9
Groundnuts	I	0.1			1.6	1.1							0.2				0.1	1.0
	RH	0.1			2.5		0.6				0.4		0.3	0.07	1.0	0.4	1.8	0.9
	RL					2.1		0.7			1.8			0.1				0.9
	RS			0.5		1.4	2.4	0.7			2.2			0.2		0.2	0.5	0.8
Soybeans	I				2.3	0.3	0.2						0.04					0.8
	RH				5.3	1.5	0.3							0.01	0.2	0.8	1.3	2.3
	RL		0.4	1.1		2.3	1.7	0.3			0.8	0.5				0.4	0.2	1.1
	RS		0.04	0.1	0.2		0.2	0.04			0.1	0.05				0.1	0.2	0.1
Other oil crops	I	0.1			1.4	1.7						0.5	2.4					1.2
	RH	3.2					10.5		77.3				0.7	0.4	0.7	2.1	0.3	1.7
	RL			0.4		3.4		0.3			12.2	2.0	0.2					1.8
	RS			0.4	6.6	2.0	2.6	0.3	4.1		1.4	2.5		0.1		0.04	0.04	3.1

Table 8. Percent of area of each country and SEAP region by crop and technology level (continued)

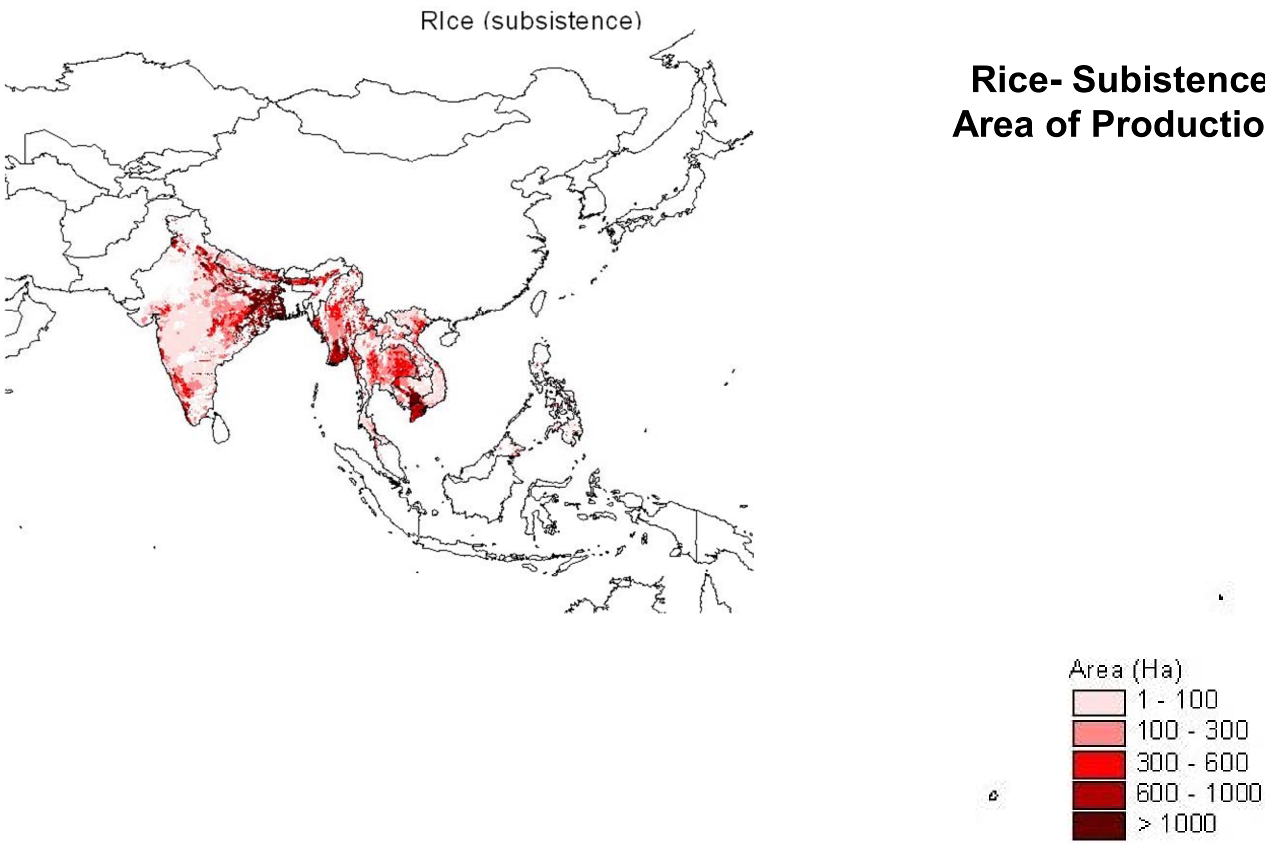
Crop	Tech level[1]	Bangla-desh	Bhutan	Cam-bodia	China	India	Indo-nesia	Laos	Malay-sia	Mong-olia	Myan-mar	Nepal	Paki-stan	Phili-ppines	Sri Lanka	Thai-land	Viet-nam	SEAP Region
Cotton	I	0.04			1.4	1.7		0.3			0.8		15.8				0.07	1.9
	RH	0.1			2.6											0.2	0.2	0.8
	RL			0.01		3.4	0.1				1.3	0.02		0.03		0.02		1.4
Coffee	RH						3.1	1.9	0.7					0.7	1.4	0.2	4.2	0.3
	RL			0.01	0.01	0.1	0.9	1.5	0.3		0.03	0.01		0.8		0.2	0.4	0.1
	RS					0.1	0.4	0.4	0.1					0.2		0.05	0.05	0.1
Bananas	I					0.2							0.2			0.1	0.2	0.1
	RH	0.3													5.1		0.7	0.04
	RL			1.3		0.1	1.1	0.7	0.5		0.3			4.5		0.4		0.2
	RS			0.1		0.2	0.1	0.1	0.05		0.04			0.5		0.5		0.1
Sugar cane	I	1.2	0.7	0.4	0.3	2.4	1.5	0.4	0.4		0.7	0.9	5.6	2.3	1.7	4.3	1.7	1.8
	RH				0.8							0.3		1.5		2.1	0.8	0.4
	RL					0.05		0.2			0.4			0.5				0.04
	RS					0.3	0.03	0.1			0.1	0.2		0.5		0.3	0.4	0.1
Fiber crops	I					0.1												0.06
	RH	3.2											0.02			1.1	0.2	0.2
	RL		0.1	0.02	0.1	0.5	1.2	0.06			0.3	0.3		1.3				0.3
	RS		0.01				0.01				0.04			0.1		0.1	0.02	0.01
Cassava	I					0.03												0.01
	RH			0.2	0.2		2.2	0.04	0.4					0.7	2.6	2.1	2.4	0.4
	RL					0.03		0.2								1.4		0.06
	RS			0.7	0.02	0.1	3.3	0.2	0.4		0.08			1.6		3.5	1.0	0.4
Sweet potatoes	I	0.1			0.02	0.03					0.01						0.1	0.03
	RH	0.2			4.2										0.7		1.9	1.4
	RL					0.01	0.01	1.0	0.04		0.01			0.02				0.01
	RS			0.3		0.02	0.8	1.0	0.04		0.02			1.6			0.1	0.1
Potatoes	I	1.1			0.4	0.4				3.7	0.05		0.5				0.02	0.3
	RH	0.7			3.4		0.2					2.9	0.06	0.05	0.6	0.05	0.2	1.1
	RL		3.5			0.1		0.3			0.06							0.04
	RS		3.5			0.3	0.05	0.3			0.1	0.5		0.01		0.01	0.05	0.1

[1] Technology level codes: I = irrigated high intensity, RH = rainfed high intensity, RL = rainfed low intensity, RS = rainfed irrigated

Source: IFPRI crop production allocation database, You and Wood (2004)

Wheat production is concentrated in northern India and Pakistan (in the rice-wheat system) and in central-eastern and northeastern China (in the temperate mixed system) (Figure 12).

Figure 12. Areas of wheat production

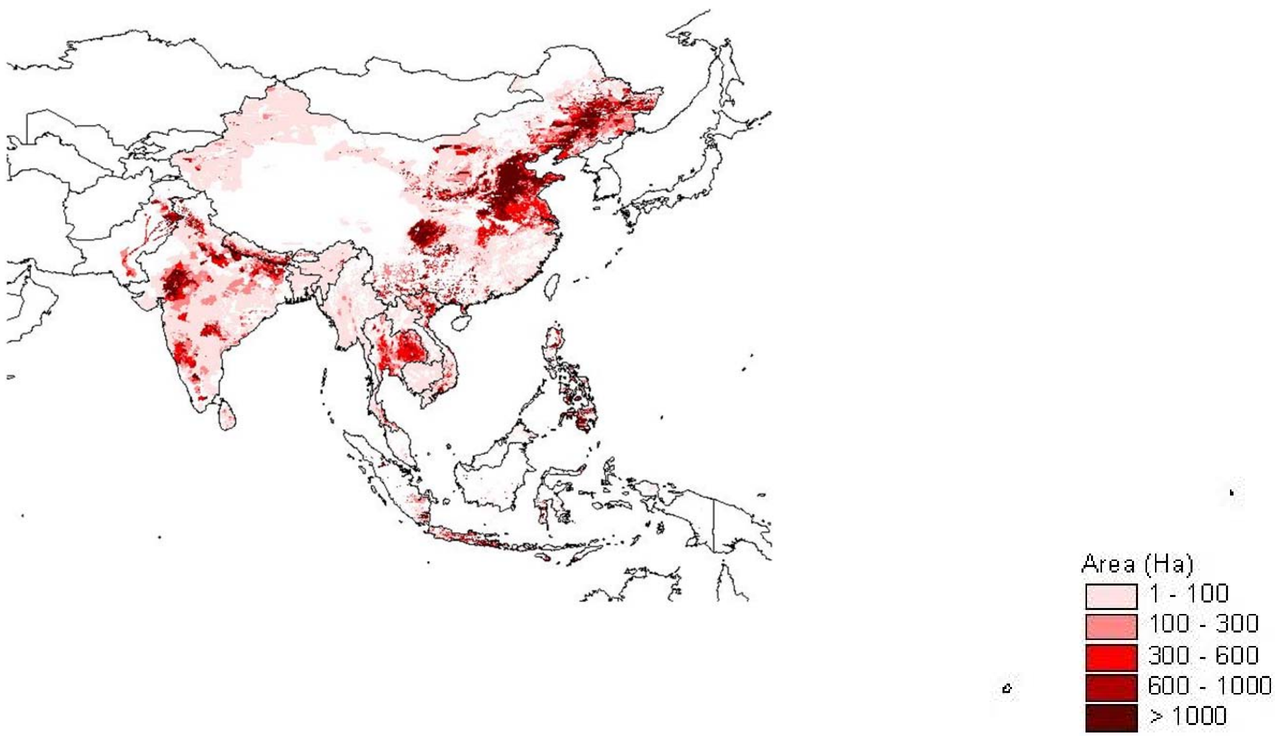


Source: IFPRI crop production allocation database, You and Wood (2004)

Wheat is produced mainly in less humid areas or during the secondary season under irrigated conditions, almost always with high levels of inputs. Wheat production accounts for about 15 percent of the area harvested for major crops.

Maize is produced in many countries and farming systems, usually in subhumid or humid areas, including large areas in eastern China, the Philippines, and Indonesia, and significant areas in parts of India, Nepal, Bhutan, Thailand and Vietnam (Figure 13).

Figure 13. Areas of maize production

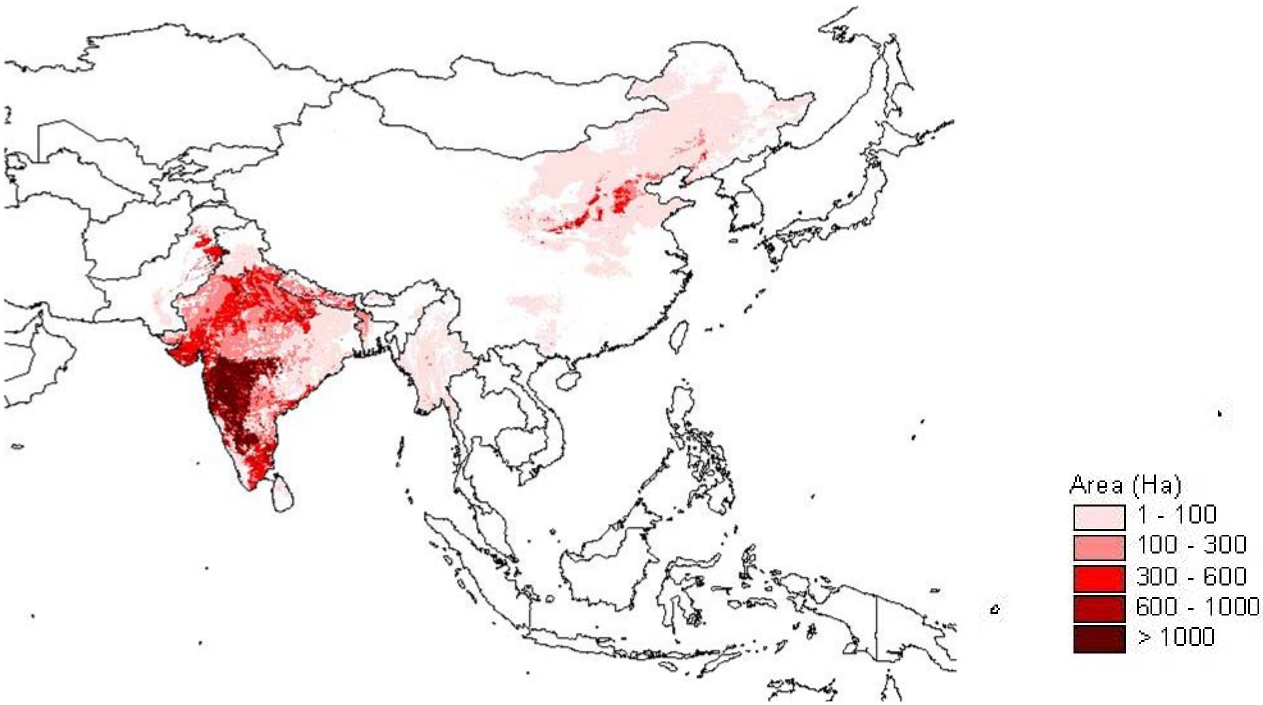


Source: IFPRI crop production allocation database, You and Wood (2004)

Maize is produced mainly under rainfed conditions using high levels of inputs, although there are significant areas of irrigated maize in Pakistan and China. Low input and subsistence maize production are most common in Bhutan and parts of India, the Philippines and Indonesia. Maize accounts for about 10 percent of the harvested area of major crops in the SEAP region.

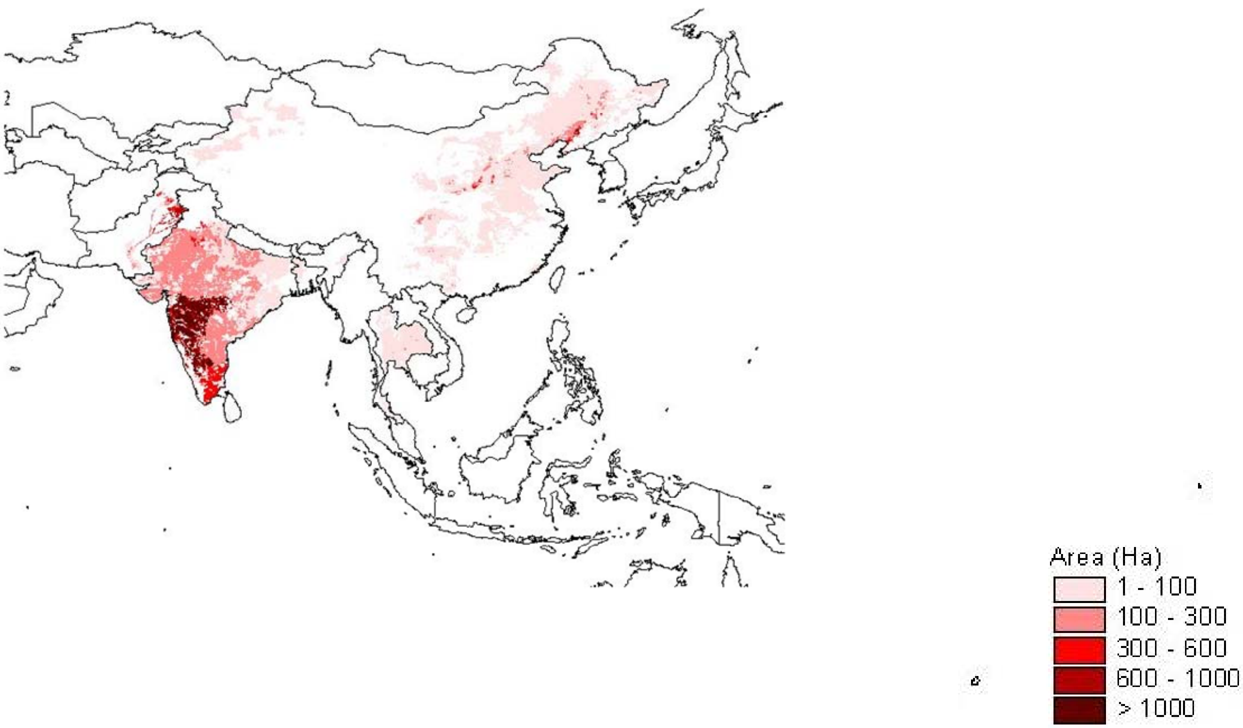
Millet and sorghum are produced mainly in India, and to a lesser extent, in China, Myanmar, Nepal, Bhutan, and Pakistan (Figures 14 and 15).

Figure 14. Areas of millet production



Source: IFPRI crop production allocation database, You and Wood (2004)

Figure 15. Areas of sorghum production

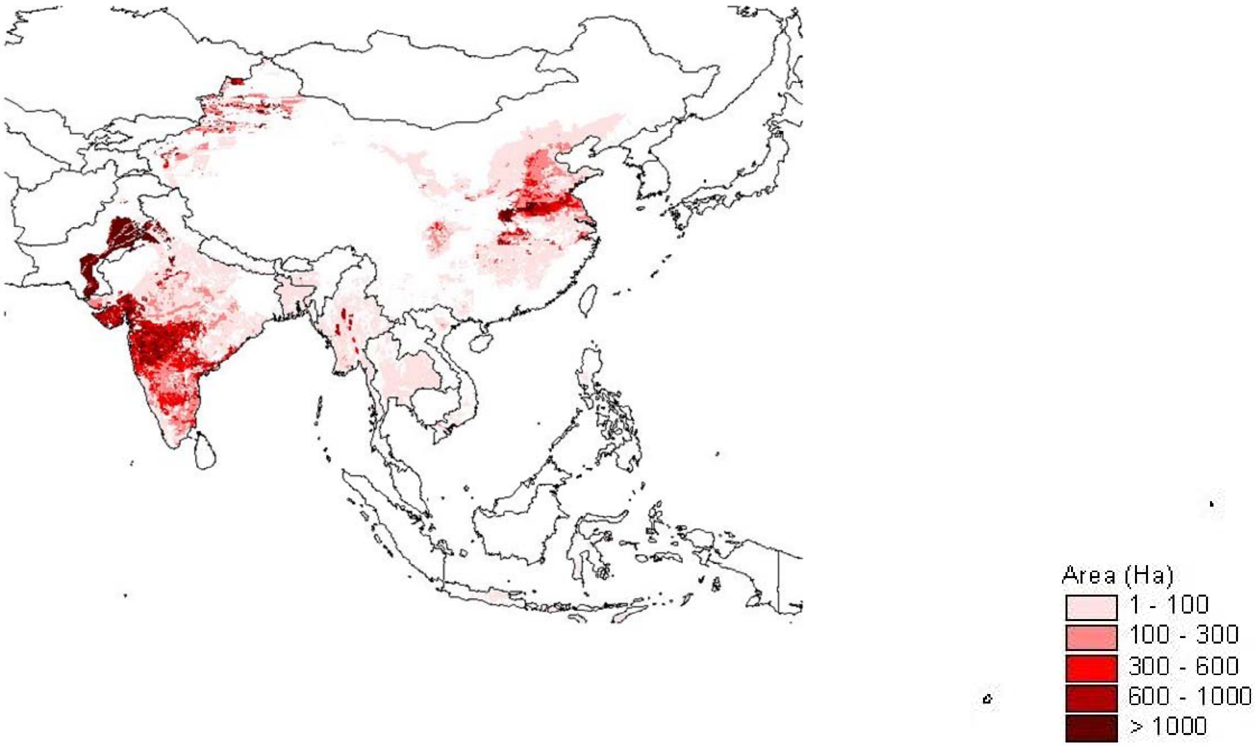


Source: IFPRI crop production allocation database, You and Wood (2004)

These crops are grown mostly under rainfed conditions (except in Pakistan) in semiarid agro-ecological zones. A high level of input use is more common for millet than sorghum. Most sorghum is produced using little or no purchased inputs. Millet and sorghum account for about 8 percent of harvested area of major crops.

Cotton is grown mainly in semiarid and subhumid areas of China, India and Pakistan (Figure 16).

Figure 16. Areas of cotton production



Source: IFPRI crop production allocation database, You and Wood (2004)

In Pakistan, cotton production is entirely irrigated, while in China and India rainfed production is more common (although significant areas of irrigated cotton are also found in both countries). Cotton is produced using high levels of inputs in irrigated areas of all three countries and in rainfed areas of China, while more limited amounts of inputs are used in rainfed cotton production in India. Cotton accounts for about 4 percent of the area harvested to major crops.

Pulses are grown mainly using little or no purchased inputs, and are particularly important in Myanmar and India (Table 8). Groundnuts are found in China, India, Indonesia, Myanmar and Vietnam, grown using varying levels of inputs (more inputs in China than other countries). Soybeans are grown mostly using high inputs in rainfed areas of China, while significant areas are also grown generally using less inputs in India and Indonesia. Other oil crops are common in Malaysia and to a lesser extent in Myanmar, Indonesia, China and India; and are grown mostly using limited inputs (except in Malaysia and Indonesia). Sugarcane is grown mostly under high input irrigated conditions in many countries, especially in Pakistan, India, Indonesia, and Thailand. Sweet potatoes are grown mainly in China and Vietnam using high levels of inputs under rainfed conditions. Potatoes are also grown mainly under rainfed conditions using high levels of inputs in cooler climates such as the highlands of China and Nepal. Irrigated potatoes are important in Mongolia. Other crops considered (barley, coffee, bananas, fiber crops and cassava) account for less than one percent each of harvested crop area in the SEAP region.

3. AGRICULTURAL DEVELOPMENT TRENDS AND TECHNOLOGY OPTIONS

Agricultural Development Trends

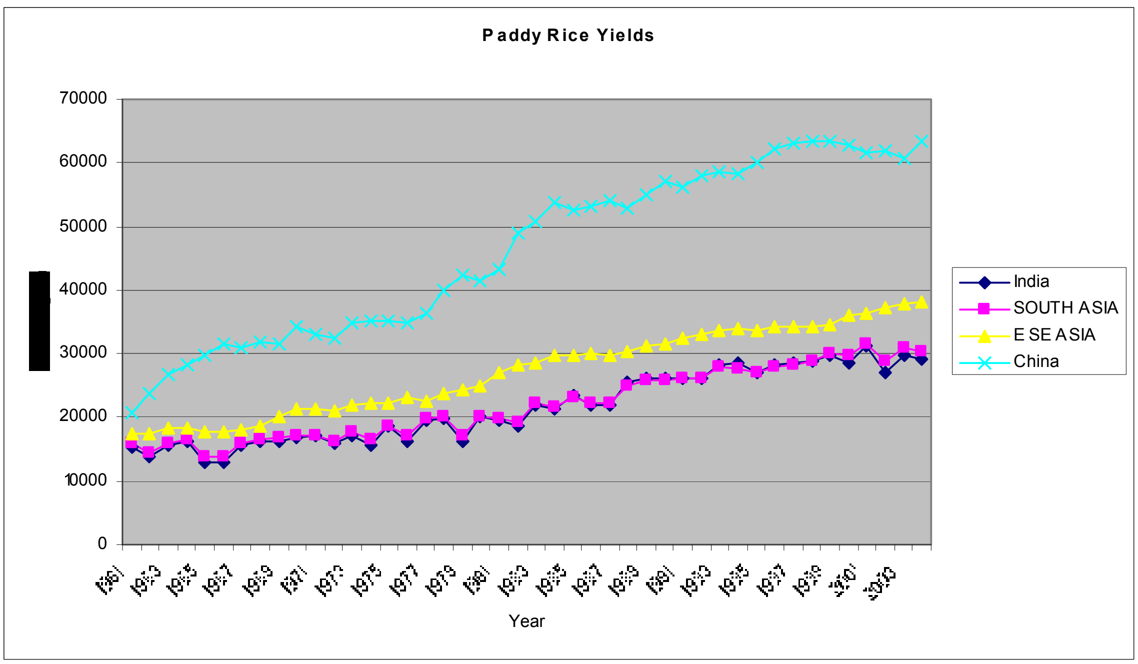
The development of agriculture in the SEAP region since the 1960s has been phenomenal, stimulated by the Green Revolution, which involved adoption of high yielding crop varieties (especially of rice, wheat, and to a lesser extent maize) together with rapid increase in complementary inputs of irrigation (in many cases), fertilizer, mechanical power, and other inputs. Between 1970 and 1995, average cereal yields more than doubled in China and nearly doubled in India, while increasing by more than 50 percent in the rest of the SEAP region (ADB 2000).

Yield growth was particularly rapid for paddy rice, wheat, maize and cotton, especially in China; but substantial growth has occurred even for millet and sorghum (Figures 17 to 22). Since the mid-1990s, yield growth has slowed for paddy rice in South Asia and China, but paddy yields have continued to grow (although more slowly than in the 1970s) in the rest of East Asia and the Pacific (Figure 17). Growth in wheat yields has also slowed in South Asia, but has continued (with significant year to year variation) in China (Figure 18).

Outside of China, wheat yields have not grown substantially in East Asia (mainly in Mongolia and Myanmar) since the 1960s, and in fact have declined since the mid-l980s. Growth in maize yields has slowed in China since the mid-1990s, but maize yields have continued to increase in the rest of East Asia and the Pacific and in South Asia (although yields in these areas are still well below those in China) (Figure 19).

The long term growth in cotton yields has been dramatic in China, increasing more than five-fold between the early 1960s and the early 2000s, though with substantial inter-annual variability (Figure 20). Cotton yields have not grown significantly since the late 1980s elsewhere in the SEAP region. Millet yields doubled in China between the early 1960s and the early 1990s, but since have shown no clear trend (but high variation) (Figure 21). Millet yields in India grew little between the early 1960s and mid-1980s, but since have grown significantly (more than doubling between 1985 and 2003. Sorghum yields quadrupled in China between the early 1960s and the mid-1990s, but have since shown no clear trend (but high inter-annual variation) (Figure 22). In India, sorghum yields doubled between the early 1970s and the early 1990s, but have since declined. Yields of several other crops (e.g., soybeans, beans, sweet potatoes) followed similar qualitative trends; i.e., growing more rapidly in China than elsewhere in the region since the 1960s, but with declining growth in recent years (Figures 23, 24, 25). For some crops (e.g., sugarcane and potatoes), long term yield growth has been fairly similar in China, Southeast and South Asia (Figures 26 and 27), while for cassava, yield growth has been more rapid in South Asia than in China or elsewhere in East and Southeast Asia (Figure 28).

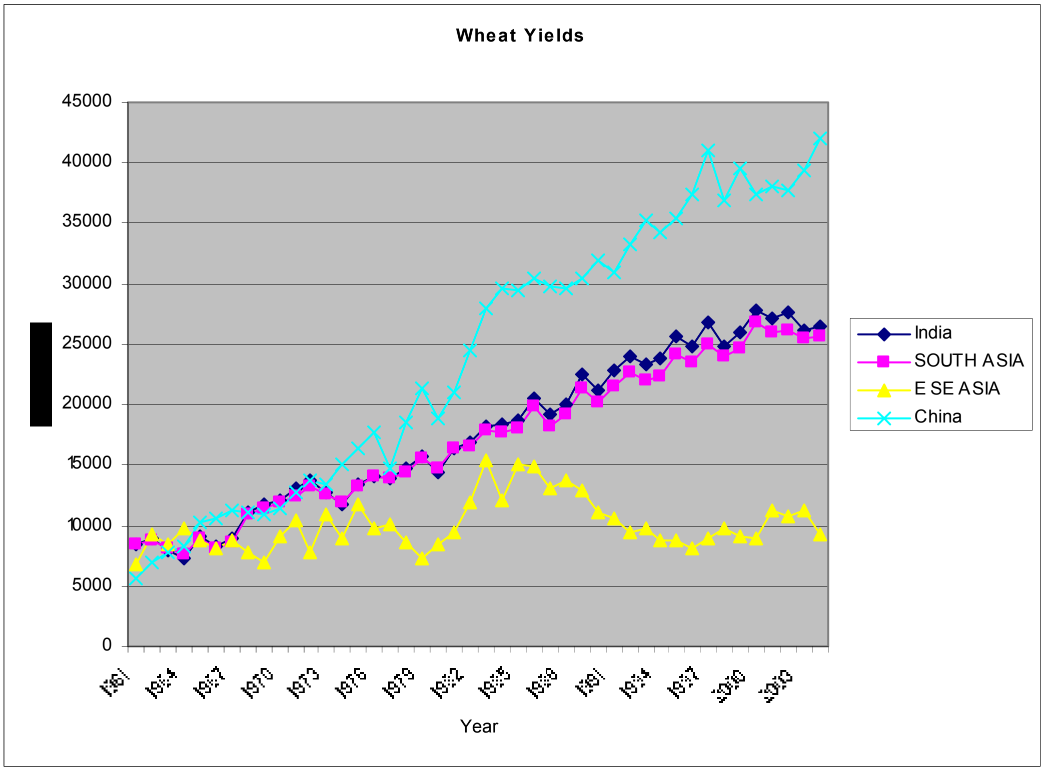
Figure 17. Paddy rice yields in South, Southeast and East Asia*



* Figures for South Asia include India. Figures for East and Southeast Asia exclude China.

Source: FAOSTAT 2006

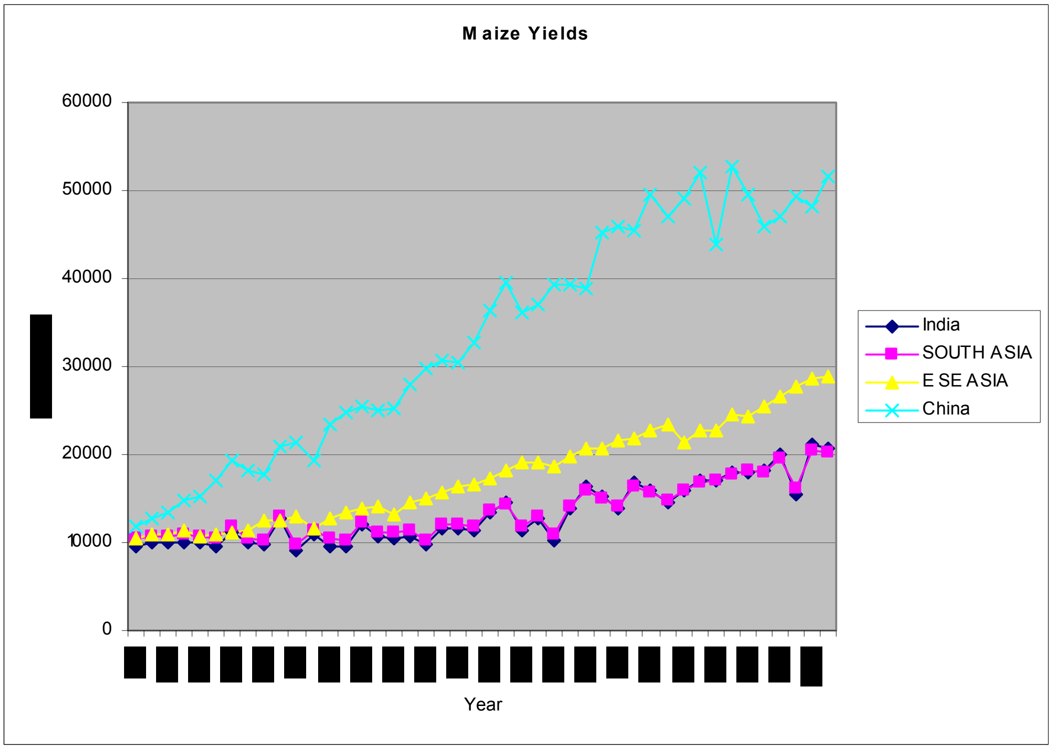
Figure 18. Wheat yields in South, Southeast and East Asia*



* Figures for South Asia include India. Figures for East and Southeast Asia exclude China.

Source: FAOSTAT 2006

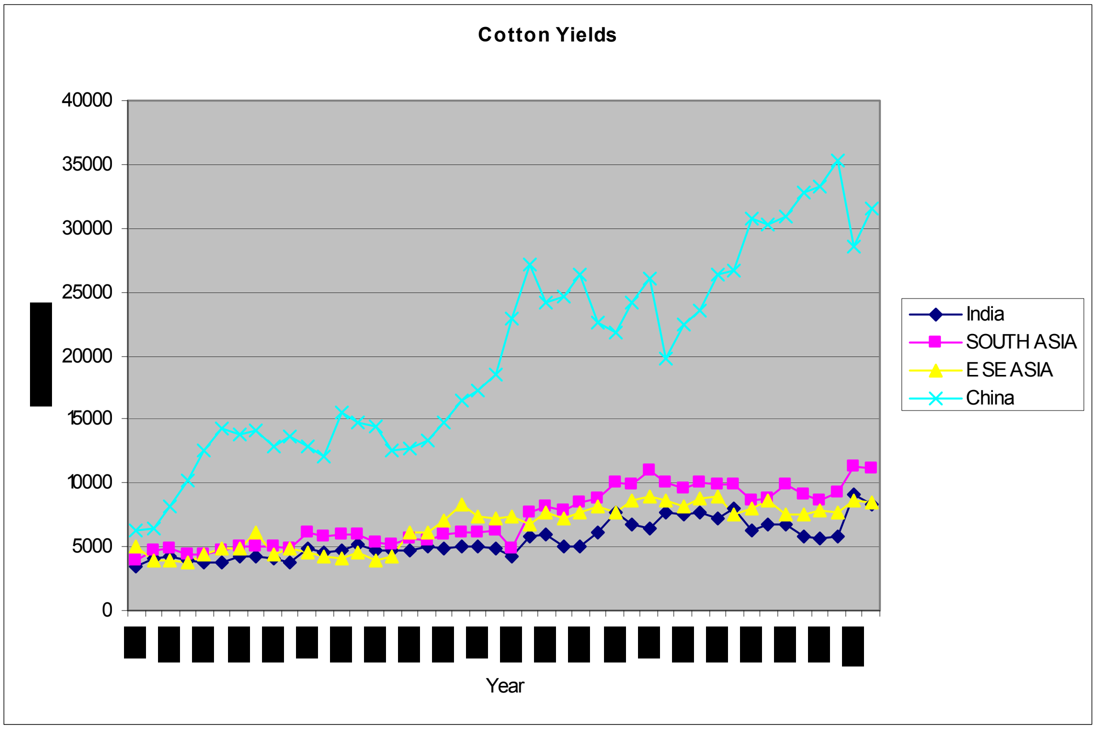
Figure 19. Maize yields in South, Southeast and East Asia*



* Figures for South Asia include India. Figures for East and Southeast Asia exclude China.

Source: FAOSTAT 2006

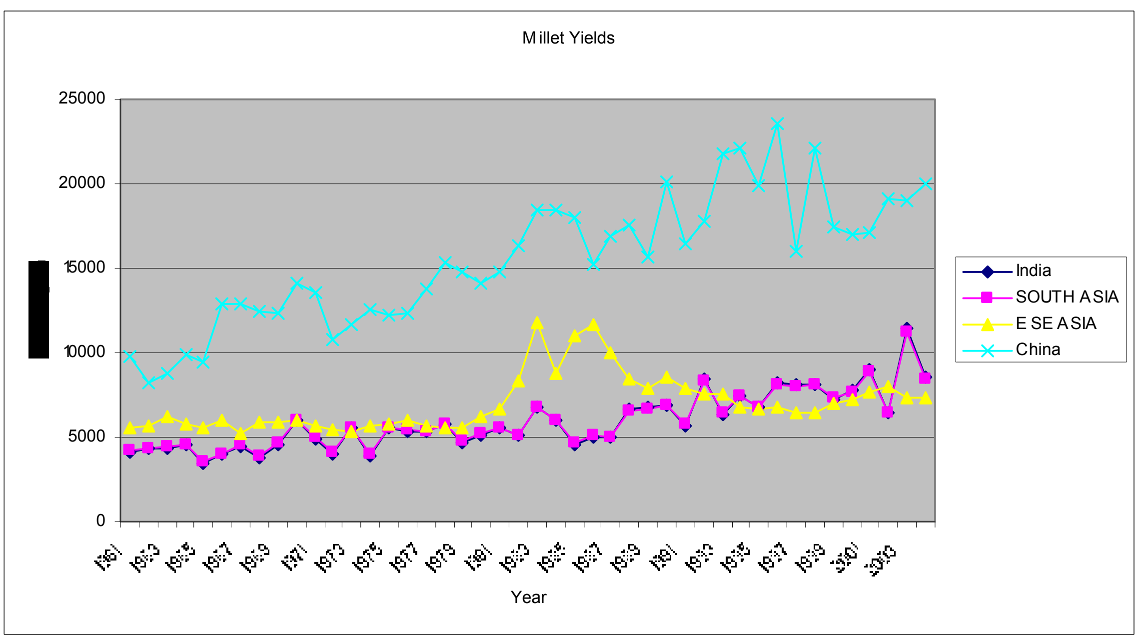
Figure 20. Cotton yields in South, Southeast and East Asia*



* Figures for South Asia include India. Figures for East and Southeast Asia exclude China.

Source: FAOSTAT 2006

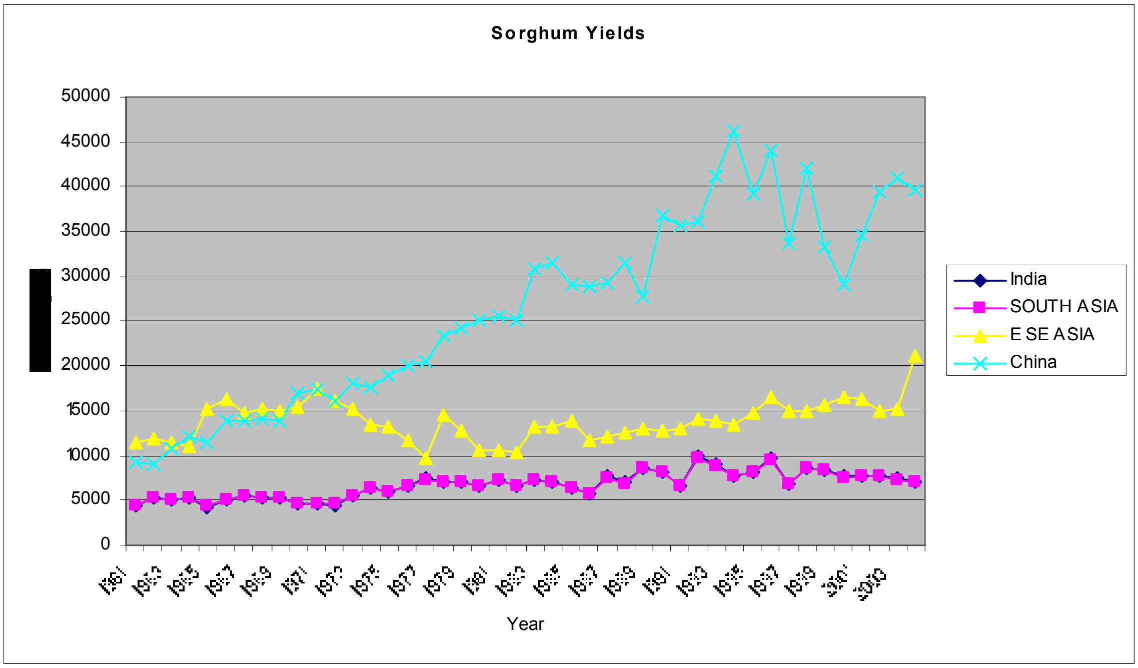
Figure 21. Millet yields in South, Southeast and East Asia*



* Figures for South Asia include India. Figures for East and Southeast Asia exclude China.

Source: FAOSTAT 2006

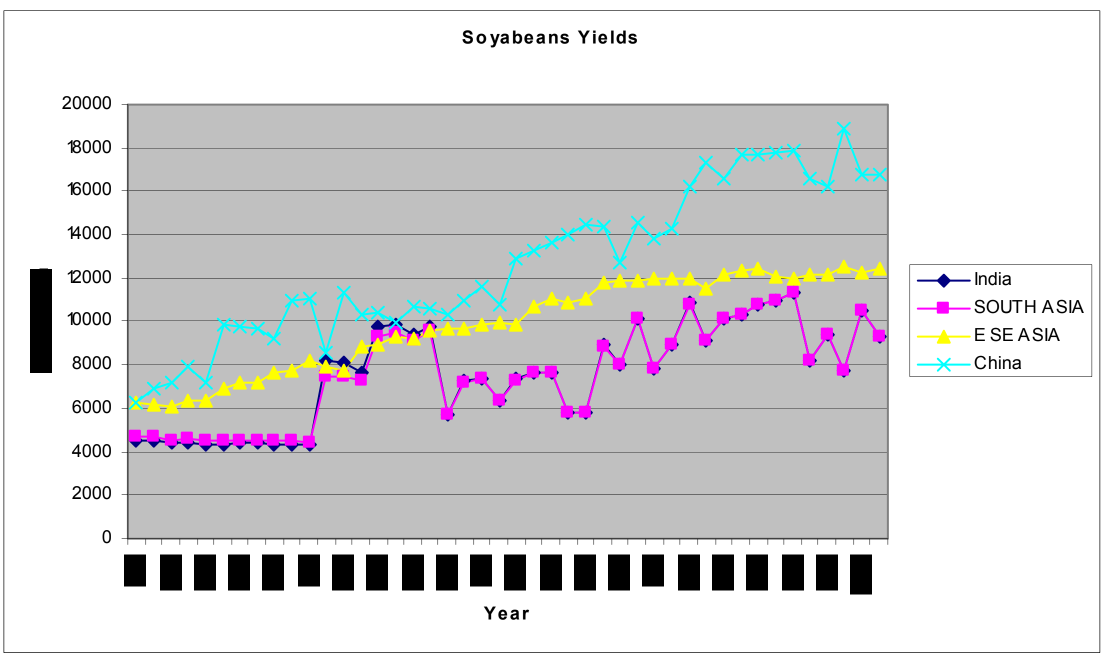
Figure 22. Sorghum yields in South, Southeast and East Asia*



* Figures for South Asia include India. Figures for East and Southeast Asia exclude China.

Source: FAOSTAT 2006

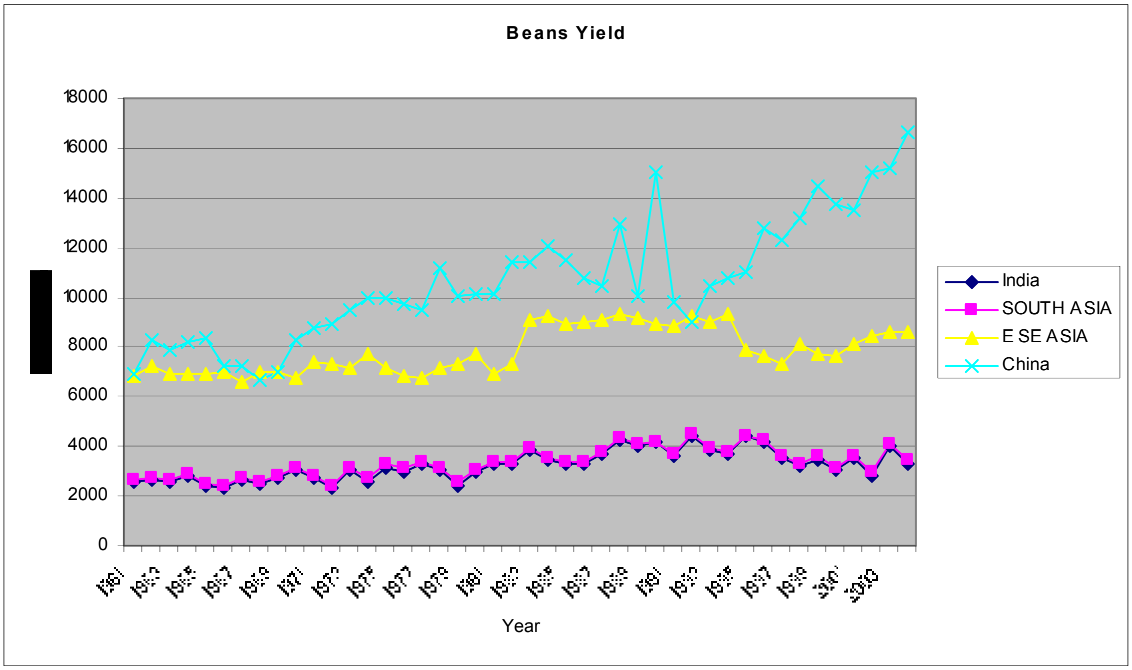
Figure 23. Soybean yields in South, Southeast and East Asia*



* Figures for South Asia include India. Figures for East and Southeast Asia exclude China.

Source: FAOSTAT 2006

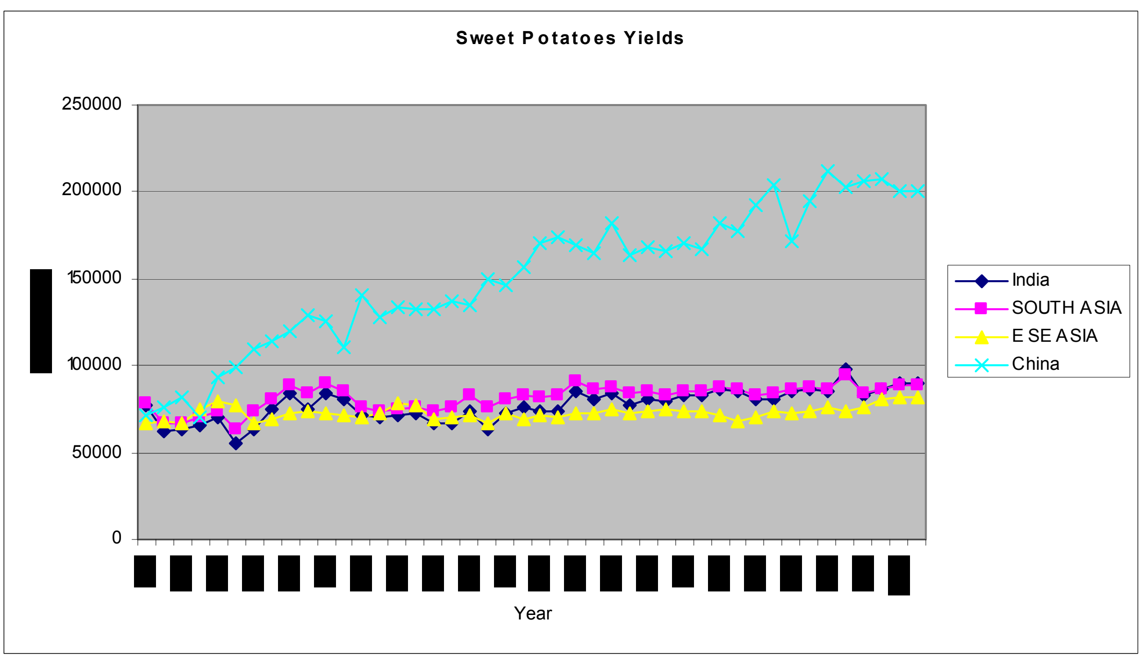
Figure 24. Beans yields in South, Southeast and East Asia*



* Figures for South Asia include India. Figures for East and Southeast Asia exclude China.

Source: FAOSTAT 2006

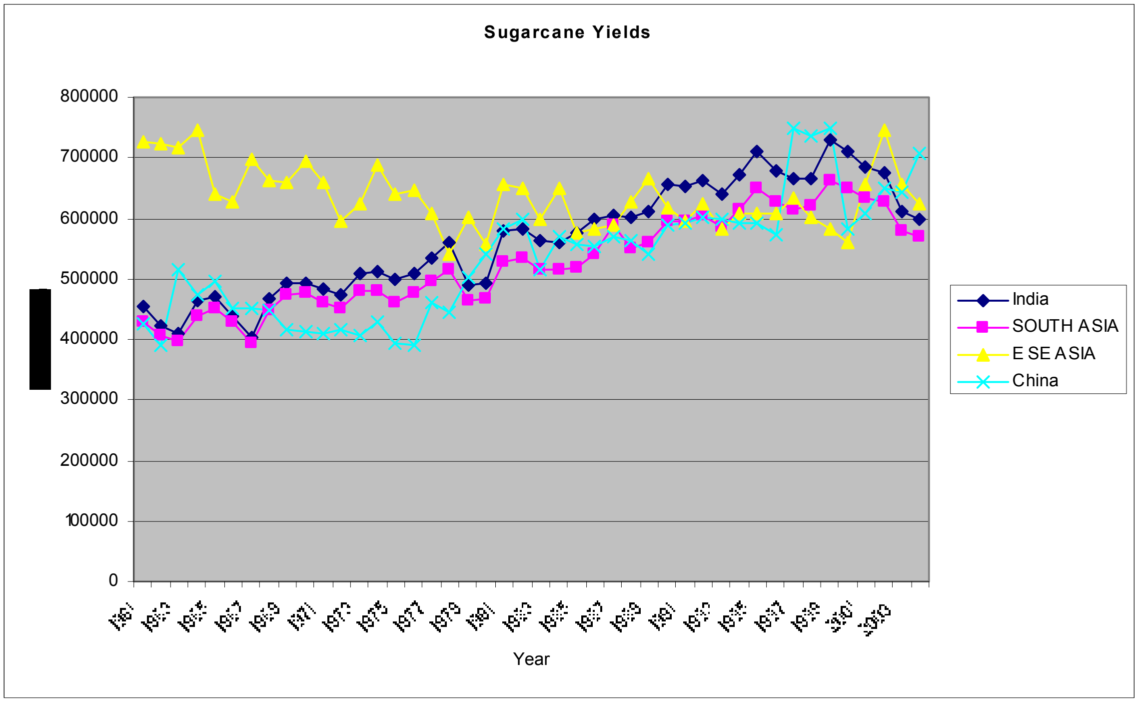
Figure 25. Sweet potato yields in South, Southeast and East Asia*



* Figures for South Asia include India. Figures for East and Southeast Asia exclude China.

Source: FAOSTAT 2006

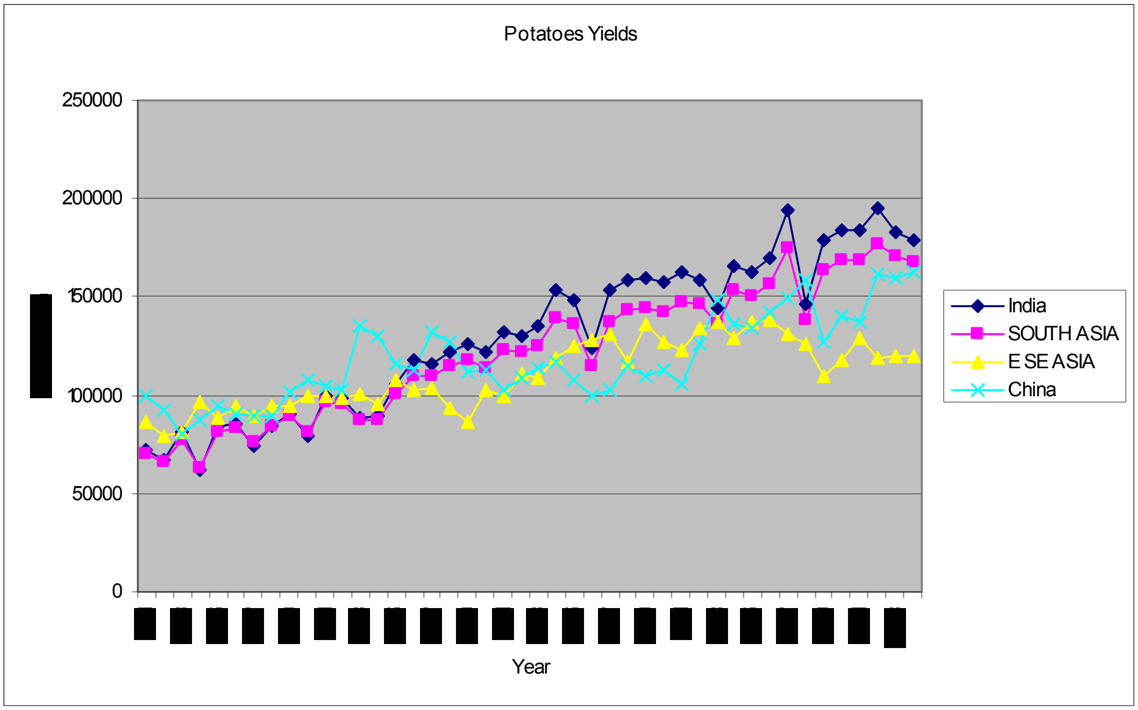
Figure 26. Sugarcane yields in South, Southeast and East Asia*



* Figures for South Asia include India. Figures for East and Southeast Asia exclude China.

Source: FAOSTAT 2006

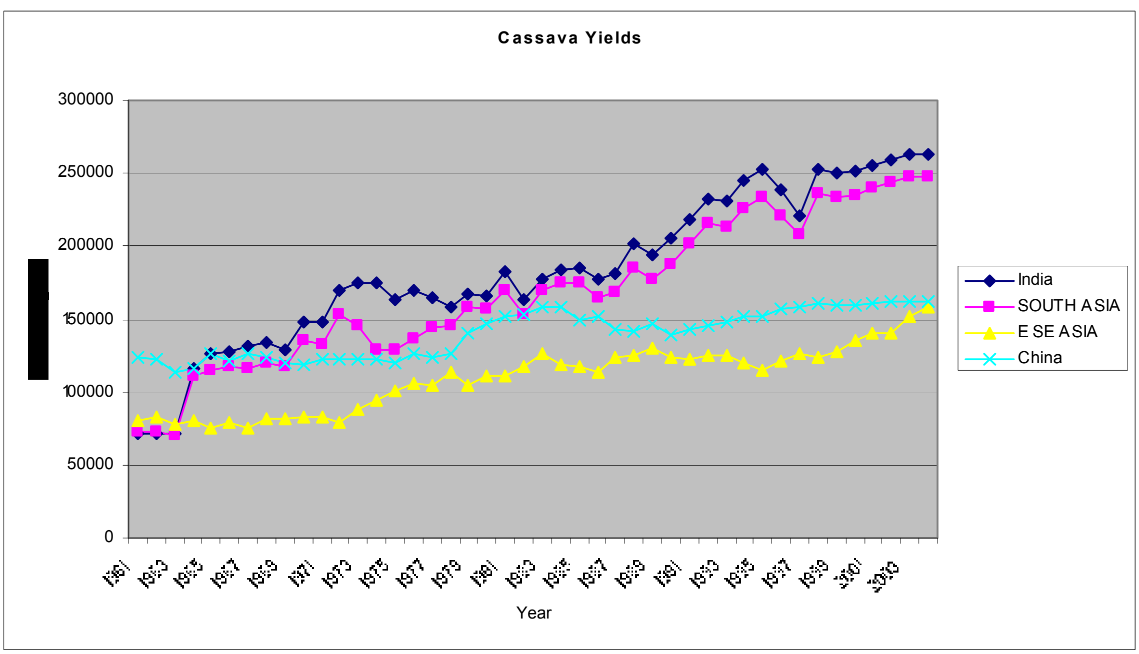
Figure 27. Potato yields in South, Southeast and East Asia*



* Figures for South Asia include India. Figures for East and Southeast Asia exclude China.

Source: FAOSTAT 2006

Figure 28. Cassava yields in South, Southeast and East Asia*



* Figures for South Asia include India. Figures for East and Southeast Asia exclude China.

Source: FAOSTAT 2006

The three main factors causing this growth in productivity were increased use of irrigation, widespread adoption of higher yielding varieties, and increased use of chemical inputs, especially inorganic fertilizer. The total irrigated area in the SEAP region nearly doubled between the early 1960s to the late 1990s, from 77 million hectares in 1961/63 (40 million ha in East Asia (including China) and 37 million ha in South Asia) to 152 million hectares in 1997/99 (71 million ha in East Asia and 81 million ha in South Asia) (FAO 2003).

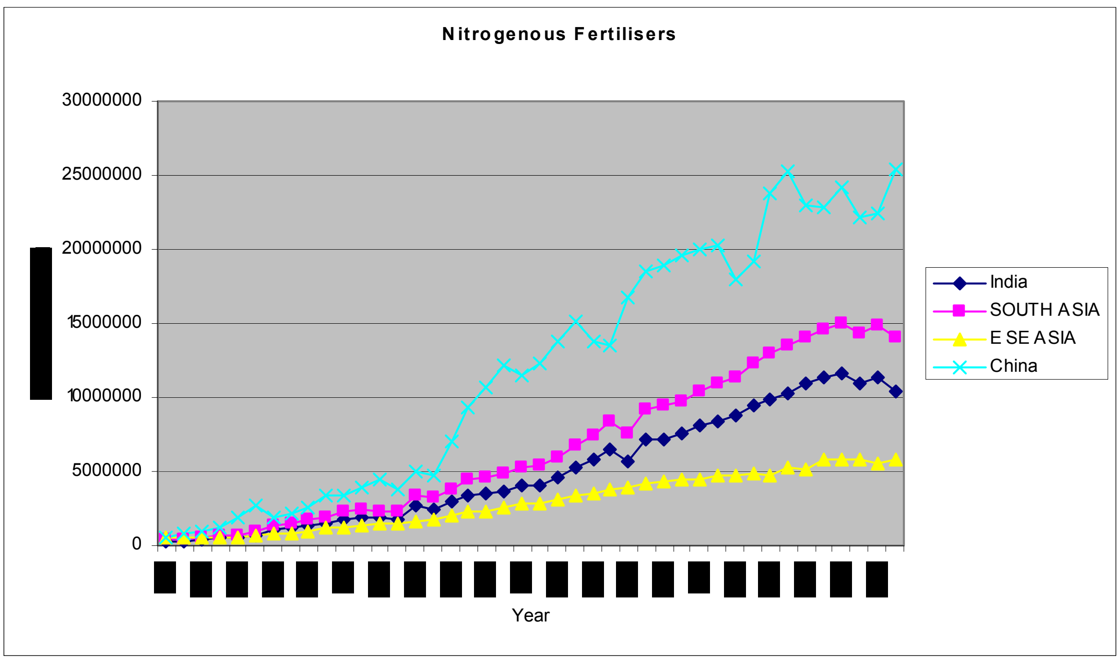
Use of modern varieties of rice increased from 2 percent of harvested area in South Asia and 5 percent in Southeast Asia in 1966 to more than 70 percent in both regions by 1999, with most of these modern varieties traceable to the International Rice Research Institute (IRRI) (Hossain, et al. 2003). Use of modern wheat varieties in Asia grew from 19 percent of wheat area in 1970 to 86 percent of wheat area in 1997, with nearly 60 percent of wheat area in the region planted with varieties with germplasm traceable to the International Center for Improvement of Maize and Wheat (CIMMYT) (Heisey, et al. 2003). By the late 1990s, 82 percent of maize area in South, Southeast and East Asia was planted to modern varieties; two thirds of the area was planted with hybrid varieties and about 21 percent of maize area used seed with CIMMYT germplasm (Morris, et al. 2003).[8] Adoption of improved varieties of pearl millet and sorghum began in India during the 1960s after releases by the Indian national research program and increased as a result of breeding by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). By 1996, 65 percent of pearl millet area in India was planted to modern varieties, most of this planted with either an ICRISAT cross or seeds having an ICRISAT parent (Bantilan and Deb 2003). By the late 1990s, 98 percent of the sorghum area in China, 69 percent in India, and 21 percent in Pakistan were planted with modern sorghum varieties, though only about 10 to 15 percent of this was traceable to ICRISAT germplasm (Deb and Bantilan 2003). By the late 1990s, improved varieties of groundnut were adopted on more than 90 percent of the groundnut planted area in China, on between 5 and 95 percent of planted area in different areas and seasons in India, and

[8] Figures for adoption of modern varieties of maize in an earlier period were not available from this source.

17 percent of planted area in southern Vietnam (Bantilan, et al. 2003). Ninety percent of potato area in Asia was planted to modern varieties by 1998 (Evenson and Gollin 2003).

Use of inorganic fertilizer use grew exponentially in the SEAP region, especially in China. Use of nitrogenous fertilizers increased more than five-fold in China and South Asia between the early 1970s and the early 2000s, and more than tripled in the rest of East and Southeast Asia (Figure 29). Growth in use of phosphate and potash fertilizers was also very rapid in these regions (Figures 30 and 31). Use of pesticides (insecticides and herbicides) and tractors also grew rapidly in the region (Figures 32, 33, and 34).

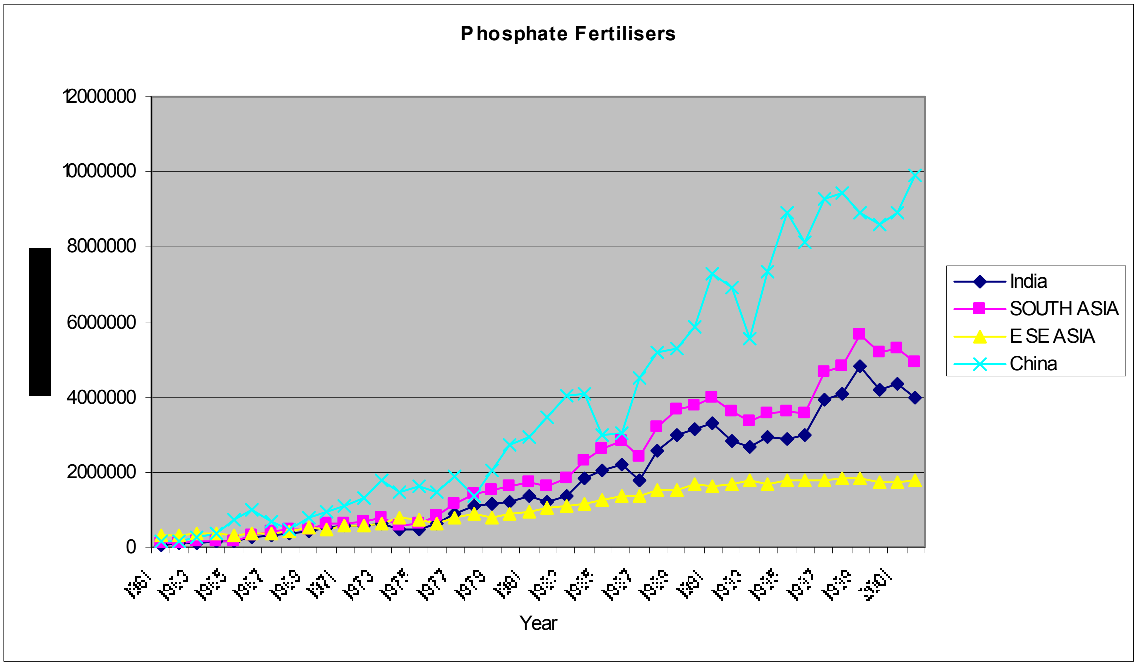
Figure 29. Use of nitrogenous fertilizers in South, Southeast and East Asia*



* Figures for South Asia include India. Figures for East and Southeast Asia exclude China.

Source: FAOSTAT 2006

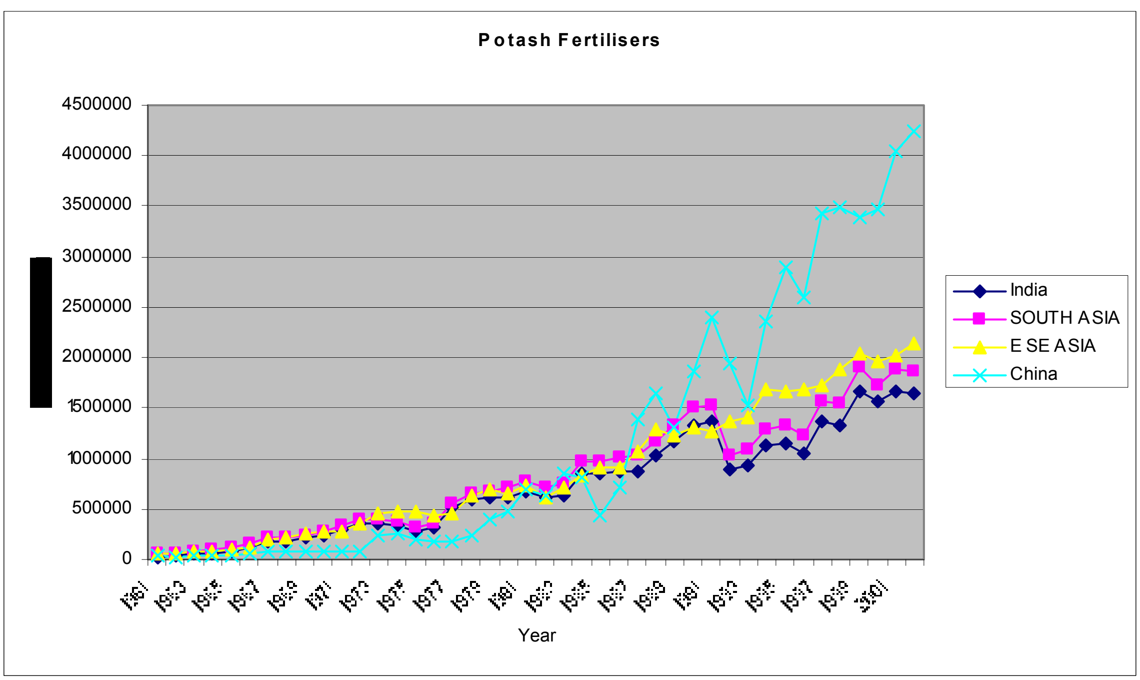
Figure 30. Use of phosphate fertilizers in South, Southeast and East Asia*



* Figures for South Asia include India. Figures for East and Southeast Asia exclude China.

Source: FAOSTAT 2006

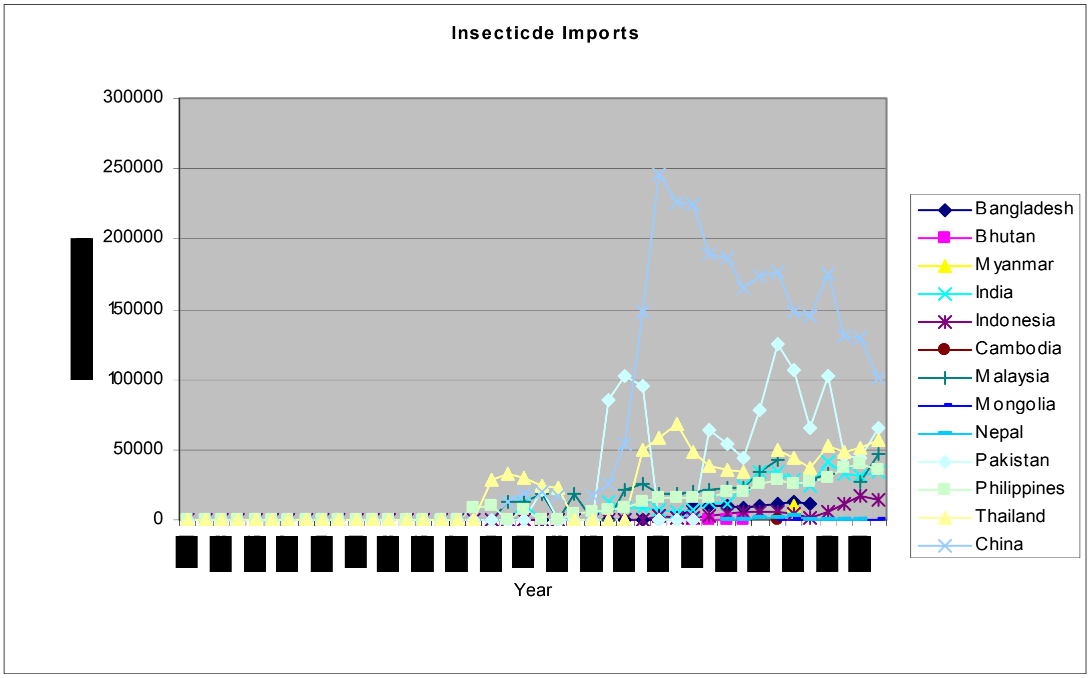
Figure 31. Use of potash fertilizers in South, Southeast and East Asia*



* Figures for South Asia include India. Figures for East and Southeast Asia exclude China.

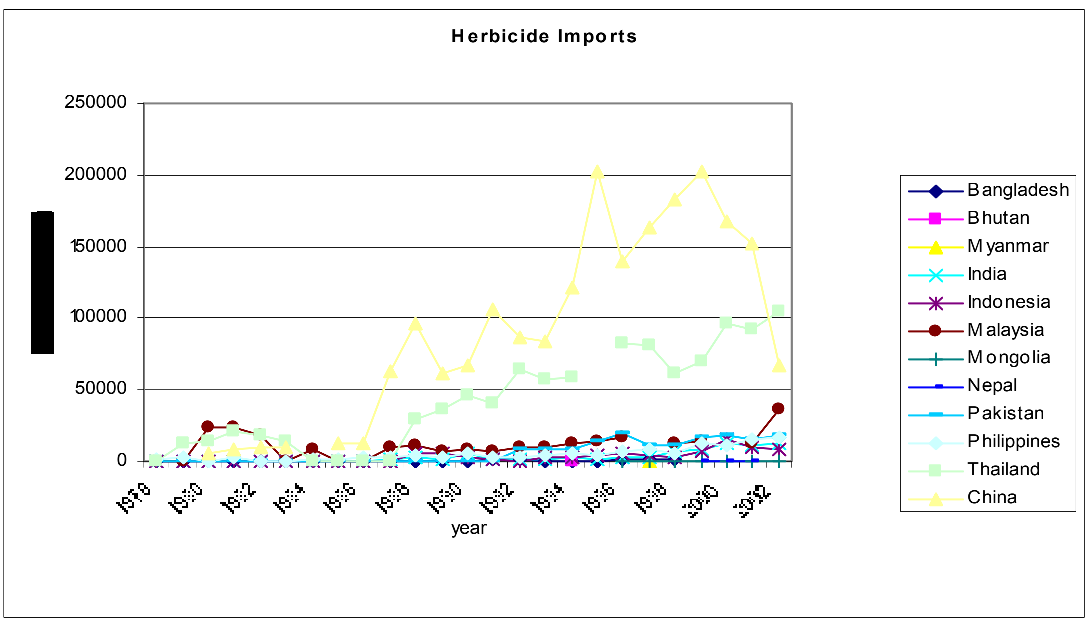
Source: FAOSTAT 2006

Figure 32. Imports of insecticides in South, Southeast and East Asia*



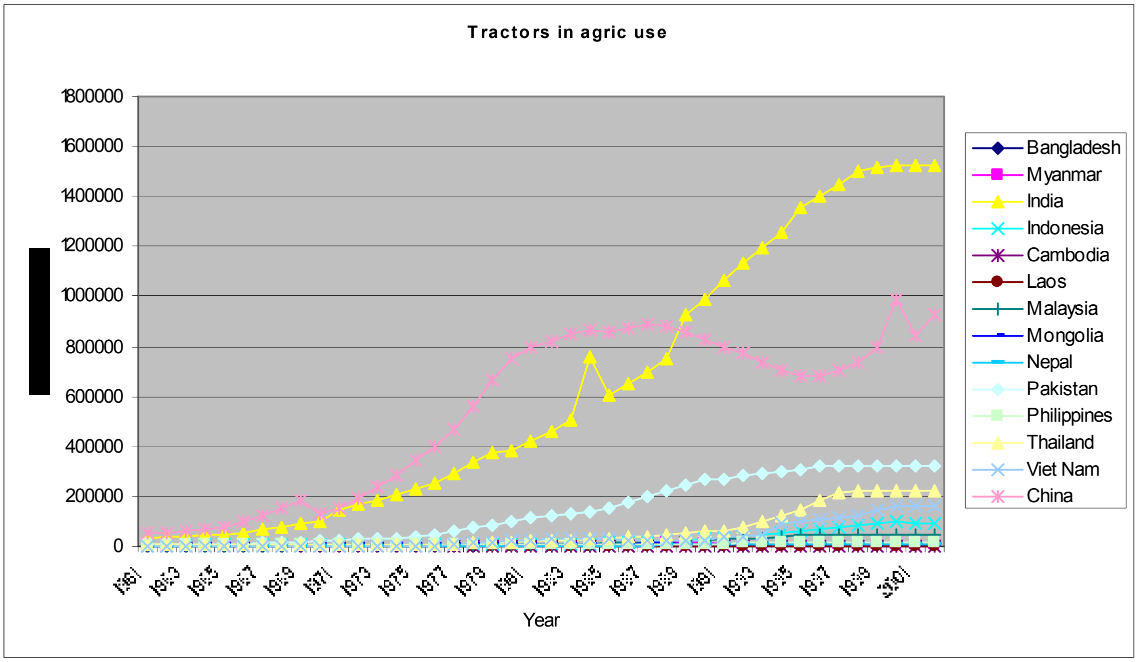
Source: FAOSTAT 2006

Figure 33. Imports of herbicides in South, Southeast and East Asia*



Source: FAOSTAT 2006

Figure 34. Use of tractors in South, Southeast and East Asia*



Source: FAOSTAT 2006

This long term rise in agricultural productivity greatly reduced the threat of famine in both China and India (where famines had previously cost millions of lives), leading to increased food availability, consumption and improved nutrition in the region. For example, per capita calorie consumption increased by one third in East Asia and by 15 percent in India between 1970 and 1995 (ADB 2000).

Beyond boosting food production and consumption, the Green Revolution stimulated a much broader process of economic development and transformation of the rural economy in the SEAP region (Rosegrant and Hazell 2000). Increased food production and use of purchased inputs stimulated the non-farm economy directly through backward linkages (increased demand for inputs and supply services) and forward linkages (increased demand for marketing, storage, transportation and processing services). Increased food security, declining food prices and increased land and labor productivity provided the incentive and ability to shift some resources out of food production and into production of other agricultural commodities and non-farm activities, contributing to the processes of agricultural diversification, commercialization, and urbanization. Increased labor productivity led to rising wages and incomes of landless laborers and small farmers as well as larger farmers, and stimulated mechanization and development of rental and repair services for farm equipment. Because of the divisibility of the improved seed and fertilizer technology, small as well as large farmers were able to adopt and benefit from the technology (where they had access to irrigation), although their adoption was initially slower because of smaller farmers' concerns about risk, and lack of access to credit and extension services (Lipton and Longhurst 1989; Hazell and Ramasamy 1991).

Thus the distribution of the income benefits from the technologies was widespread, and this contributed to greater impacts on the non-farm economy via demand linkages. Increased productivity also reduced the foreign exchange burden of food imports in food importing countries, and contributed to increased foreign exchange earnings through diversification into exportable commodities. This process of rural (and urban) development also increased the ability of households to finance private investments and of governments (through increased tax revenues) to finance complementary public investments and services such as rural infrastructure, agricultural research, development and extension, and education and health.

As a result of all of these processes (and other favorable factors such as policy reforms and market liberalization), mostly stable macroeconomic conditions, public investments in infrastructure and education, and development of the manufacturing sector), per capita income (in real terms) increased more than five-fold in China, nearly tripled in Southeast Asia, increased by 82 percent in India and 60 percent in other countries of South Asia between 1970 and 1995 (ADB 2000). The incidence of rural poverty (using the international poverty line of $1 per day in 1985 dollars, purchasing power parity) declined from 60 percent of the rural population in China in 1975 to 22 percent in 1995, while national poverty incidence fell from 53 percent to less than 12 percent in Southeast Asia and from 59 percent to 43 percent in South Asia. During this period, the absolute number of poor people in China and Southeast Asia fell from 680 million to about 310 million, while the number of poor continued to increase in South Asia, from 470 million to 510 million, as a result of population growth. By the late 1990s/early 2000s, the number of poor people in China and Southeast Asia had declined further to 258 million (212 million in China and 46 million in Southeast Asia), and had declined to 449 million in South Asia (ADB 2004).

Impacts on Less-Favored Areas

The impacts of the Green Revolution and associated rural development, although widespread, did not reach all rural areas or all farmers. As noted earlier, less favored areas without access to irrigation or reliable rainfall benefited much less from the improved rice and wheat varieties that were introduced during the first phase of the Green Revolution (up to the early 1980s), widening the gap between less-favored and more favored areas (Lipton and Longhurst 1989; Freebairn 1995). Evidence from south India shows that while both small and large farms in irrigated areas made substantial income gains during the early Green Revolution (with smaller farms catching up after an initial lag in adoption), farmers in rainfed areas made only small income gains (Hazell and Ramasamy 1991). Hence the early Green Revolution contributed to more spatial concentration of poverty in less-favored areas, although it reduced poverty overall.

During the second phase of the Green Revolution (since the early 1980s), the benefits have spread more widely to rainfed areas and other crops. As shown in the previous subsection, substantial adoption of improved varieties of many other crops under mostly rainfed conditions has occurred since the early 1980s, due largely to efforts of the international agricultural research centers (IARCs) and national agricultural research systems (NARS) in the SEAP region and elsewhere to develop germplasm for a wider variety of conditions (Evenson and Gollin 2003).

The impacts of improved varieties on production of crops have been substantial, even for crops other than wheat and rice. Based on a broad review of evidence on adoption of improved varieties and their impacts based on experimental and econometric studies, Evenson (2003a) developed “consensus estimates” of the impacts of improved crop varieties on crop yields, and found that the yield growth of most crops was increased by close to 1 percent per year between 1960 and 1998 in Asia as a result of genetic improvement (Table 9).

Table 9. Estimated contributions of crop genetic improvement to yield growth in Asia, and adoption of IARC varieties

Crop	Annual yield growth contribution of improved varieties by period					Adoption shares of IARC varieties in 1998	
	1960s	1970s	1980s	1990s	1960-98	IARC varieties	NARS variety/ IARC ancestor
Wheat	0.678	1.118	1.168	0.846	1.006	0.23	0.35
Rice	0.375	0.998	0.966	0.713	0.868	0.30	0.30
Maize	0.407	0.694	1.016	1.377	0.959	0.30	0.32
Sorghum	0.148	0.622	1.403	0.976	0.847	0.05	0.20
Millets	0.515	0.963	0.954	1.392	1.043	0.27	0.41
Cassava	0.000	0.000	0.091	0.485	0.174	0.80	0.20
Potatoes	0.811	0.672	0.759	0.846	0.825	0.05	0.07

Source: Evenson (2003a)

Improved maize productivity has benefited many rainfed maize producers in less-favored upland regions (recall that 82 percent of maize area was planted to modern varieties by the late 1990s, that most maize production in the SEAP region is under rainfed conditions, and that much of it is in sloping upland areas such as in the Philippines, Indonesia, eastern China and other countries). Surprisingly, the estimated impact of crop genetic improvement for millets in Asia is even larger than for wheat, rice and maize, while the estimated impact on sorghum is lower, but still above 0.8 percent per year (with larger impacts in the 1980s and 1990s). Since millet and sorghum are grown mainly by poor farmers in less favored semi-arid areas, these positive impacts of crop genetic improvement reached large numbers of poor farmers producing these crops in less favored areas of Asia (recall that improved varieties of pearl millet were used on almost all pearl millet area in China and two-thirds in India by the late 1990s). Hence, contrary to what many observers believe improvements in yields as a result of crop genetic improvement continued and even accelerated for several crops after the first phase of the Green Revolution, and had large impacts on rainfed as well as irrigated crops, even in less favored semi-arid areas.

The evidence also shows that the IARCs had a major impact on these improvements in almost all cases (except potatoes), either through direct adoption of IARC varieties or through adoption of NARS varieties developed using IARC ancestors. These impacts are supported by a large number of studies showing large returns to investments in public sector agricultural research in the IARCs and the NARS (Alston, et al. 2000; Raitzer 2003) and by the studies of Fan and colleagues in India and China, which showed that investments in agricultural research and development have large benefit cost ratios and large impacts on agricultural productivity and reducing poverty, especially in less favored areas (Fan and Chan-Kang 2004). For example, Fan and Hazell (1999) estimated that planting of high yielding varieties (HYV's) increased farmers value of production by 688 Rupees per hectare in low potential rainfed areas of India, but only 243 Rupees per hectare in high potential rainfed areas and 63 Rupees per hectare in irrigated areas (controlling for other types of investments), and that the impacts on poverty of using HYV's was much larger in low potential rainfed areas (Table 4). Fan, et al. (2000) estimated very high benefit cost ratios in terms of the impacts of HYV's on the value of agricultural production per rupee spent in several rainfed zones of India (B/C ratios of more than 5 in several zones), including many zones with lower land productivity, although there was large variation in returns across the rainfed zones (Table 5). The predicted impacts of HYV adoption on poverty were larger (much larger in most cases) in six of the rainfed zones than in the irrigated zone, including several low productivity zones. In China, Fan, et al. (2004) estimated the highest marginal benefit cost ratios to investments in agricultural R&D in the lower potential western region, although the B/C ratios for agricultural R&D were high in all regions (Table 6). The positive impacts of agricultural R&D on rural poverty reduction were even more striking, with agricultural R&D in the western region having the largest estimated impact on poverty reduction per yuan among all public investments and all regions, and more than six times the impact of agricultural R&D investments in the coastal region and nearly twice the impact of such investments in the central region. Thus, there is a strong case for continued and even increased investments by donors and governments in public agricultural research and development in the SEAP region, especially if the emphasis is on reducing poverty in less-favored areas.

Sustainability Concerns

Although the impacts of the Green Revolution in SEAP have been overwhelmingly positive, there is evidence that the rate of productivity increase has slowed down, especially in intensive rice cultivation, but also in intensive wheat production (Pingali and Rosegrant 2001). Part of the reason for this slowdown has been the long term decline in cereal prices, which has induced some reduction in use of inputs in intensive systems and reduced public investments in agricultural research and development for these crops. But even in long term experiments, in which use of inputs is controlled, there is evidence of declining productivity in intensive wheat and rice systems (Ibid.). Degradation of the natural resource base in these systems is an important contributor to slowing productivity growth and in some cases declining productivity.

Heavy reliance on subsidized irrigation has led to problems of increasing water scarcity, declining groundwater levels, salinization, and waterlogging (Pingali and Rosegrant 2001; Santikarn Kaosa-ard and Rerkasem 2000). As a result of heavy reliance on tube well irrigation, unregulated access to groundwater and policies providing cheap electricity for pumping, groundwater levels are falling rapidly in many areas, by as much as 1 meter per year in parts of the North China Plain, and by as much as 25 to 30 meters in a decade in southern India (Postel 1993). For the SEAP region as a whole, aridification (drying of the soil due to depletion of groundwater, loss of soil vegetative cover and other factors) is estimated to affect about 7 percent of the arable land (van Lynden and Oldeman 1997). Depletion of groundwater not only causes drying of the soil and increases the scarcity of water and costs of pumping, but in coastal regions can cause salt water intrusion into the wells.

Salinization is a major problem in irrigated arid and semi-arid zones, caused by excessive irrigation with inadequate drainage, and has been estimated to affect nearly one fourth of irrigated land worldwide, with India, China and Pakistan among the most affected countries (Postel 1989). In the SEAP region as a whole, salinization is estimated to affect about 10 percent of arable land, and is moderate to severe (with major impacts on productivity) on about half of this (van Lynden and Oldeman 1997). Salinization can be very costly to reverse, requiring investments in drainage and use of large amounts of scarce freshwater. At low levels, the problem may be manageable through planting of salt tolerant crops, but it can eventually lead to abandonment of large areas of formerly productive land.

Waterlogging is a greater problem in wetland cultivation in higher rainfall areas, causing reduced decomposition rates of organic matter, reduced nitrogen availability and accumulation of soil toxins (Pingali and Rosegrant 2001). Waterlogging is estimated to affect 7 percent of the arable land in the SEAP region, and is having moderate to severe impacts on about 2 percent of the arable land (van Lynden and Oldeman). The problem of soil compaction is aggravated by continuous monocropping, puddling and tillage practices in wetland rice cultivation, which cause formation of a hardpan below the topsoil with limited permeability. Soil compaction is estimated to affect about 1 percent of the arable land in the SEAP region (Ibid.).

Repeated paddy rice cultivation also reduces the nitrogen supplying capacity of the soil due to changes in the organic matter composition and reduced microbial activity under flooded conditions (Pingali and Rosegrant 2001). Farmers are then forced to apply more nitrogenous fertilizer to obtain the same yields. Excessive and unbalanced use of nitrogen rich fertilizers can accelerate depletion of other soil nutrients, including phosphorus, potassium and micronutrients such as zinc. Soil toxicities, especially iron toxicity, are also caused by continuous flooding of paddy fields with poor quality water and inadequate drainage. Relatively simple agronomic solutions to many of these problems exist, such as appropriate crop rotations and use of more balanced fertilizers, but the problems are not always correctly identified (e.g., micronutrient deficiencies are often diagnosed as pest damage) and better agronomic practices may entail some loss of profitability in the near term.

Heavy reliance on chemical fertilizers and pesticides is also causing water pollution, adverse health impacts, and contributing to pest outbreaks by promoting development of resistance and killing beneficial insects (Altieri 1995). Extensive monocropping also contributes to pest problems by reducing habitat for beneficial insects, while increasing the susceptibility of farming systems to pests by reducing biodiversity.

Degradation of natural resources is also undermining the potential for productivity and income gains in less intensive rainfed farming systems in the SEAP region. Soil erosion and soil fertility depletion are major problems in many of these areas (Scherr 1999; van Lynden and Oldeman 1997).

For the SEAP region as a whole, soil erosion is estimated to have moderate to extreme impacts (leading to substantial losses in agricultural productivity) on nearly 10 percent of the total land (nearly half of the arable land) (Wood, et al. 2000), while moderate to extreme soil fertility depletion affects about 12 percent of the arable area (van Lynden and Oldeman 1997) (Table 10).

Table 10. Land degradation in the SEAP region

Type of degradation	Light	Moderate	Strong or extreme	Degraded land as % of total land
Water erosion	Percent of total land degraded			
- Loss of topsoil	9.5	5.3	0.9	15.7
- Terrain deformation	1.2	0.9	1.8	4.9
- Off-site effects in uplands	0.2	< 0.1	0.1	0.3
Wind erosion				
- Topsoil loss	4.0	0.9	0.4	5.4
- Terrain deformation	0.4	0.6	3.2	4.2
- Off-site effects	0.1	0.5	0.2	0.8
Soil fertility decline				
- Total land	3.7	2.4	0.1	6.2
- (Arable land)	(18.0)	(11.9)	(0.5)	(30.4)
Salinization				
- Total land	1.1	0.8	0.2	2.1
- (Arable land)	(5.5)	(3.8)	(0.9)	(10.2)
Acidification				
- Arable land	(0.5)	(0.2)	(< 0.1)	(0.7)
Aridification				
- Total land	1.3	< 0.1	< 0.1	1.3
- Arable land	(6.3)	(< 0.1)	(0.4)	(6.7)
Compaction				
- Total land	0.1	< 0.1	< 0.1	0.1
- (Arable land)	(0.8)	(0.4)	(< 0.1)	(1.3)
Waterlogging				
- Total land	1.0	0.3	0.1	1.4
- (Arable land)	(5.0)	(1.4)	(0.7)	(7.1)

Notes: Estimates of arable land degradation were calculated by Scherr (1999) using FAO data on total arable land area, and assuming that all land reported by the Assessment of Human-Induced Soil Degradation in South and Southeast Asia (ASSOD) with these types of degradation were arable lands. This is generally but not al ways true, and thus these figures may overestimate soil degradation on arable lands. “Light” degradation implies little impact on agricultural productivity. “Moderate” implies major impact and a need to compensate for degradation with high management to avoid significant productivity de cline. “Strong” or “extreme” implies a major impact on productivity that can not be compensated for even with high levels of management and is unproductive under low management.

Source: Scherr (1999), adapted from van Lynden and Oldeman 1997.

Water erosion is predominant in large parts of China (more than180 million ha affected), except for the northern parts of China, on the Indian subcontinent (greater than 90 million ha) and in the sloping parts of Indochina (40 million ha), the Philippines (10 million ha) and Indonesia (22.5 million.ha). In relative terms (as percentage of the total country area) moderate to extreme water erosion is particularly important in India (10 percent), the Philippines (38 percent), Pakistan (12.5 percent), Thailand (15 percent) and Vietnam (10 percent) (Ibid.). Wind erosion (9 percent of the total area, 20 percent of all degradation) is concentrated mainly in the western and northern arid and semi-arid regions of Pakistan (greater than 9 million ha on-site and 2 million ha affected off-site), India (20 million ha on-site, 3.6 million ha offsite), and China (greater than 70 million ha on-site, greater than 8.5 million ha off-site) (Ibid.). Although large parts of these regions are natural deserts, some human-induced wind erosion is also occurring as a result of overgrazing of livestock and other human activities. Soil fertility depletion is occurring in most countries (with mostly negligible to light impact on productivity), but is relatively most important in Bangladesh (7.5 million ha), Thailand (25.5 million ha), Sri Lanka (3 million ha), Cambodia (8.5 million ha), Myanmar (2.5 million ha) and Pakistan (18.5 million ha) (Ibid.).

In contrast to the situation in intensive rice and wheat production, in many less favored areas the degradation problems are caused more by agricultural extensification (i.e., expansion of farming into more marginal and fragile areas) or by lack of sufficient intensification (e.g., shortening of fallow periods without addition of soil nutrients from organic or inorganic sources; lack of investment in soil and water conservation measures on sloping lands), than by excessive use of inputs.

Overall, estimates of the annual economic losses due to soil degradation in the SEAP region range from 1 to 7 percent of agricultural GDP (Scherr 1999). Young (1993) estimated the annual cost of soil degradation in South Asia at $9.8 - $11.0 billion, equal to about 7 percent of agricultural GDP (AGDP). Water and wind erosion accounted for more than two-thirds of the loss, salinization and waterlogging about one fifth, and soil fertility decline the rest. In Pakistan, waterlogging and salinization in irrigated areas led to estimated losses in wheat production worth about 5 percent of AGDP, and in India, total annual cereal production losses due to these problems were also valued at 5 percent of AGDP (Ibid.). Studies in China found that land degradation had reduced grain yields substantially, estimating that total grain production would have been 60 percent higher during 1983-89 in the absence of land degradation, with most of this loss caused by increased flooding and drought and soil erosion (Huang and Rozelle 1994 and 1996; Huang, et al. 1996). Without the effects of land degradation (mostly erosion), rice yields would have grown 12 percent faster in the late 1980s and early 1990s, while erosion reduced production of maize, wheat and cash crops in north China by up to 20 percent during this period (Ibid.). These authors estimated that the economic loss from soil degradation in China in the late 1980s reached $700 million (1990 prices)—less than 1 per cent of AGDP (Ibid.). Magrath and Arens (1989) estimated that agricultural productivity on the island of Java was declining by a rate of 2 – 5 percent per year due to soil erosion, causing annual economic losses of about 3 percent of AGDP. Repetto, et al. (1989) estimated that for two crops grown on 25 soil types, the costs of soil erosion in Java in 1984 equaled 4 percent of the annual value of rainfed agricultural production.

In addition to soil degradation, other sustainability concerns in less favored rainfed upland and dryland areas include deforestation (especially in uplands and highlands), degradation of rangelands (mainly in drylands), declining biodiversity (as a result of forest and rangeland degradation), and reduced water availability and quality (IFAD 2002). Many of these problems are interrelated, and are often linked to unsustainable management of common pool resources as a result of situations of unregulated open access. Control of such resources by central governments has often contributed to these situations, since central governments are usually unable to enforce use restrictions in remote areas and local resource users have little ability or incentive to manage them sustainably, given their lack of authority and the threat of eviction (IFAD, undated). In recent years there have been increased efforts to devolve authority over such common property resources to local communities, with promising results. For example, "social fencing" of common resources promoted by group or community based approaches has been found to be effective in developing and enforcing local systems of sanctions, as well as fostering equity by linking benefits to labor and other contributions (IFAD 2002). In the IFAD-supported Nepal Hills Leasehold Forestry and Forage Development Project, degraded forests were leased to the poorest people in the surrounding villages for growing fodder, generating substantial benefits for the poor, including women, while promoting regeneration of the natural productivity of these areas (Ibid.).

4. AGRICULTURAL TECHNOLOGY OPTIONS TO REDUCE POVERTY AND ENSURE SUSTAINABILITY

In response to concerns about the sustainability of Green Revolution technologies and their ability to benefit poor farmers in less-favored areas of Asia and elsewhere, many observers are advocating new technological approaches in developing country agriculture. Some advocate agroecological or low external input and sustainable agriculture (LEISA) approaches, based on ecological principles of farming (Reijntjes, et al. 1992; Altieri 1995; Pretty 1995). Advocates of organic farming promote a similar set of agro-ecological principles, but take an even stronger stand in insisting that no artificial chemical fertilizers, pesticides, or genetically modified organisms (GMOs) should be used in agriculture (International Federation of Organic Agriculture Movements (IFOAM) 2002). By contrast, advocates of biotechnology argue that biotechnology can help to overcome the limitations of the Green Revolution and yield major benefits for poor farmers in developing countries by increasing yield potentials, increasing tolerance to biotic stresses such as pests and diseases and abiotic stresses such as drought, frost or salinity, increasing the end use value of agricultural commodities, or increasing the storability and transportability of commodities (ADB 2001).

Although some advocates of biotechnology and agroecological approaches present these approaches in opposition to one another, both approaches focus on biologically-based, rather than chemically-based, technologies; and there may be potential for realizing complementarities between these approaches. For example, Conway (1997) has argued that a combination of ecological and biotechnology approaches are needed to bring about a “Doubly Green Revolution” (Conway 1997). Others, in a similar vein, argue that integrated agricultural and natural resource management innovations are needed, combining improved germplasm (using both biotechnology and conventional methods) with improved and integrated management of soils, water, biodiversity and other natural resources to assure more productive and sustainable use of resources and reduce poverty (CGIAR Science Council 2005).

In the remainder of this section we describe these different options, their state of development and adoption in the SEAP region, their observed impacts so far, their prospects for the future, and key issues and constraints affecting their future adoption and impacts, emphasizing the prospects for these options to help improve the livelihoods of poor farmers in less-favored areas of this region.

Low external input and sustainable agriculture

Low external input and sustainable agriculture (LEISA) approaches involve limiting the use of external inputs such as inorganic fertilizers and pesticides, relying more on local and naturally available resources and a combination of traditional and improved methods to manage soil fertility, water, pests, and other agronomic needs. The particular methods used include a wide range of technologies, such as water harvesting, soil and water conservation measures, minimum tillage, application of manure and compost, incorporation of crop residues, transfer of biomass and mulching, use of leguminous cover crops, shrubs or trees in improved fallows or intercropping systems, use of crop rotation to manage soil fertility and pests, integrated pest management, and others. The ecological principles underlying these technologies involve providing favourable soil conditions for plant growth by managing soil organic matter and enhancing soil biological activity; optimizing plant nutrient availability through biological nitrogen fixation, nutrient recycling and limited complementary use of inorganic fertilizers; minimizing losses by managing microclimates and water to prevent erosion; minimizing pest and disease problems through integrated pest management; and exploiting complementarities in use of genetic resources by combining these in farming systems with a high degree of genetic diversity (Reijntjes, et al. 1992). Advocates of these approaches argue that by increasing biological diversity in agricultural systems, they help to improve food security by increasing nutritional diversity, reducing susceptibility of crops to biotic and abiotic stresses, and increasing farmers' diversity of income sources.

Adoption and impacts of LEISA approaches

Many of these approaches have been used for centuries in the SEAP region. Water harvesting, which involves concentrating rainfall runoff from a larger area into a smaller catchment area for either domestic or agricultural purposes, has been practiced for thousands of years in semiarid and arid areas of China and India, as well as in other dryland areas of the world (Oweis, et al. 1999). In many areas, use of water harvesting declined as a result of massive investments in irrigation systems, but interest in these technologies has recently grown as a result of the high costs and problems associated with modern irrigation systems, and continued and increasing problems of water scarcity and low agricultural productivity in dryland areas not served by irrigation. In recent years, researchers and development programs have sought to design and promote a variety of water harvesting techniques for agricultural purposes in semiarid areas, usually as part of integrated watershed development projects promoting other LEISA technologies as well, such as construction of soil and water conservation measures, planting trees and contour vegetation, etc.

Among the largest and most successful modern efforts to promote water harvesting has been an integrated watershed development program in the Loess Plateau in Gansu province in northwestern China, which began in 1995 and was projected to reach 3 million farms by 2005, with very favorable impacts on farm income and reduced land degradation reported, and a relatively high economic rate of return of 29 percent (Li, et al. 2000; Kelley and Byerlee 2003) (Box 1). Integrated watershed projects in India, such as the Indo-German Watershed Development Programme in Maharashtra, the Government of Rajasthan Watershed Development Programme, and the KRIBHCO Indo-British Rainfed Farming Project in upland areas of Gujarat, Rajasthan and Madhya Pradesh, are promoting water harvesting, soil and water conservation measures and other aspects of watershed management by tens of thousands of farm households in hundreds of villages, also with favorable reported impacts on crop yields, farm income, water availability, land degradation, and social indicators (Kelley and Byerlee 2003; Pretty and Hine 2001) (Table 11).

Table 11. Selected programs and projects promoting LEISA technologies and their reported impacts

Farming system	Country	Project/technology	Adoption		Reported impacts
			No. of farmers	Area affected (ha)	
Wetland rice	Bangladesh	IPM for rice, fish and vegetable production, tree planting	150,000	54,000	Rice yields up 5-7% (up 4% in dry season, 11% in rainy season)[1] 80% of farmers no longer use pesticides (77% no longer use during dry season more than two years after project intervention)[1] Average cost savings of reduced pesticide use of $92/ha/year[1] Overall cost of production of rice reduced 12% in dry season, 30% in rainy season[1] Reduced year to year rice yield variation from +/- 9.5% to +/- 5%[1] Reduced rice crop failure rate from 0.54% to 0.3%[1] Potential net income from fish and vegetables $1110/ha (= $130 per participating farmer) for fish, $204/ha or $31 per farmer for vegetables[1] 69% of women produce own vegetable seed Number of households consuming vegetables daily doubled, fish more than doubled[1] 41% of participating farmers have trees growing on dykes[1] Increased farmer empowerment and innovation – farmers experimenting with shrimp, native fish species, alternative vegetables; formation of grassroots orgs[1]
	China	Fish in rice program, Jiangshu Province		69,000	Profit per ha. nearly tripled Better diet Malaria incidence reduced from 11.6 to 0.1 per 100,000
	India	National IPM Programme	77,000		Conventional pesticide use down 50% Incomes increased by Rs 1000-1250/ha Rice yields up by 250 kg/ha
	Indonesia	National IPM for Rice Programme	1,000,000	500,000	Rice yields up 0.5 tons/ha Lower inter-year variation in yields 25% of farmers no longer use pesticides
	Sri Lanka	National IPM and Crop Management Programme, improved production of rice, vegetables and other field crops	55,000	33,000	Reduced pesticide use from 2.9 to 0.5 applications per season for rice Reduced pesticide costs from $6-40/ha[2] Lower pest numbers in IPM fields[2] Yields up 12-44% for rice, 7-44% for vegetables, depending on location Net income increased 38-178% for rice ($115-319/ha), 12-129% for other crops[2] Diffusion of IPM to non-participating farmers – estimated 55,000 adopting IPM with only 30,000 participants in FFS[2]

Table 11. Selected programs and projects promoting LEISA technologies and their reported impacts (continued)

Farming system	Country	Project/technology	Adoption		Reported impacts
			No. of farmers	Area affected (ha)	
	Sri Lanka	Gal Oya and Mahaweli Participatory Irrigation Schemes	500,000	500,000 – 1,000,000	Increased water use efficiency Some increases in rice yields Fewer complaints about water distribution
	Vietnam	IPM in rice in Mekong Delta	2,000,000		70% reduction in pesticide spraying Rice yields unchanged
	Vietnam	National IPM for Rice Programme	250,000		Pesticide expenditure down 80% Urea use down 10% Fertilizer application spread more evenly throughout season Rice yields up 3%
Irrigated rice-wheat system	India, Pakistan, Bangladesh	Zero tillage for wheat after rice[3]	1,000,000[3]	5,600,000[3]	Reduced costs of production by $65/ha[3] Water use reduced 10%[3] Sequestration of soil carbon[3] Reduced use of herbicides[3] Increased wheat yield[3]
Rainfed arid/semi arid systems (with or without some irrigation)	China	East Gansu water harvesting	100,000	70,000	Wheat and maize yields up 40% and 38% Increased availability of drinking and irrigation water Reduced soil erosion Decreased use of pesticide and fertilizer Increased social capital Increased capacity of women
	China	Loess Plateau Watershed Rehabilitation[4]	> 1 million[4]	90,000[4]	Farm income/capita increased 343%[4] Reduced sediment inflow to Yellow River[4] Economic rate of return of 29%[4]
	India	Integrated Watershed Hills Projects[4]		350,000[4]	Grain yields up 75 – 100%[4] Reduction in runoff from 33% to 4%[4] Project economic rate of return of 17%[4]
	India	Indo-German Watershed Development Progamme, Maharashtra	20,000	92,000	Dryland crop yields up 250% Milk production increased Wells wet more months per year Increased fodder grass production Household grain production up 40-100% Favorable social impacts (increased school attendance, reduced migration, more hope, development of social capital)
	India	KRIBHCO Indo-British Rainfed Farming Project	4,600		Grain yields up from 400 kg/ha to 800-1000 kg/ha Increased fodder grass production Water tables up 1 meter in 3-4 years Second season crop possible for many farmers Sharp reduction in seasonal emigration

Table 11. Selected programs and projects promoting LEISA technologies and their reported impacts (continued)

Farming system	Country	Project/technology	Adoption		Reported impacts
			No. of farmers	Area affected (ha)	
	India	Government of Rajasthan Watershed Development Programme	15,000 users groups	> 3 million	Sorghum and millet yields more than doubled without addition of fertilizers Grass strips have improved yields by 50-200%
	India	Society for People's Education and Economic Change, Tamil Nadu	45 villages		Sorghum and millet yields doubled Extra crops, fruits and timber trees planted New activities started (health care, roads, credit schemes) Empowerment – local Cluster Level Governing Council to address emerging concerns
Upland rice maize systems	India	Aga Khan Rural Support Program[5]	4,000[5]	5,000[5]	Rice yields up from 200 to 560 kg/ha (wet)[5] Rice yields up from 990 to 1,850 kg/ha (dry)[5]
	Nepal	BTRT Watersheds Project[5]	3,000[5]	1,300[5]	Rice yield up 240 per cent, from 500 to 1,700 kg/ha[5]
	Nepal	Jajarkot Permaculture Project	580	350	Rice yield up 50 per cent to 2,400kg/ha Maize yield up 33 per cent to 1,600 kg/ha 40% of the participating hh food self sufficient
	Philippines	Contour farming on sloping lands in Claveria (ICRAF) – contour hedgerows, natural vegetative strips, ridge tillage[6]	2,000	6,000	Maize yields up 15-25% (with leguminous hedgerows and mulching) Land values up 35-50% Erosion reduced from 85 t/ha to 0.3-1.1 t/ha[6] Labor costs for establishment and maintenance of contour hedgerows high (124 days per year for pruning)[6] Labor costs much lower for natural strips[6] Labor costs of tillage and weeding greatly reduced with ridge tillage, while yields maintained in near term[6] In long term, yields will be lower (0.5 t/ha within 15 years) using conventional tillage due to soil degradation[6]
	Philippines	IPM for highland vegetables	1,719		80% reduction in pesticide use 50% reduction in inorganic fertilizer use Vegetable yields up 20% Increase in net income of 17%
	Philippines	Upland project – IRRI[5]	450[5]	520[5]	Rice yields up 113 per cent to 1,490 kg/ha[5] Maize yields up from 645 to 2,110 kg/ha

Sources: Pretty and Hine (2001), except where other sources indicated according to the footnotes below:

[1] Barzman and Desilles (2002)
[2] Jones (2002)
[3] Hobbs (2001a, 2001b)
[4] Kelley and Byerlee (2003)
[5] Stoll (undated)
[6] Garrity (2002)

Minimum or zero tillage is a more recent innovation, and has recently been widely adopted in the rice-wheat farming system in the Indo-Gangetic plain of India, Pakistan and Bangladesh. Since being introduced by researchers from a consortium of IARCs and NARS in the late 1990s (with support of IFAD), adoption of zero tillage for wheat has grown rapidly to more than one million farmers on an estimated 5.6 million hectares (Rice-Wheat Consortium 2005) (Box 2). Such rapid and widespread adoption of a natural resource management innovation is rare, although zero or minimum tillage has also been adopted on a large scale in intensive mechanized farming systems elsewhere, with global adoption estimated to be as high as 90 million hectares (Murray 2005). Farmers' wheat yields have reportedly improved while their costs have been reduced by an average of $65 per hectare (Hobbs 2001b). This innovation also conserves water and reduces herbicide use (Ibid).

Integrated pest management (IPM) has also been widely adopted, especially in intensive rice cultivation in the SEAP region (Tripp 2006). There is not universal agreement on the definition of what IPM is, but it is clearly a departure from the widespread practice used in such intensive systems of preventive, calendar-based application of pesticides. Instead, farmers are taught how to recognize pest problems in the field and methods of controlling them with reduced or no use of pesticides. A wide variety of methods are possible to reduce pest problems, including use of agronomic practices such as intercropping and crop rotation to provide habitat for pest predators and break cycles of infestation, including plants that are repellent and/or attractive to pests in the cropping system to push and pull them away from valuable crops; use of traps, bio-pesticides, and pest resistant crop varieties. Success relies less on implementation of a standard package than upon farmers learning the principles of the approach and becoming able to apply these principles in their own fields.

Since the early 1980's, FAO has been quite successful in promoting IPM in intensive rice cultivation in the SEAP region using the Farmer Field School (FFS) approach. In the FFS approach, groups of farmers learn principles of IPM and other livelihood improving sustainable agriculture technologies through weekly lessons conducted in the field for at least one season, and are encouraged to apply these principles through experimentation on their own farms (Barzman and Desilles 2002).

This approach emphasizes strengthening farmers' capacity to adapt to their own situations more than adoption of specific technologies and inputs. The approach was initially used in Indonesia, and subsequently has been used in many other countries, including India, Bangladesh, Philippines, Sri Lanka, and Vietnam (Pretty and Hine 2001). By the late 1990s, more than 3 million farmers in these countries (mostly in Vietnam and Indonesia) had been trained in IPM methods through FFS, with substantial reductions in use of pesticides and associated health and economic costs, as well as maintaining or increasing yields (Ibid.; Table 11). In Vietnam, a mass media campaign was used to increase the spread of the impacts of the FFS approach. Besides promoting IPM, FFS have also promoted other innovations, such as aquaculture and vegetable production in combination with paddy rice production, integrated soil fertility management, and other aspects of integrated crop and natural resource management. These activities (especially those related to fish and vegetable production) have also contributed to improved farm incomes (Ibid.). IPM has also been promoted in other farming systems besides intensive rice production, with mixed success (Jeger 2000; Way and van Emden 2000). This is in part because farmers generally use less pesticide in other farming systems, so there is less to be gained. In addition, many cropping systems in the region are of more recent origin than wetland rice, and natural pest control mechanisms are often less well developed (Tripp 2006).

Methods of soil conservation have been promoted in upland areas in several countries for decades, but with limited success. Technologies promoted have included physical structures such as construction of rock walls, check dams and terraces, as well as vegetative approaches such as alley cropping with contour hedgerows or grass strips (Lapar and Pandey 1999; Suthipradit and Boonchee 1998). Contour hedgerow systems with leguminous trees has been one of the main conservation farming practices prescribed for intensive open field cultivation in Southeast Asia, becoming a common feature of extension programs for sustainable agriculture on sloping uplands (Garrity 2002). The advantages of this system over more conventional use of physical structures was seen to be its lower cost and the ability to restore soil fertility by mulching materials from leguminous plants, while being as effective as physical measures in controlling erosion (Ibid). However, adoption of these practices has been very limited despite years of effort to promote them by researchers, government agencies and NGOs.

The case of contour hedgerows in the Philippines is a good example. Although contour hedgerows are effective in reducing soil erosion, they have not been widely adopted because they are often not well suited to farmers' economic conditions and constraints (Ibid.; Fujisaka 1993). High labor costs of establishment and maintenance and loss of farmland occupied by the hedgerows are major constraints to adoption (Lapar and Pandey 1999). Other constraints included limited impact on farm income in the near term, hedgerow competition with crops, poor adaptation of introduced species and lack of planting materials, and insecure land tenure (Mercado, et al. 1998). In many cases, adoption was facilitated by the use of subsidies (e.g., planting materials and fertilizer). Although this can be effective in promoting initial adoption, it can undermine farmers' commitment and sustainability of the approach (Maglinao and Pommasack 1998; Cramb, et al. 2000). Adoption was significantly higher in areas with good access to markets, where production of high value crops increases the returns to adopting such labor intensive investments, whereas in more remote and less densely populated areas such intensive technologies are of less interest to farmers (Lapar and Pandey 1999; Cramb, et al. 2000). Wiersum (1994) found a similar result in Indonesia.

Other, less labor intensive, approaches such as natural vegetative strips and ridge tillage appear to have more potential in less intensive systems (Garrity 2002). For example, in Claveria, Philippines, where IRRI and ICRAF promoted contour hedgerows for several years, farmers adapted the system to be less labor demanding by leaving uncultivated strips along contours that were revegetated by native grasses and forbs. These strips were found to have many advantages, including requiring little labor maintenance, being very effective in minimizing soil loss, and causing little competition with crops or additional weed problems compared to introduced species (Garrity 1993). They have proven to be popular in northern Mindanao, and were spontaneously adopted by hundreds of farmers by the late 1990s, with the practice rapidly spreading (Garrity, 2002; Mercado, et al. 1998). The major limitation of natural vegetative strips is that they do not restore soil fertility, as do the promoted contour hedgerow systems in which leguminous shrubs or trees are planted. However, this is a similar limitation as in many systems in which fodder grasses or cash crops are planted (Garrity 2002).

Ridge tillage, in which alternate rows along the contour are left untilled, has also been shown to reduce erosion dramatically (by 49 to 58 percent), and when combined with natural vegetative strips, reduces erosion on steeply sloping lands (where erosion rates on bare soil of 85 tons/per hectare were found) to an insignificant 0.3 – 1.1 ton/ha (Ibid). Ridge tillage was found to maintain yields similar to those found under conventional tillage while drastically reducing costs of labor used for tillage and weed control (Ibid.). Over the long term these practices are predicted (using a biophysical model based on long term crop experiments) to maintain crop yields (assuming soil nutrients are provided using fertilizer) while yields under conventional tillage practices will decline as a result of soil degradation, with a divergence in maize yields of 0.5 ton/ha by the 15th year (Ibid.). Contour vegetative strips are predicted to increase yields gradually as a result of reduced soil degradation and increased soil moisture retention. Such labor and soil saving practices offer more favorable prospects for widespread adoption, especially in lower intensity systems, than the highly labor-intensive soil conservation practices that are often promoted.

Similar problems limit adoption of sloping agricultural land technologies that have been promoted in other Southeast Asian countries (Suthipradit and Boonchee 1998). In Indonesia, adoption of terraces and contour hedgerows has been limited by high costs (especially for terraces) and lack of apparent and direct near term benefits (Agus, et al. 1998; Utomo, et al. 1998). Lack of planting materials, insecure land tenure, shortage of capital, and incompatibility with existing farming systems are constraints to perennial tree planting in the uplands; while unavailability of planting materials and requirements for fertilization and replanting limit farmers' planting of improved grasses (Agus, et al. 1998). Farmers also complain about the complexity of the technologies introduced and the need for routine maintenance (Utomo, et al. 1998). In a study of a farmers' views of alley cropping in five Asian countries (China, Indonesia, Laos, Thailand, and Vietnam), Eusof and Phien (1998) found that farmers appreciated the effectiveness of the technology in reducing erosion, and found in most cases that it increased yields modestly, but were concerned about problems of weeds, pests and disease associated with the practice.

Prospects for the future

The potential to build on the demonstrated success of many LEISA approaches in the future appears to be very great. The ability to reduce input use, increase household incomes and reduce environmental and health costs using technologies such as zero or minimum tillage and IPM has been amply demonstrated in intensive rice-wheat and rice systems, and there are many millions of farmers in these systems that have yet to benefit from exposure to these approaches. The ability to reduce farmers' costs without jeopardizing productivity, thus leading to near term increases in profits and income were key to the success of these innovations. Incorporation of other profitable livelihood improving elements into the approach, such as promotion of aquaculture and vegetable production through the Farmer Field Schools also contributed to the success, and this lesson will be important in future efforts. Organizational innovations such as the FFS approach and the Rice-Wheat Consortium played a key role in enabling these technical innovations to be rapidly scaled up to reach millions of farmers, and similar approaches can help to extend the impacts even further. As continued scaling up occurs, it will be essential to use participatory approaches and recognize that although these innovations have great potential, they are not likely to be suitable in all contexts or for all farmers.

There is also substantial potential to improve farmers' livelihoods and natural resource management in less-favorable dryland areas, using approaches such as water harvesting and other aspects of integrated watershed development in sloping areas. The benefits of water harvesting and soil and water conservation are usually more immediately apparent in sloping dryland areas than in more humid upland areas, hence the prospects for widespread adoption and impacts are likely greater in dryland areas. Despite these advantages, water harvesting and watershed management in dryland (or more humid) areas face many key issues and constraints that may prevent rapid up-scaling of these approaches, such as the need for effective collective action and secure property rights, and distributional impacts of such interventions. These issues are discussed in the next subsection.

In more humid uplands, such as much of Southeast Asia, adoption of LEISA technologies has been very limited, mainly due to the high labor cost and low near term return of the promoted technologies, despite their importance and demonstrated effectiveness in reducing land degradation. A more targeted approach to promotion of technologies appears necessary to be more effective. In upland areas that have favorable market access and that are densely populated, promotion of labor intensive land management practices such as terracing and contour hedgerows has potential where it is linked to sustaining and increasing the production of high value cash crops. Less labor intensive practices such as natural vegetative strips and ridge tillage may be attractive to farmers even in these systems, especially where farmers have high labor opportunity costs (e.g., due to nonfarm activities in peri-urban areas). In less densely populated areas more remote from markets and more reliant on subsistence food crop production, labor intensive practices are less likely to be of interest to farmers, but use of less intensive means of soil conservation, such as natural vegetative strips and ridge tillage, is a promising approach. As with other LEISA approaches, effective participatory approaches are needed to identify and promote technologies appropriate to different contexts, and several key issues and constraints must be addressed if large scale adoption and adaptation of such measures is to occur.

Key issues and constraints

The preceding discussion highlights one of the key questions concerning LEISA technologies (and all other technology options), namely, what works well where and why (or why not)? Given the great diversity of biophysical and socioeconomic conditions found throughout the SEAP region, it is obvious that no single technology or approach will be suited to all environments. As we have seen, some of the most promising recent LEISA innovations – zero tillage and IPM – have their greatest potential in favorable irrigated environments where agricultural production is highly intensive (Table 12 summarizes the discussion in this section).

Table 12. Potentials of LEISA technologies in less-favored areas and key issues and constraints affecting adoption

LEISA technology	Where adopted so far	Potential in less favored areas	Key issues and constraints
Zero tillage	Wheat-rice system in high potential irrigated areas of South Asia	- High potential for further expansion in this system - Potential in less-favored areas less clear, but probably low due to less intensive use of tillage, lower value crops, poverty	- May not be suitable in low activity clay soils with low organic matter content due to soil compaction - High weed pressure, especially in more humid areas - Costs of herbicides may be prohibitive for poorer farmers, especially for low value subsistence crops - Costs of labor for weeding also may be prohibitive for poor farmers, especially vulnerable households such as female-headed and HIV-affected households - Labor availability for weeding greater in more densely populated areas
Integrated pest management	Intensive rice systems in high potential irrigated and humid areas of South and Southeast Asia	- High potential for further expansion in this system - Potential in less favored areas less clear; probably less due to less use of pesticides and lower value of crops	- IPM reduces risks of pest outbreaks - Need for training in principles of IPM, development of farmer knowledge and skills; such training involves high costs and skilled facilitators, which can limit upscaling - Farmers involved more in off-farm activities (often poorer households) may not be able to afford the time required for training - Skills learned in IPM do not readily diffuse to other farmers or necessarily stimulate other innovations

Table 12. Potentials of LEISA technologies in less-favored areas and key issues and constraints affecting adoption (continued)

LEISA technology	Where adopted so far	Potential in less favored areas	Key issues and constraints
Integrated watershed management, water harvesting, SWC measures	Sloping semi-arid areas of China and India	- High potential in semi-arid and arable arid less favored areas where relieving soil moisture constraints has immediate productivity impact - Less potential in more humid upland areas because of lack of near term productivity impact	- Collective action required for effective watershed management, this requires investment in participatory processes and local social capital (bonding and bridging) - Ability of external programs to develop local bonding social capital is questionable; successful efforts often focused in areas where such capital already exists ("cherry picking") - Watershed development programs often have negative distributional impacts on poorer households, by restricting access to common property resources used by the poor - Initial investment costs of SWC measures are often high, involve perceived risk, and usually cannot be financed with credit, inhibiting investment by poor households - High labor costs of SWC investments may be prohibitive for households involved in off-farm activities and vulnerable labor scarce households (e.g., female-headed, HIV positive) - Opportunity cost of land taken up by SWC measures can be prohibitive for smallholders in densely populated areas, even when the productivity impact is high; however, land constraints also can induce labor intensive investments in land improvement - Insecure land tenure often limits farmers' willingness to invest in SWC measures, unless investment increases their tenure security - Insecure and unclear rights to use of common pool resources undermine efforts to improve management - Traditional institutions such as free grazing on common lands also sometimes undermine efforts - Externalities of improved watershed management are often positive (e.g., reduced sedimentation and flooding, improved groundwater recharge), but not always (e.g., increased harvesting of water upstream reduces water availability downstream) - Addressing externality issues is a major challenge. Technical assistance likely to be insufficient. Regulatory approaches often difficult to enforce and can worsen poverty. Subsidies are usually unsustainable and can sometimes contribute to more land degradation. Negotiated approaches appear to offer promise where rights are clear and parties to negotiation have legitimacy, but transaction costs of negotiating and monitoring agreements may limit success, and poorer households may be excluded or disadvantaged.

Table 12. Potentials of LEISA technologies in less-favored areas and key issues and constraints affecting adoption (continued)

LEISA technology	Where adopted so far	Potential in less favored areas	Key issues and constraints
Organic soil fertility management practices (e.g., manure, compost, improved fallows, green manures, incorporating crop residues)	- Location and extent of adoption not clear; various case studies with small areas affected in particular locations	- Potential of intensive practices like manure and compost likely greatest in peri-urban settings where high value crops such as vegetables are produced for the market, and where intensive livestock operations (poultry, dairy, pigs) provide a supply of manure - Potential of semi-intensive measures like improved fallow greater in medium population density settings where fallows still practiced but need for soil fertility improvement is clear - Potential of some measures may be greater drylands due to soil moisture conservation benefit of organic matter	- High labor costs of many organic practices are often prohibitive unless high value crops being produced - Labor costs may be prohibitive for labor scarce vulnerable households - Lack of access to and high alternative demand for organic materials for fuel and fodder can be a serious constraint, especially in densely populated semi-arid and mountain areas - Adoption of improved fallows likely limited for land poor households, due to inability to leave land fallow, unless they have off-farm opportunities - Land fragmentation may prevent adoption, because of high costs of transporting bulky organic materials to distant plots

Essentially, these innovations are a reaction to excessive intensification that occurred during the Green Revolution, when farmers were encouraged by policies and technology promotion programs to use high levels of chemicals, water and other inputs without fully understanding the consequences of this. The rapid pace of change brought by the Green Revolution created opportunities for more efficient and sustainable ways of using these inputs to be devised and disseminated.

These same innovations may not be suited to other farming systems and bio/social contexts. Many soils tend to become compacted over time without tillage, particularly low activity clays with low organic matter content (Lal 1984). Weed control can be very difficult in humid tropical environments, requiring frequent and heavy use of herbicides or manual labor. Heavy use of herbicides may be beyond the financial reach of most farmers in less favored environments, especially if they are in remote areas producing subsistence crops and with limited off-farm income. Manual weeding may be feasible and effective in densely populated settings where labor is plentiful relative to land, but the value of labor spent weeding by hand may be too low (relative to other productive uses of labor or to the value of leisure) to induce farmers to spend their efforts on manual weeding rather than using conventional tillage, especially for a low value or low productivity crop.

Farmers need to develop management knowledge and skills to adapt complex innovations such as IPM to their own conditions. The FFS approach and other participatory approaches have demonstrated effectiveness in strengthening farmers' abilities to manage such complexities. However, not all farmers may be able to afford the time invested in developing such skills. For example, a recent study of FFS in southern Sri Lanka found that participants in FFS tend to have somewhat larger farms (1.02 ha of paddy compared to 0.82 ha for non-participants) and are much less likely to be involved in off-farm work as a farm worker or casual laborer than non-participants (13 percent of participants were involved in off-farm work compared to 40 percent of non-participants) (Tripp, et al. 2006). Thus, the FFS approach may have greater difficulty in peri-urban areas where many farmers are involved in off-farm activities, or for poorer households in rural areas who depend upon off-farm employment as a result of small farm size.

These issues highlight the critical importance of developing technologies that are profitable in the near term to farmers, given their biophysical and socioeconomic conditions, not too risky, and suited to the farmers' capacities and constraints. These considerations will militate against large scale adoption of LEISA technologies in many instances, as the earlier discussion of adoption of soil conservation practices in humid uplands indicates. Such practices are simply not profitable enough in the near term for many farmers to find them attractive, unless high value production is involved (Cramb, et al. 2000; Wiersum 1994). By contrast, soil and water conservation measures may be much more profitable in the near term in low rainfall areas, since they can have an immediate productivity impact by conserving scarce soil moisture (Pender, Place and Ehui 2006). Thus, some technologies are better suited to more marginal agricultural environments.

The risks associated with adopting an innovation are also important. Limited information is available on this issue from the published literature, although there are good reasons to expect that LEISA technologies can often reduce farmers' production risks. In low rainfall areas, water harvesting, soil and water conservation measures, and agronomic practices that increase soil moisture (e.g. reduced tillage, mulching, manuring, composting) can reduce production risk as well as increasing production by conserving soil moisture (Shaxson 1988; Reijntjes, et al. 1992; Hassan 1996; Haggblade and Tembo 2003; Kaboré and Reij 2004; Hengsdijk, et al. 2005; Pender and Mertz 2006).[9] Soil and

[9] For example, in the semi-arid Sahelian zone of West Africa, tens of thousands of farmers are using planting pits to conserve soil moisture, often with manure or compost to increase fertility (Kaboré and Reij 2004). These technologies can more than quadruple sorghum yields and provide a return to farmers' labour 33% higher than the rural wage rate (Ibid.). Similar planting basin systems have emerged in Zambia, Cameroon, Nigeria, Uganda and Tanzania. In Zambia, tens of thousands of farmers have adopted conservation farming methods, including use of planting pits, minimum tillage, crop residue retention, leguminous crop rotations, and improvements in seeding and input application (Haggblade and Tembo 2003). These technologies have been found to increase cotton yields by more than 40% and maize yields by more than 30%, and increase returns to peak season labour by 150% for cotton and 90% for maize (Ibid.). Hengsdijk, et al. (2005) showed (using a soil water balance model) that use of stone bunds in the moisture stressed highlands of Tigray, Ethiopia, could increase yields by up to nearly 20% on a slightly sloping field (2% slope) if the farmer does not plant at the optimal sowing date, but would result in a small loss in yield if the farmer planted at the optimum date (which is however unknown to the farmer in advance). On a steep slope (40% slope), however, the moisture conserving benefit of stone bunds is outweighed by the amount of cultivated area lost as a result of the bunds, and stone terraces result in less yield across a wide range of sowing dates (Ibid.). Thus, the impacts of such technologies are sensitive to locally varying factors such as slope, soil type, rainfall distribution and other factors.

water conservation measures can also reduce the risk of losses due to erosion and landslides during heavy rainfall events. For example, surveys conducted in 360 communities in Central America after Hurricane Mitch found that farmers using practices such as agroforestry and cover crops suffered lower economic losses, while their plots experienced less erosion and had 20 to 40 percent more topsoil (Holt-Giménez 2001). Although there is little empirical evidence from tropical regions that soil organic matter can actually be increased significantly, the risk reducing benefits of preventing drastic reductions in organic matter are well known from temperate regions and include reduced sensitivity to flooding and temperature extremes, erosion, and acidification (Scialabba and Hattam 2002; Alföldi, et al. 2002; Mäder, et al. 2002). For example, rice grown using conventional high input technologies in Japan was nearly wiped out by an unusually cold summer in 1993, while organic farmers' yields were 60 – 80 percent of the annual average (Scialabba and Hattam 2002). The better composition of water stable aggregates in the soil and reduced soil compaction also lead to better performance of organic systems in both flood and drought conditions (Ibid.). IPM may reduce risks of pest outbreaks by reducing destruction of beneficial insects and development of resistance (Altieri 1995; Kenmore 1986). Some evidence supporting this was found in Bangladesh, where year to year variability in rice yields and the incidence of crop failure was lower for farmers who adopted IPM (Barzman and Desilles 2002), and in Sri Lanka, where fewer pests were observed in fields where IPM was used (Jones 2002). Reduced use of fertilizers and use of organic soil fertility management practices may also reduce susceptibility of plants to pests through alteration in crop growth and nutritional levels (Ibid.; Altieri and Nichols 2003). Thus, combining IPM with integrated soil nutrient management may help to reduce pest risks.

Despite such advantages, LEISA technologies may not always reduce farmers' risks, or may not be perceived as doing so. Adopting any new technology involves some opportunity costs, whether it is simply the time spent learning about the technology, the labor invested in constructing a terrace or planting and maintaining a hedgerow, the land occupied by such measures, the biomass that could have been used for other purposes (e.g., use of crop residues as fodder or fuel rather than as mulch, use of manure as fuel rather than as an organic soil amendment; use of legumes for food rather than as green manures or cover crops); or the use of livestock or other capital owned by the household to implement the technology rather than for other purposes (e.g., use of bullocks and carts to haul manure). Such costs must be considered in determining whether a new technology is profitable, but they also affect the impacts of risk. Since such costs are usually quite tangible to the farmer while the benefits of adopting a new approach are uncertain, farmers are understandably reluctant to commit to paying such costs, even if the expected net return of the investment is positive (and especially if not).

These problems are compounded when investments are irreversible in nature (meaning they involve sunk costs that cannot be recouped later by marketing the asset), and households are liquidity constrained (Fafchamps and Pender 1997). In such circumstances, farmers may rationally not invest even when the discounted net present value of the investment is highly positive, and this is more likely the poorer the household (Ibid.). Sunk costs and irreversibility of investment are invariably involved when the investment involves learning. Investments in land improvements also are largely sunk costs, unless the land market functions well and the value of such investments is readily observable and is capitalized into the value of the land (Pender and Kerr 1999), a condition that is rare in most rural areas of the world.

Poorly developed credit markets and liquidity constraints have ambiguous impacts on LEISA technologies. Liquidity constraints are often binding for poor farmers as a result of poorly developed credit markets in rural areas. Evidence from south India demonstrates this (Pender 1996).[10] Besides the impact that this has on farmers' willingness and ability to make investments with substantial sunk costs, it causes farmers to discount the future more heavily, causing them to take a short-term perspective that may rule out investments that pay off only in the long term (Ibid.; Holden et al. 1998; Holden and Shiferaw 2002). Such problems are likely to be particularly prevalent among poor farmers in less-favoured environments. However, such constraints can also favour adoption of low external input technologies, since these technologies require less ability

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[10] Pender (1996) estimated farmers' private discount rates in two villages in semi-arid south India using both experimental games involving real rewards and hypothetical questions. He found (using both methods) that the discount rate of most farmers was much greater than the interest rates charged in formal credit markets (mean discount rate above 50%), and that discount rates were lower for wealthier farmers. Both of these findings indicate the presence of binding credit constraints upon poor farmers.

to purchase inputs (although liquidity constrained households still may be disadvantaged in adopting labour-intensive technologies if labour hiring is used by wealthier households (Tripp 2006).

Labor opportunity costs and constraints are particularly critical for many poor and vulnerable households, such as female headed households and households with HIV-positive members, and these may prevent such households from adopting labor-intensive investment or practices. Labor constraints and high labor opportunity costs are also likely more of a concern for households involved in off-farm employment and non-farm activities, as Pender and Kerr (1998) found in one village in south India with regard to investment in indigenous soil and water conservation measures[11] and as the example of participation in FFS in Sri Lanka discussed earlier shows (Tripp, et al. 2006). Conversely, labor saving technologies such as zero tillage (unless dependent upon manual labor for weeding), natural vegetative strips and ridge tillage may be well suited to such households.

Farmers' education and capacity to absorb complex innovations also can be important constraints for many LEISA technologies, as suggested by the concerns raised by farmers about the complex sloping land management technologies that were promoted in Southeast Asia. Better educated and more intelligent farmers may be better able to learn and apply principles of IPM and sustainable land management taught in FFS, although Tripp, et al. (2006) found no significant difference in education level or in indigenous knowledge of local insect control methods (prior to the FFS) between FFS participants and non-participants in Sri Lanka. Thus, although knowledge constraints and technological complexity may limit farmers' initial interest in technologies, these problems may be overcome with suitable educational efforts, provided that the technology is profitable and not too risky to farmers.

Land constraints are also important for technologies that use scarce land, such as terraces, contour hedgerows, natural vegetative strips and improved fallows. In densely

[11] In a study of determinants of farmers' soil and water conservation investments in three villages in semi-arid India, Pender and Kerr (1998) found in one of the villages that the value of investment was reduced by 2.4 Rupees for each additional percent of household income earned from non-farm activities. The impact of non-farm income was statistically insignificant in the other two villages.

populated areas where farm sizes are very small, adoption of these measures may be limited by such considerations, despite the abundant availability of labor relative to land (Pender, Place and Ehui 2006; Hengsdijk, et al. 2005; Herweg 1993).[12] Land constraints by no means imply that such investments will never be made in densely populated settings, as evidenced by widespread adoption of terraces in very densely populated areas of Java, for example. In some circumstances, adoption of such highly labor-intensive practices may reflect farmers' best attempts to cope with severe poverty, rather than offering a pathway out of poverty (Geertz 1963). On the other hand, farmers' responses to increased population pressure may lead to technological innovation and more profitable and sustainable land management, as argued by Boserup (1965) and demonstrated in a several case studies in Africa (e.g., Tiffen, et al. 1994; Scoones, et al. 1996; Adams and Mortimore 1997; Kaboré and Reij 2004).[13] However, even in the famous case of Machakos in Kenya studied by Tiffen, et al. (1994) these responses did not derive solely from rural population growth; access to markets and technical assistance and development of the large urban market in Nairobi were major reasons for this success story.

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[12] For example, Hengsdijk, et al. (2005) estimate that use of stone bunds (at recommended spacing) in Tigray on a slope of 40% occupies about 30% of the field area, which is why these investments lead to lower yields on such steep slopes. Based on data from the Soil Conservation Research Program, which conducted research on soil conservation measures in six sites (representing different agroecologies) of the Ethiopian highlands in the 1980s and 1990s, Herweg (1993) argued that the space occupied by soil conservation measures, especially on steep slopes, was one of the important factors limiting their attractiveness to farmers. Small farmers in densely populated areas of western Kenya are reluctant to plant leguminous cover crops in an improved fallow for even one season, despite the boost in productivity this causes. As one farmer stated, "It's better to have even one gorogoro (tin) of maize [from a depleted field planted with maize] than to be guaranteed no maize at all this season by planting a cover crop we can't eat" (Delve and Ramisch 2006).

[13] In the Machakos district of Kenya, Tiffen, et al. (1994) found using historical records and photographs that substantial environmental recovery of once highly degraded lands occurred over a fifty year period, despite a five-fold increase in population. They argued that this was evidence supporting Boserup's (1965) hypothesis that population growth induces household responses to intensify agricultural production and improve land management as a result of increasing land/labor ratios, investments in infrastructure, and market development. Other case studies in Africa (cited in the text) have also illustrated farmers increased investments in land improvement in the context of population pressure. However, such "success stories" are far from universal in Africa and elsewhere, as many studies find population pressure to be associated with more land degradation (Grepperud 1996; Templeton and Scherr 1997; Boyd and Slaymaker 2000; Pender, et al. 2001). The importance of agriculture in rural livelihoods and opportunities to produce high value crops are two factors that appear to be important to sustainable responses to population pressure (Boyd and Slaymaker 2000).

Constraints in access to other assets, such as livestock, equipment, and biomass also affect the potential of LEISA technologies. Farmers without access to livestock are less likely to apply manure to their fields, unless a well functioning market for manure exists. Even if a manure market does exist, the high cost of transporting a bulky input such as manure relative to its value means that significant transport is unlikely to remote areas or fields, and is less likely for low value subsistence crops commonly grown in remote areas. Lack of access of equipment such as a bullock cart to transport such materials also can constrain farmers' ability to use them. In arid and semi-arid areas, especially densely populated ones, access to biomass in general is a major constraint, limiting farmers' ability and willingness to apply scarce biomass to the soil as a fertilizer, when it may have higher use value as fodder or fuel. At the same time, scarcity of fodder in such areas means that livestock pressure on edible plant vegetation is usually high, limiting farmers' ability to use vegetative conservation practices, especially where free grazing is practiced.

Land tenure is often cited as an important issue with regard to investments in sustainable land management practices. Absence of land tenure security, where this is a problem, is likely to undermine farmers' willingness to invest in measures that yield returns only in the longer term, since farmers risk not being able to fully benefit from the value of their investment (Feder and Onchan 1987). Where landowners or occupants have insecure tenure, improving their land tenure security through land titling and registration efforts can promote land improving investments, as Feder and Onchan (1987) found in Thailand. This is not necessarily the case, however, since farmers with insecure tenure may invest in the land as a means of increasing tenure security (Besley 1995; Otsuka and Place 2001). Furthermore, land titling may not increase tenure security, which in many customary tenure systems is already secure without title, while increasing potential for conflicts and opportunities for rent seeking behavior by elites (Platteau 1996). Thus, like technologies, different institutions are likely to be needed in different environments, and promotion of "solutions" to farmers' problems such as land titling should be based upon adequate understanding of the local context.

For land tenants, it is often the case that they invest less than owner-operators in land investments because they may be able to benefit from the investment for only a short time. However, the nature and length of land tenancy arrangements will have a large impact on whether land tenants invest in land improvements. For example, Cramb, et al. (2000) found that tenant farmers were willing to invest in soil conservation measures in one area of the Philippines where they had fairly secure and long standing access arrangements, while less secure tenure arrangements were a disincentive to investment in another area. Well-intentioned efforts to regulate land tenancy and land-to-the-tiller land reforms, as have occurred in India, can have the perverse effect of making it more difficult for tenants to arrange secure long term leases with landowners, undermining their incentive and ability to invest in sustainable land management (Pender and Kerr 1999).[14]

Besides property rights over land, property relationships with regard to other natural resources, such as trees and water, are also important, but less often considered. In some places, ownership rights to trees are separate from ownership of the land upon which the trees are growing. This may be the case where farmers have been granted land use rights on forest land, where the government places restrictions on cutting trees on private land, or where customary traditions allow for such separate rights. Similarly, access rights to water are not necessarily bundled with rights to the land upon which (or under which) a water body is found. For example, religious traditions (such as in many Islamic societies) may stipulate that water must be freely available to anyone who needs it. Such relationships can certainly influence the incentives and ability of farmers to invest in planting trees or developing water resources, and add to the context dependence of the potential for adoption of LEISA technologies.

Tenure relationships and traditions concerning use of common property resources such as grazing lands and forest areas also can have a major influence on farmers' willingness and ability to adopt LEISA technologies, as well as upon the impacts that such technologies may have. Some of these approaches, such as integrated watershed management, inherently involve decisions about management of common property as well as private land, and thus are subject to the complex set of factors that influence the

[14] In land lease markets in south India, the duration of land leases is usually no more than one or two years, in part because land-to-the-tiller legislation creates a risk to the landowner if long term leases are used (Pender and Kerr 1999).

ability of communities to attain effective collective action (Ostrom 1990; Baland and Platteau 1996; Agrawal 2001; Knox, et al. 2002). Proponents of watershed development projects and other efforts to promote collective action in rural communities are sometimes naïve in their belief in the ease with which collective action can be obtained, or the extent to which the benefits may be captured by local elites (Tripp 2006). For example, Kerr (2002a), in a review of a large number of watershed development projects in semiarid India, found that ". . . the projects most successful in achieving conservation and productivity benefits also had the strongest evidence of skewed distribution of benefits toward larger landholders . . . watershed development often asks the poorest, most vulnerable people to provide a valuable environmental service to the wealthiest landowners" (Op cit., p. 1398).

Grazing traditions on common and private property can also affect the potential for farmers to invest in land management practices (especially vegetative ones). Where free grazing of livestock is allowed on croplands after harvest, farmers may not be able to use practices such as incorporating crop residues or planting grass strips even on their private land, unless such traditions are changed. Conversely, where rights to exclude (or include) livestock in croplands are well established, arrangements between crop farmers and herders often occur, leading to improved management of both land and livestock. For example, in some parts of semi-arid India, it is common for shepherds to pay farmers for grazing rights on croplands at some times of the year when the availability and value of fodder is high, and for farmers to pay the shepherds for grazing (and providing valuable manure) when the fodder value is low.

The preceding discussion of heterogeneous bio/social environments and constraints emphasizes that the impacts of promoting any particular technology or approach may be quite heterogeneous and subject to unintended consequences. The impacts on poorer households, in particular, are not necessarily always favorable, as Kerr's (2002b) findings for watershed management in India illustrate.[15] Not only may the elites within communities be best able to capture the benefits of programs requiring community collective action and providing subsidies, but many of the constraints that affect the potential of LEISA technologies are most binding for the poorest households (Tripp 2006).[16] Poorer households tend to be more constrained in their access to land, other assets, liquidity and human capital (almost by definition), often are in lower potential areas with less access to markets, and are often less involved in high value crop production and more dependent on off-farm income, all factors which tend to retard adoption of LEISA technologies. To the extent such factors are important constraints to adoption of LEISA technologies, promotion of such technologies is likely to benefit the wealthier households to a greater extent. In this respect, LEISA technologies are not so

[15] In his review of watershed development projects in 86 villages in Andra Pradesh and Maharashtra, Kerr (2002a) found that larger landowners were much more likely than smallholders and landless people to report benefiting from the projects, while smallholders and landless people were more likely to report suffering harm as a result of the projects. In Maharashtra, only 12 percent of landless respondents and 19 percent of respondents owning less than 1 hectare reported benefiting from the projects (across all types of projects), compared to 26 percent of respondents owning between 1 and 2 hectares and 45 percent of those with more than 2 hectares. The reported benefits were skewed towards larger landowners for all types of projects. By contrast 19 percent of landless respondents reported being harmed by the projects, while 10 percent or less of landowning respondents reported being harmed. The main cause of harm was loss of access to common lands for grazing.

[16] In a wide ranging review of literature on low external input technologies (LEIT), Tripp (2006) found that "there were virtually no cases in which a significant uptake of LEIT was weighted towards the poor and many examples in which the better-off were more likely to take advantage of LEIT" (p.191). In the case studies presented in that book, the findings supported that general conclusion from the literature. A case study of watershed management in western Kenya found that uptake of soil and water conservation (SWC) practices was much greater in the high potential area, where crops made a greater contribution to livelihoods, and greater among households with more agricultural income (Longley, et al. 2006). In Honduras, uptake of LEIT for hillsides was much greater for farmers involved in cash crop production, while households with more dependence on off-farm income (who were poorer on average) were less likely to adopt (Richards and Suazo 2006). These findings are similar to findings of Boyd and Slaymaker (2000) and Place, et al. (2002) based on case studies in several African countries. In both high and low potential zones of western Kenya, larger farm size was consistently related to use of SWC (Longley, et al. 2006), while in Sri Lanka (Tripp, et al. 2006) and Honduras (Richards and Suazo 2006), there was no correlation between farm size and adoption of LEIT. There were many cases in which LEIT were taken up by poorer farmers, but "in no case did the technology favor the less rather than the better resourced, nor was it particularly effective at reaching those at the bottom of the ladder" (Tripp, 2006, p. 193).

different than other technologies that advocates of these approaches dismiss as being unsuited to address poor farmers' needs (Ibid.).[17] On the other hand, poorer households may tend to have lower opportunity cost of labor than wealthier households, which may encourage them to adopt more labor intensive LEISA approaches than wealthier ones, although the findings of Pender and Kerr (1998) concerning factors determining farmers' investments in soil and water conservation (SWC) measures in three villages in semi-arid south India on this are mixed.[18] However, some of the poorest and most vulnerable households, such as widow-headed households and HIV-affected households often face the most severe labor constraints.

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[17] Few studies compare determinants of LEISA technologies with determinants of other types of technologies, as most adoption studies are focused on a narrow range of technologies. Exceptions to this include recent studies of livelihoods and land management led by IFPRI and collaborators in Ethiopia, Uganda and Honduras. These studies show that the impacts of different aspects of wealth on adoption of different technologies are mixed. In the highlands of Tigray, northern Ethiopia, Pender and Gebremedhin (2004) found that households with more land were more likely to adopt reduced tillage, but less likely to use contour plowing or fertilizer on a particular plot. Households with more oxen are more likely to use contour plowing and manure or compost, but less likely to use reduced tillage. Households with better access to roads were more likely to use fertilizer and contour plowing, but less likely to use reduced burning. Household more dependent on off-farm income (who tended to have higher incomes) were more likely to use reduced tillage. In the highlands of Amhara, northern Ethiopia, Benin (2006) found that households with more land were more likely to use fertilizer in higher rainfall areas, and more likely to use contour plowing in lower rainfall areas. Households with more oxen or other livestock were more likely to use fertilizer in higher rainfall areas and more likely to incorporate crop residues in lower rainfall areas. Households closer to roads were more likely to use crop rotation but less likely to use reduced tillage or contour plowing. In Uganda, Nkonya, et al. (2004) found that households with more land are less likely to use fertilizer or manure and compost on a given plot, but more likely to use slash and burn. Households producing horticultural crops are more likely to apply mulch and household residues. Households with better access to a market are more likely to use fertilizer. In Honduras, Jansen, et al. (2006) found that amount of land owned was not significantly associated with farmers' propensity to use LEISA practices or inputs such as fertilizer, herbicides or insecticides. Households with more livestock are less likely to use fertilizer but more likely to use insecticides. Households with more farm equipment are less likely to use herbicides and zero or minimum tillage. Households with better access to market towns are more likely to use zero or minimum tillage, while in areas of higher road density, households are more likely to use fertilizer, no burning and incorporate crop residues, but less likely to use zero or minimum tillage. Households more dependent on off-farm income are more likely to use no-burning but less likely to use zero or minimum tillage. Coffee producers are less likely than basic grains producers to incorporate crop residues or use fertilizer. These varied findings show that the factors determining use of inputs such as fertilizer as well as LEISA practices are highly dependent on the context and the specific technology considered, but generally support the argument that LEISA practices are not generally more suited to poor households in less favorable environments than use of fertilizer or other divisible inputs.

[18] Pender and Kerr (1998) found that households with more land invested less in SWC (on specific plots) in two of the villages, but more in the third village. Low caste households invested more in two villages but less in the third village. Households with greater endowment of male labor invested more while those with more female labor invested less in one village. Households more dependent on farm income invested less in one village. Households with more education invested more in two villages. Some of these findings support the hypothesis that poorer households sometimes invest more in labor intensive LEISA practices. but this varies across villages and depends on the poverty indicator.

The distributional effects of LEISA approaches within and across communities are also affected by the negative or positive externalities that may be ameliorated or exacerbated by these approaches. Many of these approaches generate positive externalities or reduce negative ones. Use of IPM reduces pesticide pollution of water sources, benefiting not only the farmers adopting the practice but others as well. Minimum tillage conserves scarce water by reducing evaporative losses resulting from tillage, resulting in less demand for irrigation water, potentially benefiting other water users, even if they are not using minimum tillage. Soil and water conservation measures in upland areas reduce erosion and runoff, thus reducing sedimentation and pollution of water bodies and risks of flooding downstream. Conservation measures also reduce "intertemporal externalities" by conserving scarce resources for future generations.

Not all of the environmental or intertemporal impacts of LEISA approaches are necessarily beneficial, however. Water harvesting, tree planting, and soil and water conservation in upland areas may reduce the availability of water to downstream users.[19] Soil conservation also reduces transport and deposition of soils to lands at lower elevations. Although deposition of soils from higher elevations on farmers' lands is not necessarily a bonus (e.g., if the soils deposited are of low quality or cause surface crusting and sealing), in general the soils that are most erodible are those with higher levels of organic matter and nutrients (Stocking 1996), thus tending to improve soils in receiving areas (the high fertility of the alluvial soils of the Indo-Gangetic plain is testament to the beneficial effects of erosion and deposition occurring over millions of years). One can certainly argue from an equity standpoint that "gifts" of soil from usually poorer upland farmers to usually wealthier lowland farmers should not be

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[19] For example, research in Sumatra by ICRAF for the IFAD-supported project, Rewarding the Upland Poor for Provision of Environmental Services (RUPES), has shown that reforestation of the upper watershed of Singkarak Lake would reduce the total annual amount of water flowing into the lake somewhat (although forests buffer intra-annual fluctuations in water flow, by reducing runoff rates and storing water in the soil), as a result of the use of water by trees (Meine van Noordwijk, personal communication; van Noordwijk, et al. 2004). In Ethiopia (and other countries), there is major concern about the impacts of water use by eucalyptus trees, which are commonly used in land rehabilitation projects (Jagger and Pender 2003). There are also reportedly concerns in Sudan and Egypt about the impacts that widespread use of water harvesting and SWC structures in the Ethiopian highlands may have on water availability downstream (since these help Ethiopian farmers to capture and use more water), although studies of these impacts are not yet available (Peter Sutcliffe, personal communication).

promoted. The point is simply that soil erosion is not necessarily bad for everyone, and efforts to reduce it thus may not be beneficial for everyone.

These issues raise the question of how the problem of externalities should be addressed. Promoting technologies through technical assistance programs can help, if the technologies that are promoted help to alleviate these problems and farmers were otherwise unaware of the technologies and how to implement them (e.g., IPM, zero tillage). However, the level of uptake of sustainable agricultural practices may be inconsistent with what would be socially optimal, if farmers were to consider the costs and benefits of their action upon others. One approach that has been used in the past, with limited success, is the regulatory approach; i.e., require farmers to use prescribed practices such as terraces or to refrain from using certain practices, such as cultivation on steep slopes or using slash and burn to prepare their fields. Such requirements often fail to reduce land degradation and negative externalities because they are difficult to monitor and enforce. Farmers' resentment of such approaches and their responses may lead to worse degradation than may have occurred without such approaches. An example of this is the burning of state forest land in Indonesia that often followed in the wake of past evictions of farmers by the government (Suyanto, et al. 2005). Where farmers are not interested in conservation structures such as terraces but are forced to establish them, they may maintain them poorly, which can contribute to land degradation problems such as formation of gullies. In addition, the prescribed practices may be unsuited to the local situation, which can also contribute to degradation. Finally, such approaches are not likely to help reduce poverty.

Another approach is to use subsidies to promote adoption of sustainable agriculture measures. This has often been used in the past by research and technical assistance programs, such as in watershed development projects in India (Kerr 2002b) and conservation farming projects in the Philippines (Cramb, et al. 2000). McDonald and Brown (2000) argue that soil and water conservation technologies must either provide immediate, tangible benefits to farmers or be supported by incentives. However, as noted by Maglinao and Phommasack (1998), such incentives can undermine the sustainability of the effort. Hellin and Schrader (2003) found that conservation structures established with incentives in four sites in Central America were either removed or poorly maintained by farmers. In such cases, incentives are ineffective or possibly even worse, may contribute to the land degradation problems that they were meant to solve.

A third approach is to seek to address externalities through negotiation processes. For example, downstream users in a watershed may try to negotiate with upstream users to take measures to protect the water from pollution and sedimentation. The downstream users may offer some kind of payment or reward in exchange for agreed management practices being implemented. Although this appears similar to the subsidies discussed above, the difference is that the initiative comes from local people who are direct stakeholders in the issue, which may make sustainability easier to achieve, since the downstream users will have an interest in continuing to monitor compliance. Such negotiation mechanisms may work if the rights of each group are clearly recognized and accepted and the transaction costs of reaching and enforcing agreements are not too large (Coase 1960). There is growing interest in such payments for watershed services, although examples of successful implementation are rare. Within relatively small and cohesive communities such negotiation and collective agreements is more likely than between communities, and the ability to ensure that all resource users to obtain benefits is greater. The famous example of the village of Sukhomajri near Chandigarh in India is one of the best examples, in which the benefits of a locally initiated watershed development effort were broadly shared in the community in return for compliance with grazing restrictions, leading to dramatic improvements in natural resource management, household food production, and livelihoods (Dixon, et al. 2001). Lack of replication of this experience is sometimes taken as indicating that it is too dependent on local leadership and other idiosyncratic factors that are difficult to replicate. However, it may rather be lack of local control over resources that prevents more such examples from occurring (Ibid.).

Another case where prospects for successful negotiated solutions appears promising is where there is a single affected user downstream, such as a hydro-electric facility, with the interest and ability to pay users upstream to take actions to prevent sedimentation and pollution from imposing costs on the facility. In this case one of the keys to success of a negotiated approach will be to have an effective organization of the upstream resource users that has the legitimacy and support of the users and the ability to monitor and enforce an agreement. Without such an effective organization with the capacity to negotiate and commit to an agreement, the prospects of an effective reward system being established appear unlikely, as the transaction costs to the downstream user of attempting to negotiate and enforce agreements with a large number of individual farmers is likely to exceed the potential benefits that it may receive as a result.[20]

These examples highlight the importance of effective local institutions and organizations that are responsive to the needs of poorer members for LEISA technologies (and as other technologies) to achieve their potential to help reduce poverty and ensure sustainable natural resource management. Such organizations are particularly important where collective action is required, but not only in this case. Organizations and networks that facilitate linkages to information and resources from outside the community (e.g., to agricultural technical assistance or market opportunities) are also likely to be important. The former type of organizations (that facilitate collective action within a community) are referred to in recent literature as representing "bonding social capital", while the latter represents "bridging social capital" (Putnam 2000). One recent study by Krishna (2002) of the performance of villages in Rajasthan in India found a synergy between these types of linkages; i.e., that local networks were more effective in generating collective action in villages where there were political agents capable of linking the villagers to outside agencies. Preliminary results of research on a social forestry (*Hutan Kamasyarakatan* (HKm)) program in the Sumberjaya watershed in West Lampung, Sumatra (which provides tenure security to groups of farmers in protected state forest land through contracts requiring the groups to protect remaining forest land, plant multi-strata coffee agroforestry systems (rather than monocropping coffee), and use SWC measures), also suggests that the groups that have been successful in obtaining HKm contracts have had had both bridging and bonding social capital (Kerr, et al. 2006). In general, however, there is limited evidence on the impacts of such different types of social capital on agricultural innovation or other aspects of rural development (Tripp 2006).

[20] ICRAF is investigating the possibilities for promoting such payment for environmental services schemes in Southeast Asia through its IFAD-supported program "Rewarding the Upland Poor for Environmental Services" (RUPES). It is too early to tell whether such efforts will be effective and scalable.

Whether outside agencies such as development projects can be effective in creating social capital (whether bonding or bridging) that is sustainable and serves the interests of the poor is an open question. Some observers are optimistic about the role of external agencies, and see the large number of farmer groups organized by such agencies as representing advances in social capital creation (Pretty and Ward 2001). There are, however, good reasons to remain circumspect about the prospects for external agencies to create social capital. There are many examples of local groups rapidly formed to benefit from a particular project that serve basically that objective, and cease to exist once the project ends (Tripp 2006). Most efforts to develop village seed producer groups and convert them into commercial enterprises have failed (Tripp 2001). Böhringer, et al. (2003) describe the difficulties that group tree nurseries formed with project support in Africa often suffer as a result of disputes over responsibilities and management, and show that individual nurseries are usually more productive. Besides their level of efficiency, project initiated groups may not be representative of poorer members of the community, or may be captured by powerful elites (Gugerty and Kremer 2002). In a study in Kenya of the impact of projects promoting agroforestry, Place, et al. (2003) found that many villagers complained that the groups formed were often dominated by better-off farmers. In my own experience visiting villages participating in a watershed development project in Rajasthan during the early 1990s, I observed that in several cases the chairman of the local users group that had been formed by the project was the local Rajput (i.e., a descendant of the local rulers from the medieval period), and in some cases that leader was not able to provide the names of the other members of the users group. It seems unlikely that such rapidly organized groups by project demands are usually sustainable and serve the best interests of the poor.

There is evidence that projects can be effective in building on and developing local social capital if sufficient investment is made in this aspect of project management and the approach is truly participatory and responsive to local concerns. In his evaluation of watershed projects in semiarid India, Kerr (2002b) found that projects run by an NGO or as a collaboration between the government and an NGO selected villages where people had demonstrated the willingness and ability to take collective action to solve common problems, and devoted more time and resources to organizing communities to establish locally acceptable interventions for watershed management. These projects were more successful than government projects that adopted a more technocratic approach. Although all projects were effective in reducing soil erosion, the NGO and NGO/government projects were particularly effective because they introduced effective social institutions to limit exploitation of uncultivated lands. Projects with an NGO component had more impact on increasing farmers' net returns in rainfed cultivation per Rupee invested, even though such projects invested somewhat more per hectare. Despite this success, all projects faced equity concerns, with larger landholders more likely to perceive benefits than smaller landholders, and landless people most likely to perceive negative impacts (due to losing access to common property resources important to their livelihoods), even in the more participatory projects.

There are also questions about the ability to replicate successful participatory watershed approaches on a wide scale (Ibid.). The most successful projects were few and may have enjoyed special attention that may not be replicable. The availability of sufficiently well trained staff in methods of social organization is likely to be a serious constraint. Furthermore, the selectivity used by the more successful participatory projects indicates an element of "cherry picking", suggesting that success is likely to be more difficult in the broader population of communities where local social capital and collective action are less well established.

The difficulty of upscaling other LEISA approaches has been noted in other studies as well. Despite their demonstrated effectiveness in promoting increased farmer knowledge of IPM and other agroecological farming practices, the high cost of FFS per farmer trained is seen by some as a significant barrier to scaling up this approach (Norton et al. (1999); Quizon et al. (2001); Thiele et al. (2001); Tripp (2006)). IPM efforts in Indonesia and the Philippines are estimated to cost \$49 and \$47 per farmer, respectively (Feder, et al. 2004b; Quizon, et al. 2001), and van den Berg, et al. (2002) estimate a cost of \$12 per participating farmer in FFS in Sri Lanka. Whether such costs are "high" depends of course on the benefits obtained and the costs and effectiveness of alternative means of achieving the same objectives.

The impacts of FFS from several case studies reported in Table 6 suggest that the benefits per farmer can be quite high relative to the costs. For example, Barzman and

Desilles (2002) report an average cost savings in rice production of $92 per hectare per year resulting from participation in FFS in Bangladesh. Given that the farmers surveyed own 0.45 hectares of land on average, this translates into a potential return (if farmers grow only rice) of about $40 per year per farmer, which compares very favorably with the unit costs estimated above. Much higher income impacts are reported by Barzman and Desilles for farmers that also adopted fish production ($130 per participating farmer), so the above estimate appears conservative. Similarly, Jones (2002) reports that that annual net income from rice in Sri Lanka was $115 to $319 per hectare higher for participants in FFS, which translates into annual gains per farmer of $70 to $190, assuming 0.6 hectares planted on average.[21]

These estimates suggest that the costs of FFS training are not high compared to the benefits obtained, although it is not clear how well these case studies addressed methodological concerns such as the statistical significance of the differences reported, whether the participants in FFS already had higher profitability prior to the FFS (though this concern would not apply to new activities such as fish production in paddies) and whether other factors besides the FFS that may have influenced profitability were controlled for. In one of the few careful econometric studies available on the impacts of FFS, Feder, et al. (2004a) found that the training had no statistically significant impact on yields or pesticide use of the participants or others in the same communities, even though a related study found that the participants in training had superior knowledge of pest control methods and that households with better knowledge of these methods used less pesticides (Feder, et al. 2004b). Not too much should be concluded from such a finding of statistical insignificance in one study, since this may be a reflection of low statistical power due to poor data or other problems, rather than an actual lack of impact.[22] It strains credibility to believe that the FFS IPM efforts in Indonesia have had no impact on pesticide use given the evidence that these programs increase farmer knowledge of pest

[21] Jones (2002) reported that farmers in his survey cultivated between 0.4 and 0.8 hectares on average across the study regions.

[22] Conventional tests of statistical significance do not address this type of statistical error; i.e., the likelihood of incorrectly accepting the null hypothesis of no impact. Without information on the statistical power of the evidence, one can only conclude that the null hypothesis cannot be rejected, not that one is confident in the null hypothesis.

control methods and evidence that farmers with greater knowledge use less pesticide. However, the net effects may be too small to estimate econometrically (given a relatively small sample size), as argued by Feder, et al. (2004a).[23]

The claim that high costs and capacity constraints limit upscaling of the FFS approach is also somewhat contradicted by the large number of farmers that have already been trained in some countries. Nevertheless, these programs have still reached only a small proportion of farmers, even where they have been implemented most broadly, so this is a serious concern. Also of concern is the limited supply of well trained and highly committed trainers. Both the unit cost and limited supply of trainers could be addressed by increasing the use of farmer-trainers, although this has reportedly not been implemented yet on a large scale (at least at the time of the available studies) (Anderson and Feder 2005). Whether use of farmer trainers affects the performance of the approach is not known.

An important issue with regard to upscaling of FFS and other approaches to promoting LEISA technologies is the question of whether the knowledge and information provided diffuses to non-participants. In general, the available studies on this issue find limited diffusion (Rola, et al. 2002; Feder, et al. 2004b; Tripp, et al. 2006). There is also little evidence to support the claim that such efforts can catalyze a process of innovation in rural communities (Tripp 2006). Although these findings may be discouraging to some advocates of the FFS approach, they are perhaps not too surprising. Given that the basic premise of the approach is that farmers need to acquire knowledge of complex agroecological principles through intensive experiential learning, there is little reason to expect that such knowledge will easily diffuse to other farmers, even in the same community. The lack of diffusion merely shows that the training provided is important (and possibly essential) to achieve the objectives of the program. One could as well criticize investments in formal primary school education for the lack of diffusion of

[23] One reason for possibly limited statistical power in the studies of FFS in Indonesia by Feder and colleagues is small sample size. The size of the sample of households used in these studies is only 320 households. Furthermore, it is not clear from these studies how well this sample represents the 500,000 households that had received FFS training in Indonesia by 1999 or other untrained households (there were only 52 untrained “control” households in the sample).

literacy to people who have not gone to school. In this author's opinion this is not a valid criticism of the FFS approach.

The difficulty of attaining rapid diffusion of many LEISA technologies is also affected by the fact that these technologies are not embodied in a marketable product, as are the technological improvements embodied in hybrid seeds and agricultural chemicals. Unlike the case with hybrid seeds and agricultural chemicals, it may be difficult for private agents to profit by promoting LEISA technologies, since the main "product" that they are providing is information. It can be difficult to develop a market for such information (especially among poor farmers in less-favored areas), due to difficulty of excluding non-payers from benefiting from such information, difficulty in assessing the quality of information provided, poor farmers' limited ability and willingness to pay for information, and other problems.[24] Given these difficulties, together with the difficulty noted above of attaining farmer-to-farmer diffusion of technologies requiring that farmers understand complex agroecological principles, widespread adoption of many LEISA technologies is likely to depend upon exposure to publicly-funded technical assistance programs such as FFS or other approaches. In these circumstances, budgetary constraints of governments and donors are likely to remain an important constraint to the pace at which upscaling of such technologies occurs. An exception to this constraint may be where organic farming or other forms of eco-certification provide a profit motive (due to price premia) for private agents to provide training on new production methods to farmers. This approach is discussed in a subsequent subsection.

Summary

To sum up this discussion of LEISA technologies, there are many promising technologies with potential to reduce natural resource and environmental degradation, maintain or increase productivity, and contribute to improved household livelihoods. The potentials for such technologies depend greatly upon the biophysical, socioeconomic and institutional context, and upon the capacities and constraints of individual farm households. The most important factor affecting adoption is whether farmers expect to

[24] Private markets for agricultural advisory services do exist, although mainly for cash crops and mainly in developed countries.

profit from such technologies in a relatively short period of time, considering the costs and risks that they perceive. A few LEISA technologies have been widely adopted in intensive rice and rice-wheat systems in favorable areas of the SEAP region, including IPM and zero tillage. Water harvesting and other aspects of integrated watershed management have had large impacts in some less-favored semi-arid regions of China and India, promoted by large projects. Less success has been seen in promoting soil and water conservation measures in more humid upland regions of Southeast Asia (also less-favored areas), largely because the measures promoted were too costly (especially in terms of labor) relative to the benefits generated in the near term. There appears to be greater potential for adoption of less labor intensive measures such as use of natural vegetative strips and ridge tillage, especially in less intensive farming systems in less densely populated upland areas, although it is too early to tell whether widespread adoption will occur.

Despite the hope that these technologies and the approaches to promote them are pro-poor, both theory and evidence suggest that this is often not the case, with more well endowed farmers often better able to take advantage of the opportunities offered by LEISA technologies, as is the case for other technologies. Such approaches can also have negative as well as positive effects on non-adopters as a result of restrictions on resource use (e.g., grazing restrictions in watershed development projects) and externalities. The development of effective local organizations that are responsive to the needs of the poor and that are effective in facilitating collective action and shared benefits, as well as linkages to outside sources of information and resources, appear to be critical to achieving pro-poor and sustainable outcomes. It is not clear whether external projects can be effective in creating such social capital, but there is evidence that they can build on existing social capital to achieve favorable outcomes if they are participatory in nature and invest sufficiently in understanding and promoting local social organization.

The prospect for rapidly scaling up many of these approaches is open to question. Most of the successful approaches rely upon intensive interaction and training of farmers, using skilled and committed facilitators and trainers, and the knowledge gained does not easily diffuse to other farmers or necessarily catalyze a sustained process of innovation, as hoped by some advocates of these approaches. Nevertheless, the overall returns from many such activities appear to be high relative to the costs, especially when they involve technologies that reduce farmers' costs (such as IPM and zero tillage), although this has not been conclusively demonstrated using careful empirical studies. Thus, there are strong reasons to support expanded investments in such activities in the SEAP region, provided that the technologies are well suited to the contexts in which they are promoted and that the approach used is participatory with adequate attention given to building upon and promoting local social organization and to providing experiential learning concerning the principles of sustainable agriculture. More careful empirical research on the impacts of efforts to promote LEISA technologies would help to strengthen this case, and identify more clearly where such efforts are likely to succeed or fail.

Organic Farming

Organic agriculture is a specific type of low-external input agriculture that adheres to certain principles in the production and transformation of agricultural commodities. Virtually all of the discussion in the preceding section on factors affecting adoption and impacts of LEISA approaches therefore applies to organic agriculture (except issues related to use of synthetic herbicides in zero tillage systems, which are not allowed in organic agriculture), and will not be repeated here. In this section, I emphasize the special characteristics of organic agriculture and what additional implications these have for the ability to improve the livelihoods of poor farmers in less-favored areas of the SEAP region.

Organic agriculture may be either certified or non-certified. Certified organic agriculture must meet certain process standards in the production, processing, and handling of organic products, in accordance with standards established by the International Federation of Organic Agriculture Movements (IFOAM) (Kilcher, et al. 2002). The IFOAM standards provide a framework for certification bodies worldwide to develop their own certification standards, which can vary across countries depending upon specific local conditions. Organic standards have been established by most industrialized nations, as well as being specified in guidelines of the Codex Alimentarius of the FAO and World Health Organization (WHO). The Codex Guidelines are consistent with IFOAM Basic Standards and the EU Regulation for Organic Food (EU

Regulations 2092/91 and1804/99). According to the Codex Alimentarius, "Organic agriculture is a holistic production management system which promotes and enhances ecosystem health, including biological cycles and soil biological activity. Organic agriculture is based on minimizing the use of external inputs, avoiding the use of synthetic fertilizers and pesticides" (FAO/WHO 2001). Use of genetically modified organisms is also not allowed. Farmers and processors that sell organic products must be certified by accredited certification bodies, involving a system of regular inspection and certification to ensure the credibility of organically certified products.

Although organic agriculture is a form of low external input agriculture, its requirements are more restrictive, so not all forms of LEISA could be considered organic. For example, use of herbicides in a zero-tillage system would not be consistent with organic agricultural principles. Neither could use of genetically modified insect resistant Bt cotton or maize in combination with IPM be labeled as organic, although some would consider this a LEISA approach (combined with modern agricultural biotechnology).

With certification, price premiums of 10 to 50 percent are common for developing country exports of organic products (Scialabba and Hattam 2002; IFAD 2005).[25] Producers of organic products may also benefit from a more assured market than they may find for non-organic products. Non-certified organic agriculture offers no particular price or marketing advantages (unless non-certified organic production is pursued as a prelude to certification). Therefore, it seems unlikely to be widely pursued in SEAP except as a form of LEISA because of the advantages of LEISA approaches that have already been discussed in the previous section. The discussion in the remainder of this section thus focuses on certified organic agriculture.

Organic farming has grown rapidly in the past few decades, especially in industrialized nations, and organic products are one of the fastest growing segments of the retail food industry in these countries. Global organic sales have grown at double

[25] For example, Wynen and Vanzetti (2002) reported that organic producers in India earned a premium of about 20 – 30 percent over conventional products . IFAD (2005) reported premiums in the Karnataka state of India ranging from 20 to 40 percent for rice, bananas, vanilla and sugarcane. Another study surveyed organic exporters in India and found that their premiums ranged from 25 to 53 percent (Garibay and Jyoti 2003). Wynen and Vanzetti (2002) report retail premiums in Denmark of 20 to 50 percent for organic vegetables, 0 to 20 percent for organic cereals, 20 to 30 percent for organic dairy products, 20 to 50 percent for organic potatoes, and 50 to 100 percent for organic fruit.

digit rates for more than the past decade (IFAD 2005). In 2004, some 24 million hectares globally were managed organically, with most of this in three countries (Australia, Argentina and Italy), with much of this being extensive grazing land (Yussefi 2004).

Adoption and impacts of organic farming

In the SEAP region, there were about 60,000 farms producing certified organic products on about 600,000 ha in 2000-2002 (Table 13).[26]

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[26] IFAD's evaluation team estimated that organic areas were much higher in China and India in 2004 than those reported in Table 6, based on estimates from official sources (IFAD 2005). In China, there were between 600,000 and 700,000 hectares of organic land in 2004 according to the Organic Food Certification Center. India's Agricultural and Processed Food Products Export Development Authority (APEDA) reported that the area certified under organic agriculture totaled 2.5 million hectares in early 2004. This figure is misleading since it includes 2.4 million hectares that are mostly forest area used for collecting wild herbs and medicinal plants. Excluding these areas, about 76,000 hectares were estimated to be agricultural lands under organic production in India in 2004, roughly doubling the estimate in Table 13 (Ibid.).

Table 13. Number and area of organic farms (certified or in conversion) by country in the SEAP region

Country	Year (2000-2002)	Number of Organic Farms		% of All Farms	Area of Organic Farms (ha)		Average Area of Organic Farms (ha)		Organic % of Agricultural Area	
		2000-02	2005/06	2000-02	2000-02	2005/06	2000-02	2005/06	2000-02	2005/06
Bangladesh	2002	100	100		177,700	177,770	1777.0	1777.7		1.97
China	2001	2,910	1,560		301,295	3,466,570	103.5	2222.2	0.06	0.60
India	2002	5,147	5,147*		37,050	114,037*	7.2	22.2	0.03	0.06*
Indonesia	2001	45,000	45,000		40,000	52,882	0.9	1.2	0.09	0.12
Laos	2001		5		150	60		12.0	0.01	< 0.01
Malaysia	2002					600				
Nepal	2001	26			45	1,000	1.7		0.001	0.02
Pakistan	2001	405	28	0.08	2,009	20,310	5.0	725.4		0.07
Philippines	2000	500	34,990		2,000	14,134	4.0	0.4	0.02	0.12
Sri Lanka	2001	3,301	3,301		15,215	15,379	4.6	4.7	0.65	0.65
Thailand	2002	1,154	2,498	0.02	3,993	13,900	3.5	5.6	0.02	0.07
Vietnam	2002	1,022	1,022		6,475	6,475	6.3	6.3	0.08	0.07
SEAP region		59,565	93,651		585,932	3,883,117	9.8**	41.4**		

* Provisional figures for India

** Excluding Laos, Malaysia, and Nepal because of incomplete data.

Source: 2000 to 2002 figures from Wai (2004); 2005/06 figures from Yussefi (2006)

By 2005/06, this had increased to more than 90,000 farms producing certified organic products (or in process of certification) on more than 3.8 million ha. Most of these farms were in Indonesia, followed by India, Sri Lanka and China, while most of the area was in China, followed by Bangladesh. Despite rapid growth in recent years, only a very small proportion of farms and agricultural land (less than 0.1 percent in almost all cases, except in Bangladesh (2 percent of agricultural land) and Sri Lanka (less than 0.7 percent of agricultural land) are organic in the region. There is wide variation in the size of organic farms across countries. In China, Bangladesh, and Pakistan, most of the organic area is on very large farms, with average organic farm size over 2000 ha in China, nearly 1800 ha in Bangladesh, and over 700 ha in Pakistan. In India, organic farms are also relatively large, averaging over 20 ha. In Sri Lanka, Thailand and Vietnam, organic farms are moderate in size on average (5 to 6 ha), while in the Philippines and Indonesia, organic farms are quite small (1.2 ha in Indonesia and 0.4 ha in the Philippines on average).

There are two general types of organic farming in the region; one as part of sustainable agriculture promoted by NGOs and the second promoted by commercially oriented organic projects of private companies and governments (FAO 2004). The NGOs are working primarily with small family farms, targeting the domestic market, although they have begun to look at export opportunities as well. Not all of the organic production being promoted by NGOs is certified, as the emphasis is more on sustainable production. The commercial organic sector generally involves larger farms and focuses on production for export markets. Organic agriculture in most of the countries of the region is generally following the NGO promoted small farm model, while in China the commercial model is more prevalent (IFAD 2005). In India, both private companies and NGOs play major roles in promoting organic agriculture, although NGO-led cases are more prevalent (Ibid). In Thailand, about two-fifths of organic area is on small farms organized by farmer organizations and NGO projects, and almost all of the rest is on single large farm or on farms organized by private companies (Reunglertpanyakul, undated).

Organic agriculture has many similarities to some other farming approaches and certification schemes found in China and India. The Green Food label in China has many similarities to certified organic production, although it is based on product standards rather than process standards, and Green Food products are produced primarily for the domestic (primarily urban) Chinese market. The magnitude of production under the Green Food label is more than ten times the size of organic production in China (Ibid.). The total retail value of domestic Chinese Green Food sales in 2003 is estimated at $12 billion, comparable to the size of the U.S. organic market, while about 12 percent of Green Foods were exported to Japan and Europe (Ibid.). The success of the Green Food label in China demonstrates that a large consumer demand exists for foods that are free from risks of chemical contamination, and suggests an opportunity for increasing domestic sales of certified organic production. However, the greater recognition of the Green Food label (which has been heavily promoted by the Chinese government) also could prove to be an obstacle to acceptance of certified organic products, unless these labels were to be combined (e.g. if an additional certified organic Green Food label were to be introduced). Certified organic production has greater recognition in international markets, and the Green Food label does not always receive a premium price, as do organic products.

In India, there are no widespread alternative domestic certification schemes such as Green Food, but the holistic farming tradition of Jaivic Krishi (also known as Vedic Krishi) uses similar principles in production as organic farming, but is far more widespread. Recognition of the importance of such principles could facilitate acceptance of organic production among both farmers and consumers in India.

There is evidence of favorable impacts of organic production on farmers' costs of production and yields from several recent case studies in China and India (Ibid.). In a case study of cotton production in Maharashtra, the costs of production per hectare (including labor costs) under organic agriculture were estimated to average 3,800 Rs/ha in 2003 compared to 8,200 Rs/ha under intensive (high external input) conventional agriculture (Table 14).

Table 14. Cost of production and profitability of selected crops under traditional, organic and conventional intensive production

		Production cost ($/ha)*			Yield (kg/ha)*			Production cost/kg*			Price ($/kg)*		Profit ($/ha)*		
Crop	Year	Traditional	Organic	Conventional	Traditional	Organic	Conventional	Traditional	Organic	Conventional	Organic	Trad/ Conv.	Traditional	Organic	Conventional
	2001	330	710	580	3750	5250	6750	0.088	0.135	0.086	0.1	0.1	45	-185	95
Hill rice	2002	370	730	600	3375	6000	6700	0.110	0.122	0.090	0.12	0.12	35	-10	204
(China)	2003	400	767	640	3750	6375	6750	0.107	0.120	0.095	0.15	0.15	162	189	372
	2001		1812	1620		15000	18000		0.121	0.090	0.12	0.07		-12	-360
Ginger	2002		1849	1680		22500	29250		0.082	0.057	0.15	0.07		1526	367
(China)	2003		1885	1740		12000	14400		0.157	0.121	0.17	0.08		155	-588
Soybeans	2002		310	600		3750	7500		0.083	0.080	0.24	0.09		590	75
(China)	2003		320	675		3750	7500		0.085	0.090	0.34	0.12		955	225
	2000	220	415	360	3250	4500	5750	0.068	0.092	0.063					
	2001	230	410	385	3100	4650	5000	0.074	0.088	0.077					
Valley rice	2002	235	380	410	3100	4900	4850	0.076	0.078	0.085					
(India)	2003	250	365	435	3150	5350	4900	0.079	0.068	0.089					
	2000	665	1040	835	105000	112000	155000	0.0063	0.0093	0.0054					
	2001	680	1020	970	87500	116000	137000	0.0078	0.0088	0.0071					
Sugarcane	2002	695	965	1020	102000	121500	108000	0.0068	0.0079	0.0094					
(India)	2003	705	880	1035	92000	128000	97000	0.0077	0.0069	0.0107					
	2000	1940	2015	2845	17500	22500	31000	0.111	0.090	0.092					
	2001	1120	1210	1490	18000	28000	29500	0.062	0.043	0.051					
Banana	2002	1135	1180	1510	20500	33000	27500	0.055	0.036	0.055					
(India)	2003	1140	1095	1640	21000	36000	23000	0.054	0.030	0.071					
Cotton	2002	3085	3500	7575	450	650	800	6.856	5.385	9.469					
(India)*	2003	3355	3805	8235	450	650	800	7.456	5.854	10.294					
Rice (Thailand)*	2000		2733	2635		350	350		7.81	7.53	10	7		767	-185
Baby corn (Thailand)*	2001		4680	4733		173	150		27.05	31.55	30	20		510	-1733

* For cotton in India, costs are in Rupees. For Thailand, costs and profits are in Thai Bhat, areas in rai.

Source: IFAD (2005); author's calculations of production costs per kg. and profit per ha, except for Thailand.

Source for Thailand: Reunglertpanyakul, (undated).

The yields were higher under intensive conventional practices (800 kg/ha vs. 650 kg/ha for organic), but considering the lower costs per hectare, the cost per kg. was still lower for organic producers (5.85 Rs/kg. for organic compared to 10.29 Rs/kg for conventional). Organic costs of production per kg. were also lower than costs under traditional (low external input) practices in this case (7.46 Rs/kg.). Thus, even without the price premium for organic products, farmers' profits and income would have been substantially higher under organic production than either traditional or intensive conventional technologies in this case.

Evidence from other case studies of the costs and returns to organic agriculture relative to traditional and intensive conventional production are presented in Table 14. In two cases (upland rice and ginger in China) the unit production cost per kg. was higher under organic production than under conventional production in all years studied (and under traditional production for rice). Since there was no price premium for organic rice in these cases, farmers' profits were lower for organic production than other methods. In three cases (soybeans in China and valley rice and sugarcane in India), production costs were higher for organic than conventional production in the earlier years but lower in the later years. For soybeans, the large price premium for organic production (nearly 200 percent) led to much higher profits even in 2002, when the cost of production was slightly higher. For other crops, the price information was not available, so relative profitability could not be calculated. But given the lower cost of production for organic production in the later years for valley rice and sugarcane in India, organic production would have been more profitable than conventional production for these crops in those years even without any price premium. In the case of banana production in India, the unit cost of organic production was lower than both traditional and conventional intensive production in all years, implying that organic was the most profitable production method. In Thailand, the unit cost is slightly higher for organic rice production than conventional production, but because of the price premium for organic rice (43 percent), organic production is much more profitable (earning 950 THB/rai more profit). For baby corn production in Thailand, the advantage of organic production is even more favorable, due to slightly lower production cost per rai (1 percent lower), 15 percent higher yield and the price premium (50 percent higher) for organic production.

These results demonstrate several important lessons concerning the productivity and profitability of organic production. First, the relative cost and profitability of organic production vs. alternative approaches varies across different crops and locations. There is no single best agricultural approach for all circumstances, at least by the narrow criterion of profitability (which is essential to addressing poverty). However in many cases, organic production is more profitable than conventional methods using high inputs or traditional methods using low inputs, especially when there is a price premium for organic production. Similar results have been observed in case studies of organic farming conducted in Latin America (Damiani 2002). It is difficult to draw any general conclusions about which approach is better suited to which types of situations based upon such a small number of case studies. However, we do have several examples of organic production by poor farmers in less-favored areas (cotton in semiarid Maharashtra and hill rice, ginger and soybeans in a mountainous area in Jianxi Province of China), and in three of these four cases (cotton, ginger and soybeans) organic production was more profitable for farmers (the latter two due to the price premium). These examples demonstrate that there are opportunities to help reduce poverty in less-favored areas through organic agriculture.

Second, although organic production often results in lower yields than conventional high input production, the unit cost of production is in some cases lower under organic production as a result of substantially lower production costs per hectare. In such cases, organic farming is competitive with conventional farming even without a price premium, meaning that even non-certified organic production is competitive.

Third, even in cases where the cost of production per kg is higher under organic production, certified organic can still be more profitable because of the price premium (although non-certified organic would not be). A caveat here is that these calculations have not considered the farmers' cost of obtaining certification, which may outweigh the higher profit from certified organic production.

Fourth, the relative profitability of organic production compared to conventional production tends to increase over time as a result of yield improvement after an initial decline. This phenomenon of initially declining and then improving yields following conversion from conventional to organic production is commonly observed in studies of organic agriculture, and occurs as soil fertility improves and as farmers learn how to adapt their production methods (Ibid.; Scialabba and Hattam 2002). Thus, even if organic agriculture is not competitive initially, it may become so after some time, although this may require several years of commitment upon the part of farmers before the gains are observed.

Fifth, organic farming is not always profitable relative to either conventional or traditional approaches, and this is more likely when the price premium is low. Although there are other likely benefits of organic agriculture compared to conventional high input agriculture that should also be considered, such as reduced health and environmental costs and more sustainable production, organic agriculture will not contribute to poverty reduction if it is less profitable to farmers than the methods of farming that they are already using (although it can help prevent increases in poverty to the extent that yield declines and cost increases due to land degradation become less of a problem).

Finally, it should not be taken for granted that traditional low input, non-organic methods of production are inferior to either organic or conventional high input methods, even though yields are generally lower (often substantially so) (e.g., for hill rice in China and valley rice, bananas and cotton in India (Table 14)). The level of yield is only one of the factors important to farmers in deciding which method to use; the costs per hectare are also important to consider. In some cases (e.g., hill rice in China in 2001 and 2002 (traditional compared to organic), valley rice in India in 2000, 2001 and 2002 (lower cost per kg. for traditional compared to organic and conventional), and sugarcane in India in 2000, 2001, and 2002 (lower cost per kg. for traditional than for organic)), these costs may be so high for organic and conventional methods that traditional methods are more profitable. And even if traditional methods are not more profitable than the alternatives, they may still be preferred by farmers because of considerations of risk, liquidity constraints, labor constraints and other factors discussed in the previous section. In such cases (where traditional production is less profitable but still pursued), the key constraints should be identified and addressed through programs responsive to producers' local needs.

Prospects for the future

The global market for organic products has grown at double digit rates for the past decade, and the market is forecast to continue growing at 15-20 percent annually during the next several years (Wynen and Vanzetti 2002). Japan and Korea are presently the major markets for organic products in the region, while China represents probably the largest growth potential (Wai 2004). As incomes grow in rapidly developing countries of East and South Asia and as urbanization and “supermarketization” continue to increase, the market for higher quality foods and other commodities are likely to continue growing rapidly in these countries. Thus, the prospects appear very favorable for continued market growth for organic commodities in the SEAP region, in domestic and regional markets as well is in more developed countries.

Although market demand growth is expected to be strong, the supply of organic products is also expected to continue growing rapidly, to take advantage of the demonstrated profit potential of organic agriculture. As more governments and large private corporations take interest in organic agriculture, there are likely to be increased investments in developing accredited certification organizations within the region and elsewhere. Such developments will be welcome to organic or potential organic farmers, since they should tend to reduce the cost of certification over time. However, the increased supply of organic production and reduced certification costs, together with possible saturation of some markets (e.g., in Europe and Japan), suggest that there could be a declining trend in price premium for organic commodities over the long term. Whether small farmers will continue to be able to profit from organic production as price premiums decline depends upon how important such premiums are to profitability, which, as we have seen, varies substantially across commodities. It also depends upon how well small farmers are organized to be able to reduce the per farmer costs of obtaining certification and to obtain access to high value organic markets. As more large corporations begin to become involved in producing and marketing organic produce, it is likely to become increasingly difficult for small farmers to obtain substantial benefits from organic production and marketing, unless they are well organized and are able to develop effective marketing channels.

Besides the prospects of diminishing profit margins resulting from increased competition, organic producers are likely to face increasing market risks as the sector grows. As more producers and middlemen enter into organic production and marketing in search of lucrative profits, the risk of a scandal involving marketing of fraudulent “organic” products is likely to increase. A well-publicized scandal could undermine the credibility of organic products from entire nations or regions, and lead to closing of markets and reductions or elimination of organic price premiums. Countries most vulnerable to such reputational risks are likely to be poorer countries where regulatory institutions function poorly.

As a result of these trends and risks, farmers and farmer organizations would be well advised to proceed cautiously in pursuing organic agricultural opportunities, especially if the main motivation for doing so is the high level of price premiums currently available. Farmers are more likely to find investments in organic agriculture beneficial in the long run if they are making such investments primarily because of other expected benefits, such as more sustainable productivity and reduced health and environmental risks.

Key issues and constraints

As mentioned at the beginning of this section on organic agriculture, the production issues and constraints of organic agriculture are quite similar to those facing LEISA technologies, since similar technologies are used in either case. One important difference between LEISA approaches and organic agricultural production is that certain inputs are strictly prohibited under organic agriculture, including most pesticides (other than permitted biopesticides), inorganic fertilizers, and genetically modified organisms. Use of such inputs is not strictly prohibited under LEISA approaches (e.g., use of herbicides in zero or minimum tillage systems), although LEISA principles imply limited use of such external inputs. It may be possible to combine LEISA technologies with intelligent use of such inputs to achieve outstanding results, such as through IPM, zero tillage or integrated soil fertility management. In addition, as will be noted in the subsequent section on biotechnology, there is considerable potential (already being realized for some crops) to address pest and disease problems using GM crops, which can be complementary to IPM approaches in reducing the need for pesticides and increasing farmers' yields and incomes while reducing their risks. Thus, there may be high opportunity costs in many circumstances of advocating an overly restrictive approach that denies farmers the benefits of choosing the most suitable option from among all available technologies.

Since organic agriculture involves a major departure from farmers' normal farming practices (especially for those using conventional high input methods, but also for those using traditional methods), strengthening farmer's knowledge is a key requirement. Interestingly, farmers in China and India who were asked to rank the key areas of intervention needed to facilitate their ability to convert to organic agriculture ranked technical advice on the production technology as their top priority, followed by market information. This emphasizes the importance of effective extension technical assistance approaches. Farmer field schools, or some variant, could be a useful approach to address this need, given that the need for farmers to learn a set of principles and be able to apply them to their own situation is similar for organic farming as with IPM.

Beyond these production issues, the most important issues for smallholder farmers pursuing organic agriculture relate to certification and marketing. Certification fees are quite high, with costs often exceeding one thousand dollars. International certification in China can cost from $1,446 to $2,410, with higher costs in remote areas (Ibid.). ECOCERT (the Organic Control and Certification Organization of France) charges $570/day for the site visit, and generally three to ten working days are needed. Costs are somewhat lower for domestic certification in China, but still in the range of or $964 to $1,250 for a farm. Certification costs are lower in India but still high; about $300 per day for site visits (higher for larger farms). Such costs are obviously prohibitive for small farmers, unless they are organized into associations that can spread these fixed costs over a larger area and number of farmers.

The costs of certification can be reduced by developing internationally accredited local certification bodies, increasing the supply of available certifiers and reducing the need to employ high cost personnel from developed countries. For such systems to function, regulations governing the accredited certifying organizations have to be established and effectively enforced according to international standards (and be perceived as being effective). Policy actions of governments or private sector associations are needed to establish and implement such regulatory frameworks. Large rapidly developing countries such as China and India with substantial potential for organic production and consumption are more likely to be interested and able to develop and implement such frameworks, compared to small, poor countries such as Laos and Cambodia. Thus, just as there is a small farmer disadvantage due to fixed costs of certification at the farm level, there is likely a small country disadvantage due to fixed costs of establishing a regulatory framework. Small country disadvantages might be addressed in a similar fashion to small farmer disadvantages; i.e., by forming an association of countries to establish and implement such a framework.

Beyond the costs of establishing regulatory frameworks and paying certification fees, there are the costs and difficulties of actually achieving compliance with certification requirements. At the local level, certification and monitoring costs can be reduced and reputation enhanced by establishing effective internal control systems within organic farmers associations. Establishing and implementing such mechanisms requires considerable organizational capacity, and NGOs have played an important role in helping farmers associations to develop this capacity. This can be difficult, as the experience of the NGO, Agriculture and Organic Farming Group in India, attests (Ibid.). This NGO found that the formal requirements of group certification did not match well with small-scale farmers' capacities, requiring substantial investments of time and management capacity to meet. Because of these difficulties, some practitioners are advocating simpler non-formal or community-based quality assurance mechanisms. Although such approaches can be effective when organic products are being marketed in local bazaars where it is relatively easy for buyers to assess whether the requirements are met, they are unlikely be sufficient to assure quality control and compliance to consumers in more distant urban or foreign markets. Thus, it is difficult for associations of small farmers to assure quality and access these markets without substantial assistance, either from a competent NGO or from the private for profit sector.

The dependence of farmer associations on outside assistance to obtain access to high value markets is another example of the synergy between linking or bridging social capital and local bonding social capital. In some countries, such as India, this linking role is being played to a large extent by NGOs, while in China, the state and private sector have played more of this role. The amount of benefit that farmers receive from organic marketing depends upon who plays this role, and how competitive the market is. In case studies in India in which an NGO was playing this role, farmers tended to receive a fairly high share of the final price, usually well above 50 percent (Ibid). In China, by contrast, farmers receive in some cases as little as 5 percent of the export price, particularly when they are not aware of market prices beyond the farm gate and have little capacity to negotiate. In other cases where farmers are more organized and participate in processing and marketing their products, they receive a much higher share of the price. Achieving such gains however, requires that farmers' organizations invest in the costs of processing, packaging and marketing and bear marketing risks that they do not face when selling commodities in raw form at the farm gate or local market. Thus, not all farmers or farmer associations will necessarily benefit by pursuing such value-added activities. As with any other investment, the benefits of investing in social capital (in this case for marketing) must be weighed against the costs and risks, and considered in light of the capabilities and alternative opportunities of the people involved.

Many of the above arguments suggest that organic agriculture is more likely to be beneficial to farmers in areas closer to urban markets than in more remote areas. Certification fees are likely to be lower in such areas, and farmers are likely to be more aware and able to take advantage of marketing alternatives, rather than relying as heavily on intermediaries for market information and options. The potential for selling high value perishable commodities such as tea, fruits and vegetables – which often earn higher price premiums in niche markets than organic production of bulk commodities – is greater in areas of better market access. Most of these high value commodities also require favorable agricultural conditions, including suitable soils and climate. Thus, as with most other production and marketing options, organic agriculture is likely to favor farmers in more favored areas, in terms of both biophysical and socioeconomic conditions.

Similarly, organic agriculture likely tends to favor wealthier and more educated farmers, who are more likely than poorer farmers to have connections to assist in marketing, to be able to afford certification costs and foregone income during the transition to organic farming, and may be better able to deal with the requirements of organizing local producers' associations with effective quality control mechanisms. To be sure, benevolent NGOs often can and do help to overcome these hurdles, but such NGOs are limited in supply and also sometimes in their capacity to deal with the complexities and risks involved in marketing. Often NGOs, like the private sector, are prone to concentrate their scarce resources on more favorable environments where the likelihood of success is greater. Thus, for the vast majority of smallholders in the SEAP region, especially those in less-favored remote areas, the opportunities offered by certified organic agriculture are likely to remain remote for the foreseeable future.

Summary

Organic farming offers significant and increasing opportunities to many farmers in the SEAP region to improve the productivity and sustainability of their farming system while earning higher incomes. Significant numbers of farmers have recently begun to adopt organic farming, and many are able to increase their profits as a result. In some situations and for some crops these gains do not depend on farmers' receiving a price premium, and in such cases, the potential for adoption of organic approaches is large, even without certification, and with certification very large income gains may be possible. In other cases, organic farming is profitable, but mainly because of the price premium. In these cases, non-certified organic farming has less potential for widespread adoption, unless farmers are motivated by its other benefits beyond economic, and has less potential to reduce poverty. Pursuit of certified organic production may be risky in such circumstances, given the cost of certification and market risks involved. In cases where organic agriculture is not profitable relative to farmers' conventional alternatives, adoption is likely to be limited and unlikely to help reduce poverty where it occurs.

Where certified organic production is potentially profitable, the costs of becoming certified and the challenges of assuring compliance with organic standards and accessing markets are major hurdles. Addressing these challenges requires investment in farmer organization at the local level and usually efforts from external organizations to develop local capacities and facilitate linkages to markets. The availability and capacity of such facilitating organizations is likely to be a major constraint to rapid upscaling of successful organic agriculture ventures.

Organic agriculture is unlikely to reach all regions and all farmers, especially poorer farmers in less-favored regions. Some case study evidence demonstrates that farmers in mountainous or semiarid areas can benefit from conversion to organic agriculture, but access to markets and intermediary organizations (whether private sector or NGOs) was essential. Poor farmers have been demonstrated to benefit, but face serious challenges in doing so. The main lesson is not that organic agriculture can never benefit poor farmers in less-favored areas, but that difficult hurdles must be overcome and external investments are needed if efforts to promote organic agriculture in such areas are to succeed. These investments should be weighed carefully compared to other options to assist such poor farmers in such areas. Since some of the development necessary for organic agriculture to succeed is similar to the requirements for promoting LEISA technologies, such as development of the capacities of farmer associations and their linkages to external sources of information and resources, it makes sense to emphasize such capacity strengthening efforts, whether or not farmers decide to take up organic farming.

Biotechnology

Broadly defined, biotechnology includes "any technique that uses living organisms, or parts of such organisms, to make or modify products, to improve plants or animals, or to develop microorganisms for specific use" (ADB 2001, p. 10). This broad definition encompasses a wide array of techniques, from traditional methods such as conventional plant and animal breeding to more modern techniques such as plant tissue culture, embryo transfer, cloning, breeding using marker assisted selection, genetic engineering of plants or animals, and genomics (Ibid.). It also includes techniques used to produce pharmaceuticals and other non-agricultural products. In this discussion, we use the term "biotechnology" to refer to modern agricultural biotechnology, including the modern techniques mentioned above. Modern biotechnology is sometimes discussed as if it is synonymous with genetic engineering,[27] but many other techniques and sub-disciplines are involved.

Adoption of GM crops

There has been rapid adoption of a few genetically modified (GM) crops globally since 1996, when the first commercial use of GM crops was approved (Figure 35).

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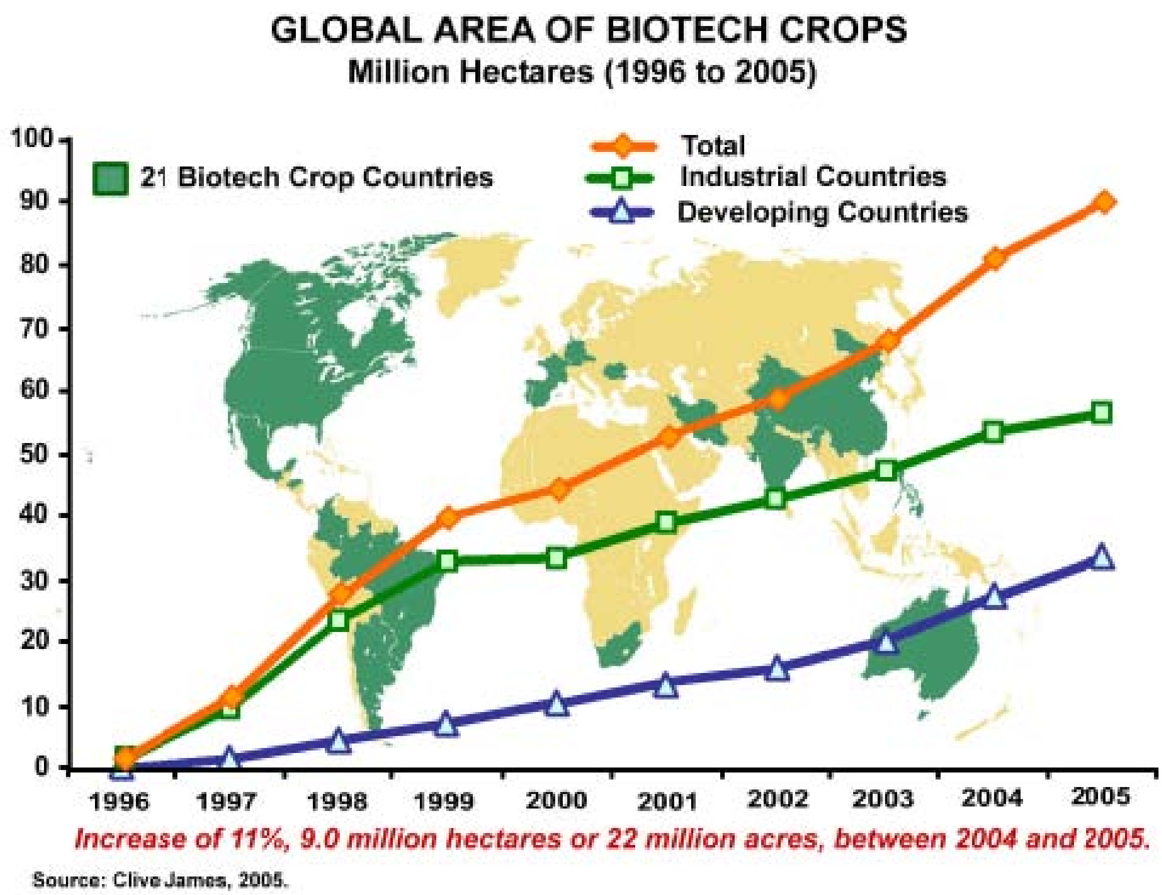
[27] Genetic engineering refers to the process of transferring portions of deoxyribonucleic acid (DNA) (genes) from one organism to another using methods of recombinant DNA technology first developed in the 1970s. The biological products of such transfers are called genetically modified organisms (GMOs) or transgenic organisms.

Figure 35. Global area of biotech crops, 1996 to 2005



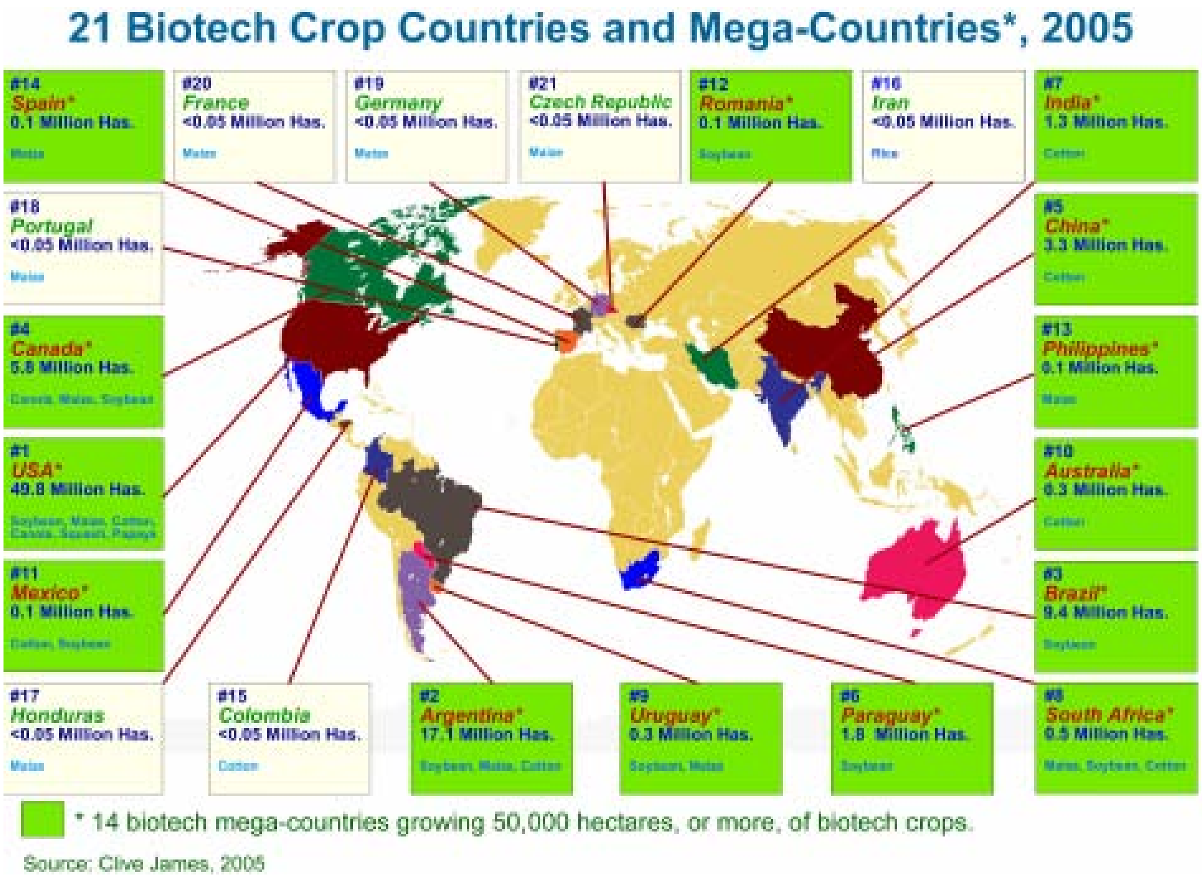
By 2005, an estimated 90 million hectares were planted to GM crops globally. More than half of this area is in the United States (James 2005). Other countries with more than 1 million hectares of biotech crops in 2005 included Argentina, Brazil, Canada, China, Paraguay, and India (Table 15 and Figure 36).

Table 15. Global area of GM crops by country in 2005

Country	Area (million ha.)	GM crops
United States	49.8	Soybean, maize, cotton, canola, squash, papaya
Argentina	17.1	Soybean, maize, cotton
Brazil	9.4	Soybean
Canada	5.8	Canola, maize, soybean
China	3.3	Cotton
Paraguay	1.8	Soybean
India	1.3	Cotton
South Africa	0.5	Maize, soybean, cotton
Uruguay	0.3	Soybean, maize
Australia	0.3	Cotton
Mexico	0.1	Cotton, soybean
Romania	0.1	Soybean
Philippines	0.1	Maize
Spain	0.1	Maize
Colombia	<0.1	Cotton
Iran	<0.1	Rice
Honduras	<0.1	Maize
Portugal	<0.1	Maize
Germany	<0.1	Maize
France	<0.1	Maize
Czech Republic	<0.1	Maize

Source: James (2005)

Figure 36. Major countries producing biotech crops



Within the SEAP region, the only country besides China and India where GM crops were used commercially by 2005 was the Philippines, where about 100,000 hectares of GM maize was grown. Four GM crops are widely used: soybeans, maize, cotton and canola (rapeseed). GM squash and papaya are also grown commercially in the United States, and GM rice has recently been approved for use in Iran.

The most important traits that have been incorporated into commercial GM crops so far include herbicide tolerance and insect resistance. GM crops with these traits (either singly or combined) account for more than 99 percent of global area of GM crops (James 2005).[28] Herbicide tolerance is the most widely adopted (in terms of area coverage, not number of farmers) trait, especially herbicide tolerant soybeans, which accounted for 60 percent of the global area of biotech crops in 2004 (Ibid.). Herbicide tolerance is adopted mainly by farmers in

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[28] Small areas of virus resistant squash and papaya grown in the U.S. account for the remainder (James 2004).

countries where extensive mechanized agriculture dominates, including the United States, Argentina, Brazil and Canada. Tolerance to various types of insects has been produced by incorporating genes encoding various forms of insect-specific toxins from the bacterium *Bacillus thuringiensis* (Bt) (Huesing and English 2004). Insect resistance is in commercial use in Bt maize and Bt cotton (with or without herbicide resistance) (James 2004). Although most area of GM crops is used for mechanized agriculture in developed countries or favorable environments in developing countries (such as in Brazil and Argentina), a substantial amount of production is now occurring on small farms and in less favored semi-arid cotton producing areas of China and India.

Within the SEAP region, farmers are growing Bt cotton in China and India and Bt maize in the Philippines. An estimated 6.4 million small farmers in China (on an average area per farm of 0.5 ha) and 1 million small farmers in India (on an average area of 1.3 ha) were growing Bt cotton in 2005, while more than 50,000 were growing Bt maize in the Philippines (on an average area of about 2 ha) (James 2005). Substantial evidence exists that Bt cotton has helped to increase yields, reduce costs of production, increase farmers' income, and reduce negative health and environmental effects resulting from high levels of pesticide use, often applied by farmers without adequate training or protective gear, in both China (Huang, et al. 2003; Huang, et al. 2002; Pray, et al. 2002; Pray, et al. 2001) and India (Bennett, et al. 2006; Qaim, et al. 2006; Qaim 2003), as well as in other developing countries (Qaim and Matuschke 2005; Qaim and Zilberman 2003). Adoption of Bt cotton led to an estimated average reduction in pesticide use of 65 percent in China and 41 percent in India, combined with an average yield increase of 24 percent in China and 34 percent in India (Qaim and Matuschke 2005). Chinese cotton producers averaged profit increases of about $500 per hectare compared to farmers using conventional seeds (Huang, et al. 2003).

Although the economic benefits of Bt cotton have been found to be positive on average, there is substantial heterogeneity in impacts on different farmers and over time depending upon local agroecological conditions, pest pressure and farmers' spraying practices, and not all farmers benefit economically (Qaim, et al. 2006; Bennett, et al. 2006). Qaim, et al. (2006) found that while Bt adopters in Maharashtra, Karnataka and Tamil Nadu realized significantly higher yields (42 percent on average) and profits on average in 2002/03 than conventional producers, Bt producers in Andhra Pradesh earned lower profits (all of these are semi-arid environments).

They explain this differential by the fact that many cotton farmers in Andhra Pradesh were affected by severe drought conditions, to which the Bt cotton hybrids were not well adapted. Although this suggests that Bt cotton is less suitable to drought-prone less favored environments, this is not because of the Bt gene itself, which does not affect the plant's performance under water stress. Rather, the inferior performance of Bt cotton in this case is due to the nature of the underlying germplasm to which the Bt gene is inserted. Such problems may arise due to the regulatory approval process; if the regulatory process for GM crops is slow, by the time they are commercialized they may be inferior to other conventional varieties whose characteristics have been improved in the meantime (Ibid.). Bennett, et al. (2006) found variations in returns to Bt cotton within the Maharashtra region in 2002 and 2003, with the highest returns in the region where farmers use more irrigation and spray for bollworm and sucking pests most intensively (leading to greater cost reductions resulting from use of Bt rather than sprays), and with a higher proportion of dark soils. They argued that differences in farm size or seed costs could not account for these differences, and instead attributed the different outcomes to differences in patterns of input use across the regions. Despite such heterogeneous responses, the authors of these studies argued that most adopters of Bt cotton did benefit during 2002 and 2003 (Ibid.; Qaim, et al. 2006). Regardless of the distribution of economic benefits, the health and environmental benefits of reduced pesticide use are obvious.

There are fewer published studies of the impacts of Bt maize in the Philippines, since approval is relatively recent (commercial production began in 2003) and adoption is limited. One recent study conducted in 2003-2004 in Isabela, Camarines Sur, Bukidnon and South Cotabato found that Bt maize farmers were able to increase yields 37 percent on average, reduced insecticide cost by 60 percent and, despite higher seed costs (twice as expensive as conventional hybrids), increased profits per hectare by 88 percent, leading to an aggregate welfare benefit for adopting maize farmers of P43 million (Yorobe and Quicoy 2004). In another recent study, Cabanilla (2005), using a mathematical programming model and data collected from groups of farmers in four locations, found that both Bt maize and hybrid maize are substantially more profitable than the traditional variety in both seasons and all states of pest infestation, that Bt maize is slightly less profitable than the non-Bt hybrid when pest infestation is low, but much more profitable under moderate or high pest pressure. These results are consistent with the context specificity of the economic impacts of Bt crops found by Bennett, et al. (2006) and Qaim, et al. (2006) for Bt cotton in India, and with the result that Bt crops are likely to be beneficial under many situations. Other research has shown that Bt maize has not had negative impacts on the availability of beneficial insects or species diversity (Reyes, et al. 2004 Alcantra 2004; Javier, et al. 2004) or on food or feed quality (Querubin, et al. 2003; Esteves, et al. 2003).

National biotechnology research and development

The GM crops developed and introduced in the SEAP region have originated from both private and public sectors. China has invested heavily in agricultural biotechnology research (about $112 million in 1999), ranking second only to the United States in public sector investment (Hautea and Escaler 2004). GM cotton in China was developed by the Chinese research system, as were numerous other GM crops not yet approved for commercial release (Cohen and Paarlberg 2004). From 1996 to 2000, 141 GM crops were developed in China, 45 of which were approved for field trials, 65 for environmental release, and 31 for commercialization (most of which were various Bt cotton varieties) (Hautea and Escaler 2004). Several minor GM crops were also approved for commercialization, including virus-resistant and longer shelf-life tomato, color altered petunia, and virus-resistant sweet pepper (Ibid.). GM rice resistant to three of China's main rice pests has been developed and tested, but is still awaiting approval to be commercialized. After initially taking a permissive regulatory stance towards GM crops, in 2000 the process became stalled as a result of biosafety concerns triggered by the Starlink™ corn episode in the United States (Box 3), and increasing concerns and labeling requirements being raised by major importing countries, including the European Union (EU), Japan and Korea (Cohen and Paarlberg 2004). Since 2000, no new GM varieties have been approved for commercialization in China, although research and testing continues. Thus, there is a growing backlog of GM varieties that have been tested but not approved, and increasing likelihood that the varieties that have been developed will become obsolete if and when they are approved (due to continued improvement of conventionally bred varieties).

India has also invested substantially in public sector plant biotechnology research (about $15 million per year), while the private sector contributes about $10 million (Huang, et al. 2002). The Indian public sector biotechnology research focuses on tissue culture and micropropagation, development of hybrids and genetic enhancement of important crops (Sharma 2001). India's success in tissue culture and micropropagation led to development of Micropropagation Technology Parks, which promote transfer of technology to entrepreneurs (Hautea and Escaler 2004). Substantial progress has been made in research on cardamom and vanilla, with 40 percent increase in yields of cardamom plant using tissue culture. Other multi-institutional public-private sector projects include use of genetic engineering to produce virus resistance in cotton, mungbean and tomato, resistance to rice tungro disease, resistance to bollworms in cotton, development of a nutritionally enhanced potato, and development of molecular methods for heterosis breeding (Ibid.). A 2002 survey of public sector research pipelines in selected countries found that India had achieved 21 transformation events in genetic modification of 11 crops, the third largest number in the SEAP region (after China and Indonesia), although none of these had gone beyond the stage of confined field trials (Mehta-Bhatt, et al. 2005). Most of these events were for insect resistance or agronomic properties such as tolerance to drought, salt or other abiotic stresses. As in China, Bt cotton is the only GM crop to be approved for commercialization in India so far.

In India, Bt cotton has been commercialized through a licensing arrangement between Monsanto and the Maharashtra Seed Company (Mahyco), to produce and sell three varieties of Monsanto Bt cotton seeds. Mahyco began seeking regulatory approval to commercialize Bt cotton in 1997, but the process was slowed by lawsuits and protests by anti-GM activists and a political uproar caused by erroneous charges that the Bt cotton contained Monsanto's "terminator gene" (Cohen and Paarlberg 2004). Eventually large scale trials were approved in 2000, and during trials conducted in 2001, some 500 farmers in Gujarat were found to have been planting Bt cotton seeds illegally. This was discovered after a major bollworm infestation left most cotton fields devastated, except for those of the farmers who had used the Bt cotton. Ironically, this incident may have expedited the approval of Bt cotton as the effectiveness of the new technology became publicly known and farmers pressed for its approval (Ibid.). Although Bt cotton was approved for commercialization, Indian government regulators are taking a more cautious stance towards approval of GM crops for food or feed use, and no other GM crops have yet been approved for commercialization. Other transgenic crops that have completed testing and are awaiting approval for commercialization include herbicide tolerant mustard hybrids and nutritionally enhanced potato varieties (Hautea and Escaler 2004).

Indonesia is investing significantly in biotechnology research through competitive grants. Several public institutions are engaged in biotechnology research on important food crops such as rice, maize, sweet potato and soybean and on some export commodities such as cacao and oil palm (Ibid.). Plant tissue culture and micropropagation techniques are well developed, and commercial production of oil palm planting material is occurring. Advanced diagnostics, in-vitro technologies and molecular marker technologies are used in improving various horticultural crops. There is also significant progress in developing GM crops, with some 24 transformation events for 14 crops (most for insect resistance properties) in the public sector by 2002 (Mehta-Bhatt, et al. 2005). However, the progress seems to be slowing. Of the 24 events identified in the 2002 survey, 11 had been suspended by 2005, with only three new events recorded, while the number of crops affected also declined (Ibid.). The reasons for the decline cited by public sector agencies included lack of funds to pursue research, development and meeting regulatory requirements, lack of sufficient progress, and technical and logistical problems. None of these has been approved for upscaling and commercialization, but there is limited field testing of GM potato and rice (Hautea and Escaler 2004). Indonesia had approved the sale of Monsanto's Bt cotton, but the company has since pulled it from the market.

The Philippine government has given priority to biotechnology in its agricultural research agenda, as well as in developing biosafety regulations. Its plant biotechnology research includes use of tissue culture and micropropagation, biocontrol, diagnostics, molecular marker technologies, and genetic engineering (Ibid.). GM research focuses on developing virus resistant banana and papaya, delayed ripening of papaya and mango, Bt maize, blight and virus resistant rice, rice with improved nutritional qualities, and coconut with high lauric acid content. By 2002, 17 genetic transformation events for six crops were recorded, with most of these involving virus resistance, improvements in product quality, or insect resistance (Mehta-Bhatt, et al. 2005). The Philippines was the first ASEAN country to formulate a policy on biosafety, and approved Bt maize in 2002. No other GM crops have been approved for commercialization, but field trials for bacterial blight-resistant rice are being conducted (Hautea and Escaler 2004).

Thailand began investing early in biotechnology, establishing the National Center for Genetic Engineering and Biotechnology in 1983. Its research has focused on developing virus resistant papaya, tomato and chili, insect resistant cotton, and salt tolerant and drought tolerant rice (Ibid.). By 2002 Thailand's public sector had achieved seven genetic transformations of four crops, most of these involving virus resistance (Mehta-Bhatt, et al. 2005). None of these has been commercialized, though virus resistant papaya is considered promising, and was being field tested and undergoing food safety tests as of 2002 (Hautea and Escaler 2004). GM seeds of multinational corporations have also been field tested, including Calgene's delayed ripening tomato, Monsanto's Bt cotton and Novartis' Bt maize. However, due to strong political opposition, none of these has been approved for commercialization (Ibid.).

The government of Malaysia has identified biotechnology as one of the five strategic technologies expected to accelerate its transformation into a highly industrialized nation, and is providing substantial funding to support this. The government is planning (as of 2004) to invest nearly $4 billion to establish the Multi-Media Super Corridor in which a Bio-valley will be located, with a goal of attracting a large amount of foreign investment ($10 billion over 10 years) (Ibid). Current research priorities include tissue culture, molecular market technologies, in vitro technology, and genetic engineering. Development of GM crops is being conducted primarily in public sector institutes and universities, with significant progress being made in developing GM rice, papaya, pomelo, orchid, pineapple, oil palm, chili and rubber. By 2002, these institutions had recorded five transformation events for five crops, involving virus resistance, insect resistance, herbicide tolerance and product quality (Mehta-Bhatt, et al. 2005). None of these have been approved for scaling up and commercialization, but confined field trials are being conducted for delayed ripening papaya.

The government of Vietnam has given high priority to biotechnology. The emphasis of Vietnam's research program is on improving and adapting technology imported from advanced countries (Tuong-Van Nguyen 2000). The use of more conventional biotechnologies such as in vitro micropropagation, virus elimination, somaclonal variation, anther culture, and haploid lines were effective in increasing crop productivity in the past decade. Genetic modification is also being pursued to breed tolerance to diseases, pests, and abiotic stresses. Rice is the highest priority crop for biotechnology research, and the Institute of Biotechnology and other institutions are developing GM rice varieties tolerant to biotic and abiotic stresses, building on prior success in developing rice hybrids. Other target crops include maize, fruits, leafy vegetables, root and tuber crops including sweet potato and cassava, sugarcane and soybean.

Several Southeast Asian countries, including Indonesia, Malaysia, Philippines, Thailand and Vietnam, are members of the regional Papaya Biotechnology Network of Southeast Asia, established in 1998. This network is concentrating on developing and commercializing transgenic papayas resistant to ringspot virus and/or with enhanced shelf life. The network is working on harmonizing biosafety regulations in the region and capacity strengthening of product developers and risk assessors.

International biotechnology research and development

Most of the research and development work being done on GM crops is being done by universities and large multinational corporations in the industrialized countries, and most of this is focused on developing crops with high market potential in these countries. In the mid-1990s, roughly two thirds of total agricultural research expenditures worldwide were in industrialized countries, and more than half of this was by the private sector (Pardey and Beintema 2001). Three fourths of global investment in agricultural biotechnology research is in the private sector (de Janvry, et al. 1999). The main investors in private agricultural R&D are the largest multinational agricultural biotechnology corporations, including Syngenta, Monsanto, BASF, Pioneer Hi-bred/Dupont, Dow AgroSciences and Bayer CropScience. Together these corporations invested more than $2.6 billion in agricultural R&D in 2002, dwarfing the expenditures of the international agricultural research system of the CGIAR, which totaled $369 million in the same year (Spielman and von Grebmer 2004).

These private corporations are the main source of GM crops currently adopted in developing countries outside of China, and their research and development efforts have already had substantial impacts on small farmers in the SEAP region, including about 1 million Bt cotton producers in India and 50,000 Bt maize producers, as noted above.[29]

Even in China, where development of Bt cotton was led by the public sector, the pubic sector efforts benefited from collaboration between Monsanto and the Chinese Academy of Agricultural Sciences and the Hebei Seed Company to introduce Bollgard cotton into China (Huesing and English 2004). As of 2000, about 60 percent of all Bt cotton area in China was planted with Bollgard-derived varieties (Pray, et al. 2002; Huang, et al. 2003). Thus many

[29] Data provided in Bennett, et al. (2006) show that Bt adopters of cotton in Maharashtra in 2002 and 2003 tended to farm smaller areas of cotton than conventional producers (1.6 ha for Bt growers compared to 2.4 ha for non-Bt growers in 2002, 2.4 ha for Bt growers and 2.8 ha for non-Bt growers in 2003).

millions of small farmers in the SEAP region have already benefited, directly or indirectly, from the biotechnology investments of the large multinational corporations.. So although these corporations are not primarily focused on developing crops suited to the needs of poor farmers in the developing world, this does not rule out their having a large impact for specific commodities. The potential for Bt cotton and other GM crops produced by private corporations – such as Bt maize – to benefit even larger numbers of farmers in the SEAP region, if the biosafety concerns and regulatory hurdles are overcome, is very large.

Despite this potential, most smallholder farmers in the SEAP region are not likely to directly benefit economically in the near term from GM products of the multinational corporations, and many may be harmed (if they are net sellers of commodities that compete with GM crops) by declining prices for their output resulting from the productivity boost due to GM commodities. For example, producers of oil crops in the region are likely to suffer lower prices in international markets as a result of downward pressure on prices due to widespread adoption of GM soybeans and canola in exporting countries. The same holds true for producers of maize and cotton in countries that do not permit GM versions of these crops, and for non-adopters in countries permitting these. Even adopters of Bt cotton and maize may suffer if the downward price pressure is large enough, compared to the cost advantages that they receive (which, as shown by the studies cited above, are not uniformly positive across regions and farmers). For example, Huang, et al. (2004) estimate using a global trade model that widespread adoption of Bt cotton in China (assumed adopted on 78 percent of cotton area by 2005 and 92 percent by 2010) would reduce the supply price of cotton by 11 percent by 2010, mainly as a result of yield increasing and labor saving effects (pesticide savings and higher seed costs are smaller and offsetting). Lower costs would boost China's cotton exports and textile industry, while other cotton and textile producers in Asia suffer from increased competition from China. For example, the trade balance for cotton in other Asian countries is predicted to be 19 percent lower in 2010 compared to baseline projections, while the textile trade balance of Japan and Korea is predicted to be 10 percent lower (Ibid). Similarly, Huang, et al. (2004) predict that widespread adoption of GM rice in China will reduce the rice trade balance of Southeast Asian countries by 14 percent, and Taiwan's rice trade balance by 12 percent.

For most other major crops in the region, GM crops are not currently available commercially and, with the exception of GM rice, none is close to being ready for commercialization. Bt rice has been tested in China and is reportedly ready for commercial release if and when the government approves it (Huesing and English 2004). However this was a product of the public research system, not of multinational corporations. In general the corporations see rice as a "second or third tier" priority for biotechnology investment because the profit potential is considered limited, although some are investing in rice R&D (Brookes and Barfoot 2003) (see Box 4 for a discussion of why rice is low priority for the private sector). Private sector investment in biotechnology for wheat is also limited for similar reasons, as are investments in "orphan crops" (crops receiving little scientific focus or research funding relative to their importance for food security in the world's poorest regions) such as sorghum, millet, pulses, and roots and tubers (Naylor, et al. 2004).

In the Green Revolution, the IARCs of the CGIAR were critical to the development of improved varieties of several crops, as noted in the earlier discussion. They could also play a very important role in the development of modern GM crops, although their role so far has been limited (Evenson 2003b). The political sensitivity of the GM issue and the dependence of the CGIAR upon donor funds from countries where opposition to GMOs is strong, such as the EU and Japan, is one reason for this (Ibid). Evenson (2003b) also suggests that another reason is "systemic" factors related to lack of investment by the IARCs in pre-invention sciences such as plant physiology, pathology and applied genetics, which may have led to quicker recognition of the potentials of biotechnology. Nevertheless, Evenson argues that the IARCs are the de-facto "gate-keepers" of modern biotechnology for most poor countries, and that their role in this should be strengthened. The World Bank, in its recent review of the CGIAR system, also criticized the system for lack of vision and leadership in conducting biotechnology research and in forging public-private partnerships (World Bank 2004).

Many IARCs are applying modern techniques of biotechnology in their efforts to develop improved germplasm. This includes use of tools such as marker assisted selection, genetic identification and characterization in crop breeding programs (CIMMYT, the International Rice Research Institute (IRRI), the International Center for Tropical Agriculture (CIAT), the International Potato Center (CIP), and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)); use of molecular-level analysis, including mapping, sequencing and genetic fingerprinting (IRRI, the International Livestock Research Institute (ILRI), and the International Center for Agricultural Research on Dryland Areas (ICARDA)); for development of enhanced nutritional qualities in crops (CIAT, the International Institute for Tropical Agriculture (IITA), and ICRISAT); and in research into new methods, such as new genetic marker types and transformation techniques (IITA and CIMMYT) (Ibid.). Many are using genetic engineering to incorporate resistance to biotic or abiotic stresses in their germplasm (CIMMYT, IRRI, CIAT, IITA, ICARDA, ILRI and ICRISAT). Yet the total investment by the CGIAR centers in biotechnology research is only $25 million annually, a tiny fraction of the level of private sector investment in biotechnology, and widely considered inadequate to meet the opportunities and challenges of the future (Ibid.). Furthermore, this amount of investment is for research on many different crops and traits, and focused in many cases on difficult environments, making the challenge of achieving major breakthroughs with this investment all the more difficult. Still, it is not clear that increasing this amount of investment by the CGIAR would be the right decision in the face of declining budgets for germplasm improvement overall (the total annual budget for plant breeding in the CGIAR is only about $100 million), the high costs of modern biotechnology research, and the uncertain return to such investments (especially to genetic modification) in the context of the current political debates and regulatory uncertainties surrounding GM crops.

Prospects for the future

Evenson (2003b) argues that the potential of the "Gene Revolution" to replace more conventional "Green Revolution" approaches will not be realized until advances in genomics and proteomics enable breeders to breed for improvements in "quantitative traits", such as the photosynthetic efficiency of plants and/or resistance to abiotic stresses such as drought.[30] Although steady progress is being made in terms of the science involved, this field is still in its infancy and the technical issues are complex; thus the prospects for near-term (within the next 10 years) breakthroughs appear to be limited (Ibid.; Naylor, et al. 2004). One possible development with very large potential impacts would be the development of genetically modified C_4 rice with

[30] "Quantitative traits" are traits involving complex inheritance and multiple genes, and are contrasted with "qualitative traits", which involve single genes with simple inheritance. Examples of some important qualitative traits include resistance to some insects and disease, tolerance to herbicides, and some characteristics affecting plant growth and development. Transfer of genes related to such qualitative traits is the basis of all commercial GM crops developed to date. Examples of quantitative traits include photosynthetic efficiency, plant structure, and tolerance to various abiotic stresses such as drought, cold, salinity and nutrient deficiencies (Naylor, et al. 2004).

a higher photosynthetic efficiency, allowing for substantially higher yield potential (Hareau, et al. 2005).[31] This may also allow increased tolerance to drought or salt stress (Datta 2002). Transgenic C_4 rice using genes from maize has already been reported in a model japonica rice background, and transgenic elite *Indica* rice is being developed by IRRI which may be able to address many issues related to efficient use of CO_2 and water (Ibid.). The Chinese government has a goal of developing "super" hybrid rice varieties capable of achieving yields of 15 tons per hectare by 2015 (Zhong, et al. 2004), and one of the likely mechanisms for achieving this will involve genetic transfer from other species (Yuan, undated). Another possible biotechnology that could have a major impact in the SEAP region in the longer term would be development of a biotechnical approach to weed control in paddy rice without the risk of herbicide tolerance spreading to wild relatives (Don Doering, personal communication). The technical feasibility of such innovations has yet to be demonstrated, and then it will require several years of testing and satisfaction of regulatory requirements to go from demonstration of technical feasibility to a product being ready for commercialization. Commercialization of such advanced biotechnology products is a longer term proposition.

In the nearer term, the impacts of new biotechnology products will be felt more through products that have already been demonstrated technically and are in the testing phase. The most important of these in the near term are likely to be nutritionally enhanced Golden Rice[32], Bt rice, herbicide tolerant rice, and bacterial blight resistant rice (Brookes and Barfoot 2003). Bt, herbicide resistant and blight resistant rice are close to commercialization. Golden Rice still will require several years of testing before it could be commercialized (Ibid.).[33]

The potential welfare impacts of these technologies in the SEAP region are quite large. Anderson, et al. (2004) estimate that the global annual welfare benefit of widespread adoption of Golden Rice in the SEAP region would be about $15 billion, with almost all of this benefit

[31] Rice, like most grasses, is a C_3 plant. C_3 plants are lower in photosynthetic efficiency and hence maximum yield potential than C_4 plants such as maize and sugarcane, which have different respiration and transpiration mechanisms.

[32] Golden Rice is transgenic rice developed to have high levels of provitamin A. The initial prototype was announced in 2000. This innovation was claimed to be ineffective by some GM opponents because the level of additional vitamin A was argued to be insufficient to make much difference (Mayer 2005). Recently, a second generation of Golden Rice has been developed having 23 times more beta-carotene than the initial prototype (Paine, et al. 2005). The estimates of welfare benefits of Golden Rice by Anderson, et al. (2004) presented below are based on the estimated impacts of the original prototype.

[33] According to some experts involved in the CGIAR Harvest Plus initiative, commercialization of GoldenRice may not occur until around 2012 (Don Doering, personal communication).

occurring in the SEAP region. The main source of this large predicted welfare benefit is increased productivity of unskilled workers as a result of improved health, and does not consider the non-pecuniary benefits to people of being healthier, or reduced costs of health care (Ibid.).[34] The welfare impacts of other GM rice focusing on increasing productivity through pest and disease resistance are estimated to be much smaller – about $2 billion annually in the SEAP region and globally (Ibid.). Using a similar methodology, Hareau, et al. (2005) estimate a similar magnitude of global welfare impact of adoption of Bt rice ($2.3 billion annually), although with more benefit occurring in rice consuming countries outside the SEAP region. They also estimate the annual welfare impact of herbicide tolerant rice ($2.2 billion) and drought tolerant rice ($2.5 billion). The distribution of welfare benefits of herbicide tolerance would be concentrated in favorable regions where direct seeding using mechanized methods is possible, while drought tolerance would have much larger impacts in less favorable environments (Ibid.). They estimate that rice production in less-favorable areas would increase by 64 percent in China, 12 percent in Vietnam, 10 percent in the Philippines, 9 percent in India and Indonesia, 5 percent in Bangladesh, 4 percent in Thailand and 8 percent in the rest of Asia, while rice production in favorable areas would decline by between 3 and 11 percent in these countries (highest in Bangladesh, lowest in Vietnam) as a result of lower average rice prices (3 to 5 percent lower in the SEAP region). By contrast, adoption of herbicide resistant rice is predicted to increase rice production in favorable regions by 8 percent in Thailand, 5 percent in Vietnam, 3 percent in Bangladesh, 2 percent in the Philippines and 1 percent in China, while reducing production in favorable regions of India (10 percent) and Indonesia (6 percent) (Ibid.). In less-favored regions, herbicide resistant rice is predicted to reduce production in China (19 percent), Vietnam (9 percent), Philippines (2 percent), and Bangladesh (1.5 percent), while increasing production in less-favored areas of India (10 percent), Indonesia (6 percent) and Thailand (3 percent) (Ibid.). Although such estimates are necessarily somewhat speculative, they are useful in indicating the potential order of magnitude of impacts of these GM crops and where these are most likely to be felt. These results show that substantial positive impacts on rice production in less-favored areas

[34] Anderson, et al. (2004) assume that labor productivity of nutritionally deprived unskilled workers in all sectors of the SEAP region would be increased by two percent. They argue that this assumption is conservative, based on estimates of Zimmerman and Qaim (2003), who estimated at least a six percent boost in unskilled labor productivity due to Golden Rice.

of many countries in the SEAP region are possible if drought resistant rice is commercialized and widely adopted, while the impacts of herbicide resistance would be more mixed (depending on the weed problems and use of herbicides in different agro-ecological contexts of different countries).

Key issues and constraints

The successful adoption of Bt cotton by large numbers of small farmers in China and India indicates the scale neutrality of this technology. As in the Green Revolution, small farmers are able to adopt technological improvements embodied in improved seeds, although there may be lags in adoption by smaller and poorer farmers due to considerations of costs and risks.

Most of the key issues and constraints affecting whether poor farmers in less-favored areas benefit from modern biotechnology operate at international and national levels, rather than at the community and household level. At the international level, there is substantial uncertainty concerning the future prospects of GM crops, due to political opposition in many countries driven by concerns about biosafety risks as well as ethical and ideological positions, the rapidly changing regulatory environment, and questions of consumer acceptance of the technology. Transfer of biotechnologies to developing countries is also inhibited by intellectual property rights issues, lack of interest of the multinational private sector in investing in development of GM crops for poor countries and less favored regions, difficulties of establishing effective public-private partnerships, and lack of investment and leadership in biotechnology by the CGIAR. At the national level, adoption of GM crops is affected in many countries by political and economic considerations, limited capacity of agricultural research and development systems, and the lack of established biosafety regulatory systems. At national and local levels, the availability of biotechnology is also affected by lack of awareness and voice of farmers in decisions being made at higher levels concerning biotechnology and development, and may also be constrained by the effectiveness of agricultural extension, input supply and credit systems, especially in remote less-favored areas.

Concerns have been raised about the risks associated with GM technologies that have different levels of scientific validity, depending upon the specific trait and cultivation environment. These include concerns about the safety of food containing transferred genes, due to allergenic effects or toxicity; whether drug resistance genes inserted as markers in developing

GM crops could result in development of drug resistant bacteria; whether engineered genes will be transferred from GM crops to other crops and to wild relatives and the potential effects this could have on biodiversity and development of herbicide resistant weeds; whether widespread adoption of GM crops will contribute to the development of herbicide and Bt resistant pests through natural selection; possible toxicity of GM crops to non-target species; and unexpected effects of integration and recombination of genes into crops on the properties of other genes (Doering 2004).

Concerning food safety, standards for assessing food safety have been established by the Codex Alimentarius and by individual countries, and testing is conducted to compare GM foods to their closest counterparts. With regard to current commercial GM crops, the EPSPS gene in herbicide (glyphosate) tolerant crops is widely present in food and feed from non-GM plants (Ibid.). A large number of studies have been conducted on mammals testing for allergenicity and toxicity of the Cry gene used in Bt crops, with no findings of adverse effects. Current commercial GM crops have been determined to be safe for food consumption by numerous scientific reviews (SOT 2002; Persley 2003; FAO 2004). Nevertheless, concerns persist about the safety of GM crops in the food supply, especially in Europe, Japan and Korea, which take a much stricter regulatory stance towards GM crops than the United States (Gruere 2006).

The concern about use of drug resistance genes in developing GM crops has prompted biotechnology companies to develop alternative methods for selection (Doering 2004). Nevertheless, the first generation of biotech crops did use such markers. Several major independent reviews concluded that it is not likely that antibiotic resistance genes used in these development processes could survive human digestion and be incorporated into bacteria (FAO/WHO 1996, 2000).

Concerns about gene flow from GM crops to other plants, especially wild relatives, are serious concerns for some crops in some locations, but not for others. Soybean is a self-pollinating species with no wild or weedy relatives in the United States, so gene transfer is not considered a serious risk in this case (Doering 2004). For other crops the concerns can be more serious. For example, engineered genes in maize could flow into corn grown under organic conditions (as a result of the fact that corn is an open-pollinating plant), thus undermining the development of organic production. The extent of GM canola planting in Canada has eliminated the nascent organic-certified canola industry there (Ibid). Flow of transgenes into landraces in centers of origin of crops is also a serious concern, as this can disrupt the ability to conserve the genetic biodiversity heritage existing in landraces. Transgenes were thought to have been found in Mexican maize landraces, most likely due to import of U.S. corn, but larger scale surveys have failed to confirm this result (Ibid.). Many factors affect whether and where such gene flows occur; careful study and regulation of this issue should be a high priority (Snow 2003; NRC 2004; ESA 2004). Besides impacts on landraces, flows of genes such as herbicide or insect tolerance to non-crop plants could lead to development of weeds that would be difficult to control (Doering 2004). There is no evidence yet of such plants resulting from commercial GM crops, but this remains a concern for the future.

Even without gene flows to other plants, widespread use of herbicide and insect tolerant transgenic crops can contribute to development of herbicide tolerant weeds and Bt tolerant insect pests through natural selection pressures. Numerous cases of herbicide resistance in weeds have been documented; glyphosate-resistant horseweed appeared after the introduction of glyphosate-resistant GM crops combined with heavy use of glyphosate in several states in the United States (Heap 2003). Development of insect resistance to the Bt toxin has not been shown yet, in part because Bt lacks some resistance-promoting features of other types of insecticides (Doering 2004). Still, this remains a serious concern, since Bt has not been used on such a large scale before, and development of insect resistance to Bt would increase the risk of infestation, not only for farmers using Bt crops, but for farmers using organic and integrated pest management approaches that rely on this property in non-GM plants for insect control (Ibid). Although herbicide tolerance is generally of less interest to poor farmers in less-favored areas, since they mostly do not use herbicides, the effects of insect resistance can be quite important in these areas, as the widespread success of insect resistant Bt cotton in semi-arid areas of China and India has shown.

There is also concern about possible toxic effects that Bt crops may have on non-target species, such as certain species of butterflies and moths. Although laboratory studies have shown toxicity of Bt corn pollen to the Monarch butterfly, further field studies showed that the risks were negligible for various reasons (Ibid). Concerns have also been raised about impacts of Bt crops on the organisms in the soil. Although studies conducted to date have not shown impacts on many soil organisms, experimental GM plants have been shown to affect soil microbes (Ibid). The impacts of such effects on soil health are not well studied.

Insertion of genes into plants can have unexpected impacts on the performance of other genes. Such effects might cause loss of fitness, toxicity, changed nutritional value, or increased mutation rates; however such effects are generally part of the screening and characterization that takes place during regulatory approval and product development (Ibid). Experimental studies have shown unintended effects of genetic modification upon plant metabolism (Kuiper, et al. 2001). The complexity and lack of information about these and other possible effects discussed above – while considered to be of low risk in the temperate crops and environments of today's GM crops – highlight the need for additional research on these topics for the crops and cultivation environments for Asia.

The many risks and scientific uncertainties surrounding GM crops has led many people and nations are urging a precautionary approach to this technology. There are also emotional, ethical and ideological dimensions to the debate that are likely to remain, even if all of the scientific uncertainties were resolved. Many people simply fear new technologies, particularly ones such as biotechnology that can affect the safety of their food and that involve highly complex issues such as discussed above. There are also ethical concerns and ideological debates about whether it is ethical or wise for human beings to use science to alter natural beings in fundamental ways. These issues can be debated at great length (this will not be attempted here); the main point for this discussion is that such political debates have a large yet uncertain impact upon the prospects for biotechnology to become more widely available and useful to farmers in developing countries.

This large and uncertain political impact is evident in international negotiations concerning biosafety regulations for GM food products. Although internationally harmonized guidelines for safety approval have been finalized, there is no clear consensus on labeling regulations for GM food, and there is an increasing risk of conflicts among relevant international agreements, including the Codex Alimentarius, the Cartagena Protocol on Biosafety and the World Trade Organization, as well as conflicts among national regulations (Gruere 2006). For example, the Cartagena protocol follows a precautionary approach in regulating transboundary movements of Living Modified Organisms (LMOs), allowing importers to request information on the specific GM content of particular shipments (i.e., to require mandatory labeling) and to decide to ban imports of GM crops as a precautionary measure. These regulations may conflict with implementation of the WTO rules on Sanitary and Phytosanitary Measures (SPS

Agreement) and Technical Barriers to Trade (TBT Agreement), depending on how these are interpreted in the context of GMOs. The approach to regulating imports under the SPS Agreement is based on an assessment of existing scientific risks, which contradicts the strict application of the precautionary principle. WTO members are not allowed to ban imports of products that they consider risky for an extended period of time unless they demonstrate the existence of significant risks or are conducting research to assess such risks (Ibid). In the case of a dispute between the United States and the EU over an EU ban of beef raised using growth hormones, the WTO ruled against the EU because the EU did not demonstrate such scientific evidence in a timely manner (Josling, et al. 2004). Further, mandatory labeling requirements for GM food crops might violate the TBT Agreement provision that imported products "shall be accorded treatment no less favorable than that accorded to like products of national origin and to like products originating in any other country", depending on whether a GM product is interpreted to be a "like product" (Gruere 2006). These issues have not been resolved, and this contributes to the cloud of uncertainty overhanging GM products at present.

Beyond the political debates and legal battles, a more important issue for GM crops may be consumer acceptance. Although consumers in the United States have not shown as much concern about GM commodities as those in Europe and Japan, there are consumer groups in the United States that are opposed to GM products, and changes in attitudes and perceptions, such as occurred after the Starlink episode mentioned earlier, could affect future demand potential for these products. Consumer acceptance in developing countries may also be a critical constraint, particularly for GM commodities being bred for improved nutritional qualities, such as Golden Rice. Although such commodities may be healthier for people to eat, people may not prefer to eat rice of a different color and possibly tasting differently than what they are used to. Unless there is a demonstrated market demand for such crops, possibly involving a price premium, farmers will be reluctant to produce them (unless they contribute to greater productivity). Thus, despite the great potential of such crops to improve nutrition, health and economic performance in many developing countries, substantial educational and outreach efforts are likely to be necessary to stimulate widespread adoption of these types of crops.

Despite the negative opinions of biotechnology among many consumers in Europe and Japan, opinion survey research suggests that consumers in many regions of the world are favorably disposed towards products of agricultural biotechnology. In an extensive international survey of 35,000 people in 34 countries, Environics International (2000) fund found that in most countries surveyed, most respondents felt that the benefits of genetically modified food crops that do not require chemical pesticides and herbicides are greater than the risk. Among the countries with the highest percentage of respondents feeling that the benefits are greater than the risk were Indonesia (81 percent), China and Thailand (72 percent), India (69 percent) and the Philippines (62 percent) (no other countries in the SEAP region were surveyed). By comparison, the lowest percentage of people responded favorably in several European countries and Japan: Greece (22 percent), France (22 percent), Japan, (33 percent), Italy (34 percent) and Spain (39 percent). Part of the reason for higher acceptance agricultural biotechnologies in developing countries may be that most people in these countries are farmers. In a follow-up question in the same study, Environics International (2000) found that 78 percent of respondents in Thailand, 77 percent in China and 74 percent in the Philippines felt that "biotechnology will benefit people like me", probably because most of these people are farmers. In a second study of 10,000 consumers in ten countries, Environics International (2001) asked whether consumers would buy nutritionally enhanced foods, and found that 83 percent in China and 78 percent in India responded yes, compared to less than 50 percent in the United Kingdom, Australia and Germany (no other Asian countries were included in the study). More recent studies in China found that Chinese consumers were willing to pay on average a 38 percent premium for GM rice and a 16 percent premium for GM soybean oil (Li, et al. 2002), and a 35 percent premium for processed GM potato products (Curtis 2003). Curtis, et al. (2004) argue that the willingness of Chinese consumers to pay a premium for GM products (in contrast to results from studies in Europe in Japan, where consumers would expect sizable discounts to purchase GM food) is due to their greater trust in government and positive attitudes towards science.

Development and transfer of biotechnologies of benefit to developing countries is also inhibited by intellectual property rights (IPR) issues (de Janvry, et al. 1999; Toenniessen 2003). The case of Golden Rice is illustrative. Initial efforts to expand research were complicated by the existence of 70 process and product patents associated with the technology owned by 32 companies and universities (Spielman 2006). Corporate and philanthropic negotiations were required to make further research efforts possible (World Bank 2004). Although the success of these negotiations could be seen as a sign that these problems are not insurmountable, this was a case of a crop and trait with limited commercial value to private companies (because of the ability of farmers to save and reuse rice seeds) and large public relations value. Such hurdles may be more difficult to overcome for products and traits that the private corporations find more commercially valuable. A small number of firms are continuously litigating over hundreds of valuable patents related to Bt technology (Krattinger 1996). Utility patents on basic and intermediate research processes are proliferating, creating increasing difficulty for researchers to make progress in this field (de Janvry, et al. 1999; Toenniessen 2003). These restrictions can be particularly onerous to the international agricultural research system and public sector research systems in developing countries, which lack the capacity and resources to fight legal battles over such issues.

IPR restrictions established in developed countries do not necessarily prevent the "freedom to operate" of IARCs and NARS in developing countries who are developing improved food crops for domestic consumption, since these laws do not have jurisdiction outside the countries where they are enacted (Pardey, et al. 2003). However, WTO requirements related to IPR protection under the Agreement on Trade-related Aspects of Intellectual Property Rights (TRIPS Agreement) can lead to penalties being imposed upon countries that violate IPR of other WTO members for internationally traded commodities (Ibid). Although most agricultural exports from developing countries do not involve food staples that are being researched by the CGIAR system (Ibid), there are substantial exports from the SEAP of some commodities for which biotechnology innovations and IPR issues are relevant, including rice (especially from Thailand), soybeans, bananas, and other tropical crops.

Problems related to IPR protection as well as the considerable resources and capability of the private sector in biotechnology have led many observers to advocate increased public-private partnerships between publicly funded researchers in the CGIAR and NARS and the multinational companies and other private sector actors (World Bank 2004; FAO 2004; Spielman and von Grebmer 2006). However, there are few examples of successful public-private partnerships. The most successful examples of a joint venture that spread biotechnology to poor farmers are the Ji Dai and An Dai seed companies in China (FAO 2004). Ji Dai is a joint venture between two U.S. based companies (Monsanto and D&PL) and the Hebei Provincial Seed Company in China, while An Dai is a joint venture between the same U.S. companies and the Anhui Provincial Seed Company in China. Under these ventures, Monsanto provides the Bt gene and

D&PL provides the cotton varieties, while Ji Dai and An Dai provide the variety testing, seed multiplication and seed distribution in China.

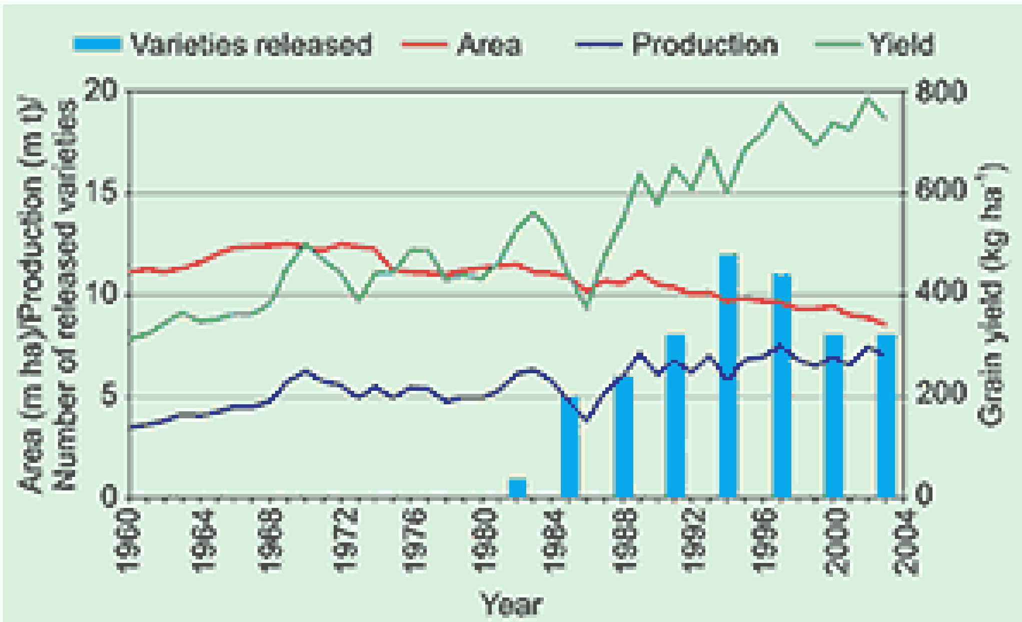
Some observers argue that lack of initiative by the public research agencies (particularly the CGIAR) is partly responsible for limited success in achieving public-private partnerships (World Bank 2004; Evenson 2003b). However, there are difficult problems to overcome for such partnerships to become a reality, including fundamentally different incentive structures in these different sectors, prohibitive costs, mutually negative perceptions between these sectors, and high levels of competition and risk associated with valuable assets and resources (Spielman and von Grebmer 2006; de Janvry, et al. 1999). Changes in public policies (e.g., use of tax incentives, grants and credits for private firms to become involved in publicly oriented research; greater investment in public research; strengthening research exemptions on use of intellectual property; and others) could help to facilitate productive partnerships that are beneficial to the poor in developing countries (Spielman and von Grebmer 2006).

Innovative organizational strategies are also needed. For example, public sector organizations could shift to having more of a role in research priority setting and financing, while private sector could play more of a role in research execution (Ibid). A "quasi-corporate" approach could be used in which public agencies establish and maintain majority ownership in private research ventures, as is found in China's approach to biotechnology research (Pray, et al. 2001; Huang, et al. 2002). *Ex ante* agreements between the public and private sector can be used to segment markets among partners. An example of this is an agreement between Zeneca and several public research organizations in Southeast Asia, in which Zeneca provided genetic material to develop delayed-ripening traits for papaya, but the product was licensed only for local non-export use in Southeast Asia (Spielman and von Grebmer 2006). Another approach is to establish third party brokering organizations to manage the research and take responsibility for IPR use. Examples include projects undertaken by the International Service for the Acquisition of Agribiotech Applications (ISAAA) and the African Agricultural Technology Foundation (AATF) (Ibid). As with technologies, it is likely that different policy and organizational approaches are suited to different contexts. However, little research is available that provides lessons on the effectiveness of alternative approaches in different contexts.

In the international agricultural research system, lack of progress in biotechnology is limited by IPR restrictions, resource limitations, international concerns about biotechnology (particularly GM crops), and lack of investment in pre-invention disciplines, as discussed earlier. Many IARCs are investing in biotechnology, and this is one of the key priority research areas recently established by the CGIAR Science Council (CGIAR Science Council 2005). Without significant expansion in the resource base or major realignment of the priorities of the CGIAR system (which was not recommended in the recent review of the system (World Bank 2004) or evident in the recent Science Council document), it is unlikely that substantial additional investment in biotechnology by the CGIAR centers will occur in the immediate future. The more important issues then are what the priorities for research should be within that envelope, and how to ensure that the research is most effective in producing new knowledge and achieving impact.

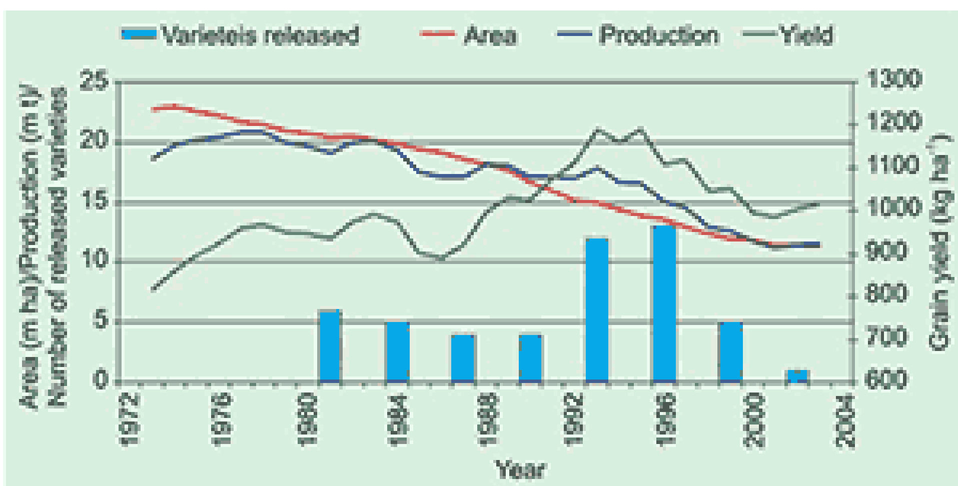
Some have argued that greater priority should be given to biotechnology research (not only through genetic modification, but also using other techniques of modern biotechnology) on orphan crops that are important to many poor people in less-favored areas but under-researched (like millet, sorghum, beans, etc.) (Naylor, et al. 2004). As shown by Evenson and Gollin (2003), there has been substantial and increasing impact of CGIAR research even in rainfed areas and for orphan crops since the 1980s as a result of increasing attention to developments for these crops and areas. For example, there were more than 400 scientists working on sorghum in the SEAP region (mainly in China and India in the late 1990s (Deb and Bantilan 2003) and 150 scientists working on pearl millet in India in 1998 (Bantilan and Deb 2003). Between 1981 and 1998, 72 new varieties of pearl millet were released in India, 41 of which were an ICRISAT cross or from an ICRISAT parent (Bantilan and Deb 2003). In Pakistan, 2 new pearl millet varieties were introduced; one an ICRISAT cross and one with an ICRISAT parent (Ibid.) (Figure 37). 132 new varieties of sorghum were released in India between 1981 and 1998; 20 of these either ICRISAT-bred or having an ICRISAT parent (Deb and Bantilan 2003) (Figure 38).

Figure 37. Three-year moving average for pearl millet area, production, and grain yield; and number of varieties (3-year total) based on ICRISAT material in India



Source: http://www.icrisat.org/PearlMillet/PearlMillet.htm

Figure 38. Three-year moving average for sorghum area, production, and grain yield in Asia; and number of varieties (3-year total) based on ICRISAT material



Source: http://www.icrisat.org/sorghum/sorghum.htm

In China, 17 new sorghum varieties were released in this period, 7 of which were derived from an ICRISAT parent (Ibid.). In Myanmar, 11 new sorghum varieties were released in this period, 7 of which were bred by ICRISAT. In Pakistan, 5 new sorghum varieties were released, four of which were either bred by ICRISAT, an ICRISAT network, or had an ICRISAT parent. In the Philippines, 2 new varieties were released, one of which was ICRISAT-bred and one bred by an ICRISAT network. A few new sorghum varieties were also released in Indonesia and Thailand, but without any ICRISAT contribution (Ibid). The impacts of these new varieties on productivity have been highly positive, as discussed in an earlier section of this report (Evenson and Gollin 2003). Also, as noted in section 2 of this report, the empirical results of Fan and colleagues in China and India suggest that more investment in agricultural R&D oriented towards less-favored areas is likely to result in more poverty reduction than comparable investment in more-favored areas, at least in those countries.

Increasing the effectiveness and impact of international and national agricultural research in biotechnology, as well as in other areas, requires continued efforts to improve linkages between international centers and the NARS, as well as improvements in the linkages and performance of the broader agricultural innovation system within developing countries, including agricultural research, extension (broadly defined to include actors outside of public extension agencies), education and their linkages to other actors in agricultural input and output marketing chains. With regard to specific requirements for biotechnology, the high costs of biotechnology research may be prohibitive for many small, poor countries (Evenson 2003), which are likely to continue to rely upon technologies developed elsewhere. However, as discussed earlier, many countries in the SEAP region do have active biotechnology research programs, and many have a several GM products in the pipeline (Mehta-Bhatt, et al. 2005). For many such countries, a more serious constraint than lack of biotechnology research capacity at the present time appears to be lack of effective biosafety regulatory systems and, in some cases, lack of political will to go forward with approvals of GM products that have already been developed and tested (Cohen and Paarlberg 2004). Until such hurdles begin to be overcome, further investments in increasing capacity for biotechnology research risk being wasted. This point applies specifically to investments in developing GM crops, and not to investments in use of other modern biotechnologies that do not involve genetic modification, and thus do not face the same regulatory hurdles and political risks. Other modern biotechnologies, such as marker assisted selection, tissue culture and others, have significant potential to accelerate the rate of development of improved germplasm for orphan crops used by poor farmers in less favored areas of Asia, and are already being used by scientists in the CGIAR centers and the NARS, as noted previously.

An important and often neglected factor in the debates about biotechnology is the role of farmers in expressing their demands (or lack of demand) for products of modern biotechnology and other agricultural research. This role is now commonly recognized in agricultural research systems, which are increasingly involving farmers in participatory on-farm research. But the role of farmers in the political debates may also be important, as the example of the approval of Bt cotton in India discussed earlier suggests (in which farmers pressed for approval of Bt cotton after its illegal use demonstrated its advantages in preventing a pest infestation). Thus, development of farmers' awareness and voice in these debates, such as by promotion of the development of farmers' associations that are responsive to the needs of poor as well as better off farmers, could be an important element of a successful strategy to develop the political will necessary to overcome political obstacles to biotechnology.

Summary

The use of modern biotechnology offers great promise to bring about the next great boost in agricultural productivity in the world, while also improving human nutrition and reducing farmers' risks and use of toxic agricultural chemicals, with large economic, health and environmental benefits possible. Although most of area planted to GM crops to date has been primarily by farmers using intensive mechanized production in industrialized or middle income countries, millions of smallholder farmers in the SEAP region are benefiting from using commercial GM crops (mainly Bt cotton). There are several GM crops that are ready or nearly ready for commercialization that could have a much larger impact in the region, including especially pest and disease resistant rice and nutritionally enhanced rice. Regulatory approval for such crops appears to be the most important barrier at present in the region to realizing the potential of already available biotechnology. To achieve this, investments in the capacity of countries to establish and enforce effective biosafety regulatory systems is critical. Sufficient political will to pursue biotechnology as an option must exist for this to occur. The role of farmers in helping to generate this political will is generally neglected, but potentially important.

The political, legal and regulatory controversies surrounding GM crops, especially those used for food, make investments in developing such crops a risky proposition until some of these issues begin to be resolved. For small, poor countries, including several countries in the SEAP region (e.g., Laos, Cambodia, Bhutan, Mongolia, Sri Lanka), it makes sense to take a cautious approach towards such investments, waiting to see how these issues are resolved by some of the major actors before investing too heavily. China has invested heavily in developing GM crops, but few of these have been approved for commercial use. Whether and when it releases GM rice is likely to be a watershed event affecting the prospects for other countries to follow suit.

Large numbers of poor farmers in some less-favored areas of the SEAP region are already able to benefit from currently available GM crops, and these benefits will increase if GM rice, maize and other GM crops currently in the pipeline are approved. The larger potential for biotechnology to address the needs of farmers in many less-favored areas may be through development of crops that are resistant to abiotic stresses such as drought, salinity and frost. There are significant research efforts already ongoing on these issues in the CGIAR system and the NARS of many countries. Such innovations are a longer term proposition, likely requiring at least a decade or more before they may be available to farmers. But substantial investments in research capacity, by both the international agricultural research system and the national systems, are needed now, if these opportunities are to become reality. Efforts to address intellectual property right restrictions are needed as well as investment in capacity. Promoting public-private partnerships can help to realize the potentials, but leadership and resources from the public sector will continue to be critical to the success of efforts to improve the livelihoods of poor farmers in less favored areas.

Investments in improving linkages and performance within the overall agricultural innovation system will also be a key to success, not only for realizing the potential of modern biotechnology, but also to realize the potentials of other technologies. Improvements in the innovation system can help to improve farmers', extension agents' and researchers' ability to identify new opportunities and exploit complementarities between different technological approaches, such as between pest resistant or herbicide tolerant GM crops and LEISA methods of integrated pest management and minimum tillage. The role of farmers' organizations in expressing their demands and assuring accountability of the system to their needs is likely to be very important in the process of improving these systems.

5. CONCLUSIONS AND IMPLICATIONS

Conclusions

Many lessons could be drawn from this wide-ranging literature review. Here I will focus on a few of the key lessons.

First, although it has been said many times before, it bears repeating: there is no one-size-fits-all technology approach that will work in all of the diverse circumstances and farming systems of a region as heterogeneous as South and East Asia. For each of the technology approaches considered, we find examples of successful adoption and positive impacts in some locations and farming systems, but not in others. Zero tillage has been taken up rapidly with reportedly very favorable impacts in the intensive irrigated wheat-rice system of the Indo-Gangetic Plain, but not to a substantial extent in other intensive systems. Integrated pest management has been successful in intensive lowland rice systems in many countries, but has been less widely adopted in upland systems. Water harvesting and soil and water conservation practices have been promoted with substantial success in semiarid areas of China and India, while efforts to promote soil conservation in the Southeast Asian uplands have had little success. Organic agriculture has contributed to significantly increased profitability and household incomes in some case studies, particularly for producers of high value crops in areas with favorable market access, but is likely much less relevant to producers in more remote areas. Bt cotton has been adopted by millions of smallholder cotton producers with very favorable impacts in subhumid and semiarid environments of China and India, and Bt maize has shown promise in upland areas of the Philippines, but producers of other crops have not seen much benefit yet from biotechnology, and may be indirectly harmed by increased competition from producers of competing crops in other countries where biotechnology is being rapidly adopted.

Second, it is difficult, but not impossible, to identify and promote technologies that will substantially improve the livelihoods of poor people in less-favored areas. Some of the most successful cases found in the literature involve approaches to use inputs more intelligently in highly input intensive systems (zero tillage and IPM), and these advantages will not easily translate to lower intensity systems in less-favored areas. Improving productivity and incomes in less favored areas often requires an increase in the intensity of some inputs (though not always, as the promising results from natural vegetative strips and ridge tillage in the Philippines shows).

In dryland environments, investing labor in water harvesting and soil and water conservation measures has been demonstrated to be able to yield substantial benefits in a relatively short period of time in many cases, because these investments increase the collection and use efficiency of what is often the scarcest resource in these environments – water. Thus, there are examples of technologies that can bring high returns in marginal environments. However, similar labor intensive conservation measures are much less likely to be adopted in higher rainfall upland areas, except where farmers are pursuing high value crops, resulting in high return to labor invested in such intensive activities.

Some key requirements for technologies to be taken up by farmers and to have a substantial impact on reducing poverty are that the technology is profitable in a relatively short period of time, especially in terms of the return to farmers' land and labor; does not substantially increase risk (and ideally helps to reduce risks); and is consistent with farmers' capacities in terms of their endowments of knowledge, management skill, land, labor, and other assets. In most cases, wealthier households have an advantage in their ability to take up new technologies because most technologies require some combination of these assets for successful application. Even low external input technologies, which are often touted as being pro-poor, are likely to disadvantage vulnerable households such as female-headed households and HIV-affected households, or households dependent on off-farm income because of limited land and other assets, because of the requirements of these technologies for labor or time spent learning new agricultural principles. Poorer farmers are less likely to be able to pay the financial and opportunity costs of obtaining organic certification, and are less able to afford the higher cost of GM seeds. There is no easy solution to this dilemma, but there are good reasons not to despair. The Green Revolution was also criticized in early years for not benefiting poor farmers, but it was later found that poor farmers (at least in areas where irrigation or sufficient rainfall was available) were able to catch up in adopting the new technologies, and even landless people benefited from increased demand for their labor and lower food costs. Similar benefits could spread to poorer households from the technologies considered in this paper, even if they are not the first to adopt.

It is clear from both the earlier experience of the Green Revolution and from more recent experiences with LEISA, organic and biotechnologies that new technologies, by themselves, are not sufficient to bring about sustainable rural development and elimination of rural poverty, although they can have a major impact. Effective organizations that are accountable to poor as well as wealthier farmers, effective institutions and a stable and supportive policy environment are also critical factors in success.

The key elements of a supportive policy environment for sustainable development and poverty reduction in less-favored areas include ensuring equitable and secure access to land and other natural resources; investing in rural infrastructure and public services in less-favored areas; improving coordination among public research and extension organizations, NGOs and farmers; and avoiding biases against these areas in policies related to commodity and input prices, access to inputs, credit, extension and other services. While a supportive policy environment is a critical element of success, policy induced distortions can lead to major problems. For example, a key message in the literature on the Green Revolution is that the negative environmental outcomes often blamed on the Green Revolution were largely due to a poor policy environment characterized by inappropriate subsidies and biased pricing and trade policies.

A common thread running through the discussion of all three technology approaches is the need for effective farmers' organizations. Such organizations are a key to reducing the costs and improving the effectiveness and responsiveness of technical assistance efforts for all types of technologies, and are particularly important in facilitating farmers' access to markets for organic products and other high value commodities. They are also critical where technologies require collective action to be effective, such as in watershed management. Both the ability to achieve collective action locally ("bonding social capital") and linkages to external sources of information and resources ("bridging social capital") are needed. It is doubtful that such social capital can easily be created by external development projects (especially bonding social capital), but such projects can build on the social capital that exists in villages if sufficient investment is made and care is taken to address aspects of social organization.

The need for and value of improved methods of technology dissemination is also evident in much of the literature. Top down transfer of technology approaches that worked relatively well with simple technology packages such as modern seed varieties and fertilizer do not work as well with complex technologies that have to be adapted to local circumstances based on understanding of agroecological principles and local conditions. The Farmer Field School approach pioneered by FAO has shown success in addressing this need, as have some other new farmer centered organizational approaches that have been tried in recent years. There are legitimate concerns about the ability to scale up the success of such approaches, although a fair amount of scaling up has already occurred in some countries. Although there are substantial costs of pursuing such intensive training approaches and the impacts often do not diffuse easily to non-participating farmers, these are not sufficient reasons not to expand investments in such approaches where they have been shown to yield large benefits relative to their costs.

These lessons from the literature should give pause to those who would advocate one particular technological approach as the solution for poor farmers in less favored environments of Asia and elsewhere. As stated by Dennis Garrity in one recent publication, "Solutions based either on agroecological or conventional approaches, when tested in the real world, often founder upon the shoals of one or more unforeseen factors" (Garrity 2002, p. 222). There is ample reason for all involved in advocating technology solutions for poor farmers to be more humble, and willing to learn from those promoting other technologies as well as from farmers. What farmers need are not technology dogmas but rather technological options that can work in their context, possibly after some experimentation and adaptation, combining what is useful from different approaches. This may involve using GM crops, LEISA or organic approaches by themselves, or integrated approaches such as integrated soil fertility and water management, in which some use of inorganic fertilizer is combined with organic soil fertility replenishment approaches and soil and water conservation measures, integrated use of IPM methods with pest resistant GM crops, or other combinations of approaches.

Achieving a more balanced and useful approach for farmers requires less dogmatic devotion to particular technologies by researchers and technical assistance programs, and a more pragmatic approach to learning what works well where and why. In pursuit of such pragmatic options for farmers, research and development programs should not ignore the potentials of traditional farming practices or intensive Green Revolution type technologies, which are well suited to farmers' needs in many contexts.

Technology strategies for poor farmers in less favored areas

Based on the findings summarized above, it is clear that improved strategies for technology development and promotion will be needed to reach poor farmers in less-favored areas of the SEAP region, and that such strategies will have to be tailored to different circumstances of these areas, since these areas are highly heterogeneous, as are the farmers that reside in them and the constraints that they face. The agricultural technologies that will help poor farmers in remote mountain areas are different from those that will work in drylands or humid upland areas with favorable market access, and technologies that can readily be adopted by households with surplus labor availability may not be usable by labor scarce vulnerable households.

Below, I offer suggestions for strategies to address key opportunities and constraints in three of the most important types of less-favored areas in the SEAP region: sloping dryland areas, humid and subhumid uplands, and rainfed semi-arid areas.

Sloping dryland areas

In sloping dryland areas such as in large areas of India and China, integrated watershed development approaches have demonstrated substantial potential. These include use of many LEISA approaches, including water harvesting and soil and water conservation measures to increase water availability and conserve soil, improved management of common property resources (e.g., regulated use of grazing lands and forests/woodlands with investments in enriching these through planting of useful trees, shrubs and grasses; recycling of soil nutrients using organic methods such as manuring, composting, and improved fallows; and targeted use of inorganic fertilizer and other inputs where soil moisture and quality is sufficient (e.g., near water harvesting or SWC structures) to ensure high returns to these inputs. Such resource management efforts are more likely to yield high returns (and hence are more likely to be adopted on a wide scale) if they enable farmers to increase production of high value commodities such as fruits, vegetables and milk. These opportunities are likely to be enhanced where demand for organically produced high value commodities is growing, and certification programs exist. Opportunities for marketing such perishable fresh commodities will be limited in areas remote from markets, however, so other opportunities should be considered in such areas. Promotion of low cost processing methods to produce more storable and transportable commodities, such as drying fruits and vegetables and producing cheese, may still enable communities with less favorable market access to benefit from producing such high value commodities in regions where markets for these processed products exist or can be developed. Taking advantage of such opportunities to improve natural resource management, productivity and marketing in an integrated way can lead to substantial reductions in poverty and improvements in natural resources, as some of the case studies cited in this paper suggest.

However, as also noted in this review, there are numerous issues and constraints that have to be overcome if these opportunities are to be fully realized. First, and most important, profitable opportunities and the critical binding constraints preventing households from realizing these opportunities must be identified and addressed. Too often, watershed development projects have focused on promoting sustainable natural resource management as the primary objective, rather than improvement in farmers' livelihoods. Such approaches are usually less successful than an approach that focuses first on the opportunities that exist to improve livelihoods in a relatively short period of time, and then building on such success with longer term investment in improved natural resource management. This requires that a participatory, bottom-up approach be used to identify watershed development activities, rather than a technocratic, top-down approach.

Through participatory diagnosis with community members, key constraints to exploiting new opportunities can be identified, and the most critical ones addressed through demand-led technical assistance programs. In many cases farmers require training in integrated natural resource management principles and methods, though it should not be assumed that this is the case, since farmers often have much indigenous knowledge about such issues. Diagnosis of key local knowledge gaps is therefore required as part of the process of identifying constraints.

Often, an important constraint in watersheds in less-favored environments is lack of bridging social capital, to enable access to information related to market and technological opportunities and improve communities' ability to demand better services from their governmental and non-governmental (NGOs and for-profit private sector) providers. Lack of local bonding social capital to facilitate local collective action in managing watershed activities is also often a constraint. Although it is questionable whether external programs can be effective in creating bonding social capital in communities where it does not yet exist, they can certainly help to develop such capital by building on local farmer and community organizations that already exist, facilitating their linkages to sources of information and increasing their voice to providers of rural services. To be able to accomplish this, watershed development programs need to invest in people with adequate training in social sciences and facilitation skills as well as in people with technological backgrounds, and provide adequate time and space in the project planning and implementation to be able to identify and exploit opportunities to build on such local social capital.

It is critical to always involve the poorest and most vulnerable groups (e.g., landless herders, female headed households, HIV-affected households) in planning and implementing such projects, since local elites may well capture most of the benefits while such projects may inflict harm upon poorer people. Efforts to strengthen the bargaining power of poorer households—such as by strengthening their security of access to resources (e.g., common grazing lands) and their rights and ability to collect compensation for environmental services that they provide (such as protecting water sources or forest areas) or for damages caused by others (such as logging companies)—and to provide improved livelihood opportunities to them (e.g., through vocational training and micro-credit programs) are likely to be essential to the success of watershed development projects in reducing poverty among the poorest households.

There may be opportunities to promote organic agriculture in the context of watershed development programs, especially in areas with relatively favorable market access. In such circumstances, promotion of effective farmer organizations is even more critical, as a means of reducing the costs of obtaining certification and monitoring compliance. Obtaining technical assistance in organic methods of production is likely to be a critical need, as IFAD's (2005) survey in China and India found, and effective farmer organizations can help to facilitate access to such training as well. At a national and international level, development of accreditation programs for organic agriculture is needed to increase the supply of accredited certifiers and reduce the costs of certification. Such programs and the certifiers trained must be rigorous to ensure that the credibility of the organic label in the SEAP region is not undermined.

With regard to agricultural biotechnology, currently available GM crops are likely of limited use in sloping dryland areas, except perhaps Bt maize in areas where irrigation or sufficient water harvesting is present. Thus, currently available biotechnology crops are likely to be of limited use for these areas. Most other GM crops that are in the current pipeline for commercialization (e.g., Bt or Golden Rice, virus resistant papaya) are also not well suited to dryland environments, although farmers and consumers in these environment could be significantly affected (either positively if net buyers of food crops or negatively if net sellers) by the impacts of such new crops on food prices. Research on drought tolerant crops could have large positive direct impacts on poor farmers in sloping drylands, although commercialization of such crops appears unlikely within the next decade. Continued and increased investments in such drought-tolerant crops (whether involving biotechnology, conventional approaches, or a combination) could yield large benefits in these areas in the longer term.

Regardless of what happens with regard to GM crops, continued investment in research and development of improved dryland food crops, such as millets, sorghum, barley, pigeonpea and groundnuts is needed to address food security needs in drylands (both sloping and flatlands). The success of the efforts of the IARC's and NARS in the past few decades in breeding improvements of such orphan crops has been notable, and the prospects for more rapid improvement appear promising given greater emphasis on these crops and regions, and the use of modern tools of biotechnology (besides genetic modification).

Humid and subhumid uplands

In the humid and subhumid uplands of Southeast Asia and the Pacific, promotion of conservation farming upland technologies has not had great success, largely because many of the technologies promoted are highly labor intensive and do not yield substantial near term benefits to farmers. Thus, however beneficial the promoted conservation measures are in reducing soil erosion, they are not likely to be widely adopted by smallholder farmers, except in areas where land is so scarce and people are so poor that they have few other options (e.g., intensive terraces in upland rice production in densely populated Java), or in areas where production of high value cash crops ensures a good return on such investments (e.g., in watersheds with favorable market access in some areas of the Philippines).

In these areas, as in sloping drylands, the first priority should be to identify the most profitable livelihood opportunities and key constraints to their realization. The agricultural and natural resource management technologies that are promoted should be based on these opportunities. For example, in areas with favorable market access, high value humid zone products such as tropical fruits and vegetables, tea and coffee may be very profitable (coffee is more storable than these other crops, so may be produced further from markets). Agricultural and natural resource management technologies that facilitate farmers' ability to sustainably produce such higher value commodities are more likely to be adopted than those focused on low value crops. Examples include agroforestry systems for growing shade coffee, alley cropping with production of high value crops such as pineapples or sugarcane on vegetative strips, and use of animal manure and compost in intensive vegetable production. There can be complementarities between different livelihood options that give rise to technological options, such as use of poultry, pig or dairy cow manure from intensive livestock operations in vegetable production in sloping peri-urban areas. As in sloping dryland areas, the prospects for organic agriculture are likely to be most favorable in areas of good market access in countries with established certification schemes and buyers, although the commodities produced will differ. The key issues and constraints that must be addressed to realize the potential of organic agriculture are also similar.

Since perennial crops (such as coffee, tea, sugarcane, tropical fruits) often have comparative advantage in humid areas, land tenure security is particularly important in these areas (long term tenure security is less critical though still important in annual crops production, since investments in annual crops pay off more quickly). However, tenure insecurity is a serious problem is a serious constraint in many humid upland areas, as noted earlier in this report. Efforts to increase tenure security are needed in such areas. One approach that appears promising (though more research is needed on its impacts) is for governments to provide upland farmers tenure security through long term contracts in exchange for their managing the land sustainably and protecting remaining forest, as is being done through the social forestry (HKm) program in Indonesia. As with watershed development programs, the success of such social forestry programs and their impacts on poorer households depends upon the presence and nature of social capital in local communities, and whether poorer groups are adequately involved and empowered in the process. For example, there are risks that the prospect of receiving secure land tenure may encourage more powerful elites in the community to evict poorer farmers from the land they are using or exclude them from groups seeking to be sanctioned. Thus, as in the case of watershed development projects, pro-poor policies and a careful social analysis is needed in communities where such land tenure options are provided.

Among current agricultural biotechnology crops, Bt maize has potential to help poor farmers in humid or subhumid hillside areas reduce their susceptibility to certain insect pests, and thus increase their incomes and food security. The main constraints to expanded availability of this technology are the political concerns, risks and regulatory barriers associated with concerns about GM food. Research on the impacts of Bt maize production in the Philippines (and in other countries producing Bt maize) will likely be very important in helping other governments in the SEAP region decide whether to proceed to allow commercialization of this GM crop. Thus far, there have been far fewer peer-reviewed studies of these impacts than the numerous studies published on the impacts of Bt cotton in China and India. Support for such research could help to facilitate biotechnology development in the SEAP region.

Beyond obtaining approval for commercialization of Bt maize, other constraints that may inhibit transfer of this technology to poor farmers in the uplands are the same as those that inhibit transfer of conventional improved maize seed, such as weak seed and extension systems, poor infrastructure and lack of credit, especially in more remote areas. Strategies to address these constraints, such as investments in seed systems and infrastructure and rural credit programs, thus could help facilitate adoption of both biotech and conventional improved varieties.

Approval of GM rice (Bt and Golden Rice) could have very large impacts on rice producers and consumers in the humid uplands if and when these are approved for commercialization. Especially for Golden Rice, consumer education concerning its nutritional advantages is likely to be needed if widespread adoption is to occur, since otherwise farmers may realize no profit advantage from producing it. If regulatory approval becomes likely, investments in such educational campaigns could yield large impacts on the uptake of this crop, human nutrition and labor productivity in the region. With regard to Bt rice and other new high yielding GM rice varieties being developed (especially in China), net sellers of rice in other countries could suffer substantial losses as a result of introduction of such productivity-increasing varieties. Although these losses would fall most heavily on intensive rice producers in the lowlands of competing countries (such as Thailand), producers of upland rice (or paddy rice in upland niches) could suffer losses due to price declines if they are net sellers of rice (but benefit if net buyers). Investments in promoting alternative crops and livelihoods for such households (e.g., through technical assistance, training and credit programs) could help to limit their losses. Research investments could also seek to boost productivity of upland rice, although the returns to such investments are likely to decline if approval and widespread adoption of substantially more productive paddy rice varieties occurs.

Virus resistant papaya is another biotechnology crop in the research pipeline that could potentially be approved and commercialized in the near term, and could have significant impacts in the Southeast Asia region. If this proves successful, disease resistance may be developed and commercialized for many other types of tropical crops. The critical first step is to have adequate biosafety systems in place to ensure producer and consumer confidence in both producing and importing countries. Clarification of the regulatory and trade issues in the WTO and other international bodies also may be needed before farmers and others are willing to invest substantially in GM versions of such export oriented commodities.

Semi-arid flatlands

In rainfed semi-arid areas, water harvesting and conservation is a critical need, although investments in water harvesting for supplementary irrigation likely has less potential than in sloping areas (rooftop harvesting for domestic purposes is still possible in such areas). Where potential exists for small-scale irrigation, investments to develop this potential may yield high returns, especially in areas with favorable market access where high value crops can be produced and marketed as a result. The risks of such investments and credit constraints are significant barriers, which could be addressed through credit and insurance programs for promoting irrigation well investments. Before promoting such investments, however, the availability and sustainability of groundwater sources should be investigated.

Problems of soil fertility depletion are severe in many semi-arid areas. Heavy use of inorganic fertilizer in crop production, especially on low value food crops, is likely to be limited by soil moisture constraints that limit its profitability and increase its risk. Targeted use of small amounts of fertilizer (micro-dosing) is more likely to effective in many dryland environments, and can help to reduce exposure to risks. Limited use of fertilizer may be complementary to suitable organic fertility and water conservation practices (such as use of manure and compost in planting pits, combined with small amounts of fertilizer). Research and technical assistance is needed to identify and promote effective and profitable integrated soil, water and nutrient management approaches in different rainfed environments and farming systems. Development of input supply systems, storage and marketing credit, and marketing institutions for cereals and other dryland crops can help to facilitate uptake of such technologies, by helping to increase profitability and reduce market risks.

Improved management of rangelands and other common lands, which are often the largest land use in rainfed semi-arid areas, is a critical need. Problems of soil fertility depletion, overgrazing and gully formation are often particularly severe in these areas. As in watershed projects, attaining effective collective action in these areas is critical to bring about improved management of these common property resources. Hence, promotion of effective community organizations, and attention to impacts on the poorest members of the community, are as critical in these areas.

Among GM crops, Bt cotton has been adopted by a large number of farmers in the rainfed semi-arid flatlands (although many use some irrigation for cotton), and has been shown to benefit a large proportion (but not all) adopters. An important issue affecting the continued performance of Bt cotton relative to conventional breeds is whether the Bt gene will combined with the best available germplasm for local conditions as new varieties continue to be developed. Delays in obtaining regulatory approval of future releases may undermine the relative profitability of Bt cotton in the future. Hence, streamlining of the regulatory approval process for new Bt varieties of the same crop as new germplasm is developed would be helpful.

As for sloping dryland areas, continued and increased investment in development of improved varieties of crops will continue to be important for improving poor farmers' incomes and food security in the semi-arid rainfed flatlands, and the prospects for continued improvement (if investment is adequate) are good. In the longer term, development of the development of drought tolerant varieties could have very favorable impacts. Investments in improved livestock germplasm and services for livestock producers (vaccinations, veterinary services, watering points, improved rangeland management, livestock credit) are also critical to improving livelihoods in these areas.

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